# Module 18—Transit and the Connected/Automated Vehicle Environment: Emerging Technologies, Applications, and Future Platforms

**Vincent Valdes:** ITS Standards can facilitate the deployment of interoperable ITS systems, and make it easier to develop and deploy regionally integrated transportation systems. Transit standards have been developed by transit professionals like you at a national level to encourage competition and limit costs within our industry. However, these benefits can only be realized if you know how to write them into your specifications and test them. There are now a series of modules for public transportation providers that cover practical applications for promoting multi-modalism and interoperability in acquiring and testing standards-based ITS Transit systems.

**Jerry Lutin:** Hello. This is Module 18: "Transit and the Connected/Automated Vehicle Environment/Emerging Technologies, Applications, and Future Platforms."

**Jerry Lutin:** Hello everybody. I'm Jerry Lutin. I retired as senior director of statewide and regional planning for New Jersey Transit, and I've been in the transportation business for over 50 years now, and frankly, this is probably the most exciting time that I've seen in my entire career because of what's happening in the field of connected and automated vehicles. So sit back; fasten your seatbelt. We're going to take a fast tour through a lot of different technological advances that are impacting the transit industry.

**Jerry Lutin:** Let's turn to the learning objectives. The first learning objective we want to cover today is to define the relationship between connected vehicle and automated transit vehicle functionality. The second objective that we're going to cover is to describe the potential for autonomous bus guidance for safety, access, and capacity. The third learning objective is going to be to describe the development of automated collision avoidance technologies for buses and paratransit vehicles. That's something I'm working on personally and enjoying very much. Fourth, we're going to explain the potential for AV/CV technologies to support first mile/last mile connections. You're going to see some exciting things that have been going on in Europe. And the last is a topic that you may not get involved in much, but it's something that I think everybody needs to understand, which is the fundamentals of rail transit system connected and automated operation, because it has a lot to do with safety.

**Jerry Lutin:** Learning Objective No. 1. We're going to talk about defining the relationships between connected vehicles and automated transit vehicle functionality.

**Jerry Lutin:** So first of all, let's define some of the terms. We need to distinguish automated vehicles from connected vehicles because the terms are thrown around a lot. Automated or autonomous? Automated means when we perform a task using machinery or computers rather than humans. We're using computers right now in an automated fashion. Even something as simple as a lawnmower—a power lawnmower really is doing a manual task with a machine. The distinction between automated and autonomous is the fact that autonomous means you have the power to control oneself or to make decisions, and that's one of the exciting parts of what we're going to talk about. Connectivity. We talk about connected vehicles a lot, and I think we need to understand that there are two different types of connectivity that are actually in the market right now. The first is connecting by using dedicated short-range communication technology—DSRC—for vehicle-to-vehicle and vehicle-to-infrastructure communications. The second type of connectivity is connecting vehicles pretty much the way we do with our computers and phones and a lot of other things, using Wi-Fi and cellular technology. You may have heard about the Internet of Things—things talking to one another—thermostats, refrigerators, and most of all cars, are also going to be connected through Wi-Fi and cellular.

**Jerry Lutin:** Now, let's talk about autonomous vehicles. How do they work? What you see on this slide is up in the upper-right is a Lexus RX450 that says Google on it. This particular vehicle was a stock vehicle that Google retrofitted for autonomous operation. And below that, you see an image—a very colorful image—and that shows a fusion of all of the different sensor inputs that the autonomous vehicle is reading. It's creating its own mental map of the environment. So on the left, we talk about what are the components—what do we need to do to get to automation? Well, the first thing is sensors. There are a lot of different kinds of sensors that are used today. Cameras are one of the most widely used ones. Radar, acoustical sensors and, if you look at the top of that car, you see something that looks like a Dixie cup up there. That is a Lidar. It is a device that transmits laser optical waves which bounce off the environment and come back and create almost a mathematical mesh model of the environment—a very detailed model of the environment. All of this goes into the next issue, which is mapping. Most of the automated or autonomous vehicles that we see in the market today that are being worked on have extensive mapping, and they generally don't always operate in places where there isn't mapping. And that mapping is like when you move around your house or your apartment at night, you can do it with the lights off, and you pretty much do it without bumping into things because you have a mental map of where everything is. The car needs to have that too. The third is perception, and that is kind of the fusing of the map data with the functionality of the car. "Okay, I know where everything is. How do I know where I am? How do I make a decision to stop if I see a pedestrian in front of the car?" And then the fourth issue there is communication. And connected vehicle technology is one way of providing the inputs that cars need to be aware of their surroundings—and transit vehicles of course, too. And communication also provides us a way to do wireless uploading and downloading to the vehicle in motion, which is very important in terms of exchanging information.

**Jerry Lutin:** This is actually a continuation of Module 11 from the previous year's PCB Transit Standards webinars, and I hope you've gone and listened to some of those because they're really great. Anyway, this reviews what was covered. In the beginning of this is transit and the connected vehicle environment—emerging technologies—and I'm not going to go through all the points, but basically this dealt with the connected vehicle side of it. So if you want to look at more and learn more about the connectivity for transit vehicles, go to Module 11.

**Jerry Lutin:** And concurrent with this, there are a number of other connected vehicle webinars that are out there for the Professional Capacity Building Program—including Connected Vehicles 101, which is really giving you a definition of what is a connected vehicle, what are all the terms and the jargon that you're going to encounter, how's the technology used, what applications are available, and how can you stay involved in it.

**Jerry Lutin:** And they're going on to Connected Vehicles 102—which is extending that into applications and implementation—and this of course goes beyond transit vehicles, which is our focus today in this webinar.

**Jerry Lutin:** Connected Vehicles 201. You can see this is part of an ongoing curriculum because it is so important for us to get the word out on these emerging technologies.

**Jerry Lutin:** We've talked a lot about the fact that connectivity is very important, but there are challenges to this, and what I wanted to show in this slide is to talk about the Government Accountability Office. The GAO did a study of some of the challenges related to connected vehicle technology. They set key milestones for the year 2040—because that's kind of the horizon year when they feel that the technology will have fulfilled its goal of entering the entire market. And the milestones were to have 90 percent of all of the U.S. light-duty vehicle fleet equipped with DSRC—dedicated short-range communication devices, 80 percent of all traffic signals to be DSRC-equipped, and about 25,000 additional safety-critical roadway locations—such as sharp curves—where we can actually use these devices to broadcast warnings to the vehicles on the roadway.

**Jerry Lutin:** But let's talk a little bit about the challenges, because this actually leads us into the automation phase as well. What did GAO find when they looked into it? Well, they found that possible sharing of the frequency spectrum with other wireless users could adversely affect vehicle-to-infrastructure technologies' performance. And this is an important issue because the DSRC is expected to operate on the 5.9 GHz part of the radio spectrum. There's a lot of demand from other parties— for example, commercial operators—and from people doing things with the Internet of Things who are competing for the frequencies. And it could be that if the Federal Communications Commission allows use of that spectrum by other users, it may limit the effectiveness of the DSRC for us. State and local agencies lack resources to deploy and maintain V2I technologies. A lot of you, I'm sure, work for departments of transportation; I worked for a public transit agency. We all know how tight our budgets are and the constraints. As we saw in the previous slide, the goal is to equip 80 percent of the traffic signals around the country with DSRC, and install DSRC at another 25,000 locations. That is a lot of equipment and a lot of installations, and it's not clear where all the local funding is coming from for that. The applications have not really been developed yet, and there's going to be a need for more technical standards. We're going to get into standards very shortly as we talk about automation. Data security is going to be a big issue as well. When we talk about wireless communications between cars and infrastructure and cars and other cars, we need to make sure that those communications are secure and cannot be hacked. We need to be able to ensure that drivers respond appropriately to V2I warnings. In other words, if you get a signal into your car from a short radius curve up ahead, how soon does it get broadcast? How does the driver know? What's the human-machine interface to make sure that warning really gets to the driver and that they know what to do? We need to assess the uncertainties related to liability issues. If the public sector is responsible for maintaining and providing the service for all of these safety-critical communications between vehicles and infrastructure, what happens if it fails? Who's responsible? Who's going to pay the insurance claims? So the full extent of the vehicle-to-infrastructure technologies' benefits and costs is really not yet clear. So we're going to explore several paths to the future.

**Jerry Lutin:** This cover that you see is the document that was released in 2016—the USDOT Joint Program Office Strategic Plan—and in that they talk about their strategic priorities and themes for 2015 to 2019. Among those are realizing the connected vehicle implementation. They want to build on the progress that's been made in recent years on designing and testing and planning for connected vehicles. But as well, they're going to start advancing automation in the DOT program. They're shaping the ITS program around research, development, and adoption of automation-related technologies.

**Jerry Lutin:** Advancing automation. What's in that priority area for the DOT? Let's talk about the program category of advancing automation in the DOT's strategic plan. There are tremendous benefits to be achieved through automation. One of the key ones is reducing the number and severity of crashes: 2016 has unfortunately seen a big increase in automobile collisions and crashes. We want to be able to reduce that. Aggressive driving has been a problem. We want to be able to reduce that through automation. Expanding the reach of transportation modes to disabled and other older users. Very important. As the population demographics change—the distribution of ages—and a lot of us older drivers are going to be on the road and probably shouldn't be driving. Provide "last mile" connectivity service for all users so we can expand the reach of transit. Increasing the efficiency and effectiveness of the existing transportation systems. We want to do more with what we have, and we need to provide guidance to State and local agencies to help them understand the impacts of automated vehicles, because policies need to be developed and we're not quite ready for that yet.

**Jerry Lutin:** “Accelerating the Next Revolution is Roadway Safety” is a Federal automated vehicles policy that was released in September of 2016 by the National Highway Traffic Safety Administration (NHTSA) of the U.S. DOT—and you can download this from the web. This is a very important document that's giving states, and vehicle manufacturers, and everybody operating in the automated vehicle space an understanding of the policy direction from the federal government. It includes four different topics: vehicle performance guidance for automated vehicles; a model state policy; they're explaining what NHTSA's current regulatory tools are to regulate the field of automated vehicles; and it talks about the new tools and authorities that the federal government is going to need in order to deal with this emerging technology.

**Jerry Lutin:** One of the things that you need to understand is that we talk about automated or autonomous vehicles, but they don't all have the same capabilities, and in fact, there are different levels of automation. Up to now, there have been three different entities that have actually been developing a taxonomy of levels of automation for the industry. The first is National Highway Traffic Safety Administration—NHTSA—came out with a policy in 2013. They've since revised that. The Society of Automotive Engineers International—SAE—also had come out with one, and now that has been adopted by NHTSA, and we'll talk about that as we get through. And the third one is the Federal Highway Research Institute of Germany, and Germany has made some significant strides, particularly with their auto industry and advancing automation. So let's go through why there are levels of automation. The first thing is we want to define levels of automation between “no automation” to “full automation” and kind of understand how things fit at different levels between them. The definition should be based on functional aspects so we all can understand it—not different marketing tools that you might see as vehicles come to market. Describe the distinctions for a step-wise progression through levels, because we think that's how the technology is going to develop. We want to make this consistent with current industry practice, and there are several different ways that the automotive industry is regulated and deals with standards, both on a regulatory and a voluntary level. We want to eliminate confusion across many disciplines: engineering, legal, media, public discourse, and you as technical people and people within the industry especially are going to be asked about these kinds of things and need to be able to talk about it. And we also want to clarify the driver's role when a driving automation system is engaged. What does the driver do? What do they not do? So let's go to that.

**Jerry Lutin:** And we're going to talk about the levels of automation that were adopted by NHTSA and developed by the Society of Automotive Engineers. And the first is Level 0. That's like your 1953 Chevy. There's no computer, there's no electronics— the human driver does everything. Level 1—an automated system can sometimes assist the human with some parts of the driving task. For example, ABS brakes have been on cars now for a long time, and when you tromp your foot on the brake and you're going to go into a skid, the car doesn't ask you for permission—it actually has a computer that takes control and pumps the brakes very rapidly. Level 2—the system can conduct some parts of the driving task while the human monitors the driving environment and performs the rest of the task. And you can see this today in certain things like adaptive cruise control, where you can set the cruise control on your car and it has a radar transceiver in front of the car that measures the distance between your car and the car ahead of you. And if that car slows down, the radar reads it and slows your car down too. So it's actually monitoring part of that driving task. You, however, have to keep your hands on the wheel and be totally aware because it's just doing this limited functionality. Level 3—the system can conduct some parts of the driving task and monitor the driving environment in some instances, but the human must be ready to take back control when the system requests. And many of you out there may have heard about Tesla and the autopilot system which it has, and Mercedes Benz, which has Drive Pilot. A lot of these systems do several things. They can keep the car at the right spacing between your car and the car in front of it. In some cases, it may know what the speed limit is because it may have a stored map and can do that. But at the same time, you have to be ready to take control. Most of these systems don't let you take your hands off the steering wheel for very long. So that Level 3—you have to be ready to take control back. Level 4 is the system can conduct the driving task and monitor the driving environment, but the system can operate only in certain environments and under certain conditions, and this is what I showed you the capabilities are for that Google car—that Lexus RX450 we saw earlier. Google has mapped the environment—they know where every traffic sign is, they know what to expect, they know what the crosswalks are, they know where the curbs are—and so if they have all this mental mapping in the car, the car can be allowed to drive. Inevitably, there is a human driver in the car to take over and under certain conditions—for example, construction may be going on that alters the environment. Emergency cones may be down there. Police may be out there or emergency vehicles that are unexpected. So it's both certain conditions and certain areas where the driver has to be ready to take over. Level 5—that is where the system can perform all the driving tasks under all conditions, and in fact cars—and we're going to see some transit vehicles actually in this presentation that don't have a steering wheel, don't have an accelerator, and don't have brake pedals. There is no control there. There is not even a driver's seat, and the idea on the Level 5 automation is that you get in, you press the button for the destination, and the automated system takes complete control of the car—takes over—and gets you to your destination with no human intervention. And, of course, the benefits of Level 5 are pretty obvious. You don't need a driver's license. You don't have to have visible coordination. You don't have to have the vision acuity that you need to drive a car. So this is going to be a huge game changer for the industry.

**Jerry Lutin:** We talked about standards, and standards really is a big part of what we want to talk about with this. We can't really get into all the standards in an hour-and-a-half webinar, but what we can do is direct you to the places where you can find out a lot more. In many instances, these standards are proprietary and you really have to buy them from the agencies. So let's talk about who's been active in it. Well, the first one here is the American Public Transportation Association—APTA. APTA provides bus procurement guidelines, and they have also been working on TCIP—which we talk about in two of the webinars that were previously done for this series for Transit Communications Interface Profiles—so we can exchange data between different transit businesses. The American Society of Civil Engineers has actually developed a very comprehensive standard for automated transit systems. The American Society of Testing and Materials International—ASTM—they have developed telecommunications network standards that are being used for things like the DSRC and for Wi-Fi and communication. And finally, the Association of American Railroads has been developing standards for something called Positive Train Control that we're going to get into as the last part of this webinar today.

**Jerry Lutin:** To continue with the standards development organizations, one of the ones that's been very heavily involved is the Institute of Electrical and Electronics Engineers. The IEEE have been doing a lot of work—and doing working groups—because this is such a new space that there is not necessarily a real clear breakdown of which standard organization should be involved with what standards. And the standards organizations—such as SAE and IEEE—are collaborating on working groups to kind of define that space and how they interact with it. So a lot of you can actually get involved in this now. Of course, the Institute of Transportation Engineers is doing standards trainings, and it is they who are sponsoring this webinar for the DOT. International Organization for Standardization—ISO—is an international body. They have been developing communications standards for vehicle-to-vehicle, vehicle-to-infrastructure. They also do a lot in terms of setting standards for vehicle dynamics. And then the Society for Automotive Engineers that we've already talked about—they have come up with this vehicle automation taxonomy and they developed a reference architecture for vehicle automation. So these are some of the standards bodies that you can look at and look at the individual standards as you need them and as you move forward. We're going to talk about a couple of them here.

**Jerry Lutin:** Emerging standards. I mentioned earlier that American Society for Civil Engineers—ASCE—their Standard 21-13 is the industry standard for automated people movers. You may have ridden on some of these in different cities, particularly airports. A lot of the airport people movers would fall under this. The IEEE P2040 means these standards are really being worked on and they are developing a standard for connected, automated, and intelligent vehicles. The ISO—the International Standards body—is working on 19091: Intelligent transport systems–Cooperative ITS–Using vehicle-to-infrastructure and infrastructure-to-vehicle communications for applications related to signalized intersections. So, very important.

**Jerry Lutin:** The SAE has several that are worth really looking at. Of course, the SAE J3016 Taxonomy and Definitions for Terms Related to On-road Motor Vehicle Automated Driving Systems. The SAE J3018: Guidelines for Safe On-Road Testing of the Various Levels—and remember I talked to you about Level 0 through 5—and here these are particularly dealing with the Levels 3, 4, and 5 for automated driving systems. And 3092: Dynamic Test Procedures for Verification and Validation of Automated Driving Systems. And of course J3131: The Automated Driving Reference Architecture. And you notice that some of these sound like they overlap with some other standards bodies, and they do. So that is an emerging area of standardization that we will continue to monitor.

**Jerry Lutin:** We are now at our first activity—our first interactive activity—and we have a quiz.

**Jerry Lutin:** So the question for this is “In a NHTSA Level 3 automated vehicle, the driver is: A) Expected to be available for control in certain areas; B) Not expected to be available for control during the trip; C) Responsible for monitoring and available to resume control; and D) In complete and sole control of the trip.”

**Jerry Lutin:** Let's go to the answers, and the correct answer is C. In Level 3, the driver is expected to be responsible for monitoring and available to resume control. The driver has to be able to take control. A, that really applies to the driver's role at Level 4 where again, we don't have mapping, for example. B is not correct. That describes the driver's role in Level 5. The driver doesn't really have to do anything except put in the destination for Level 5. And finally, in complete and sole control—that's the driver's role in Level 0.

**Jerry Lutin:** Okay, we're going on to Learning Objective No. 2, and we're going to describe the potential for autonomous bus guidance for safety, access, and capacity.

**Jerry Lutin:** And for this we're going to do a case study. Actually, we've got several case studies lined up for you.

**Jerry Lutin:** The first one is Minnesota Bus on Shoulders. This is really a form of bus rapid transit technologies where we are assisting drivers operating buses on road shoulders, which are pretty narrow. The Bus on Shoulder really helps make more efficient use of a roadway—we're going to show you a picture of that—but consider this typical section. What you have in front of you is a black strip—and we have a three-lane highway with shoulders on each side. The lanes are 12-foot high. The shoulders are only 10-foot high. Of this paved surface, only 64 percent is really being used to move people and goods. If we can use one of those shoulders, we can increase the usable surface by 28 percent and increase the capacity. So how do we do that safely?

**Jerry Lutin:** And we're going to use that one shoulder, and it's being done on a pretty wide scale in the Minneapolis/St. Paul area. Minneapolis and St. Paul has 295 miles—476 kilometers—of shoulder-running busways, and you can see here the extent of that by the red and blue lines on the map. I don't expect you to read the map, but maybe you can in the Student Supplement. You may be able to align it with different highways if you happen to be out there.

**Jerry Lutin:** Anyway, the important thing to know is that here we talked about the fact that the shoulders are 10 feet wide. They're narrower than regular lanes—and you can see that. And you can see that that bus that's heading toward us has actually filled up that lane. And a bus is 102 inches wide. And this is like a trick question. How wide is a 102-inch-wide bus? Well, it actually could be 116 or 120 inches wide when you look at the mirrors extending beyond the bus. So that's one of the things that takes up so much of the space.

**Jerry Lutin:** In Minnesota, in 2010, the Minnesota Valley Transit Authority equipped 10 of their buses with driver assist systems—and these systems allowed them to do lane keeping. It actually physically helped steer the bus in the lane. It gave them a warning if the bus was moving out of the lane. It also provided forward collision awareness by looking ahead of the vehicle. It also included devices to alert them to the potential for collisions on the side. And so it had actually a comprehensive driver interface. It had graphics that the driver could see. It actually had tactile alerts that were provided by vibrating the seat, and also haptic by providing vibration through the steering wheel. This was a pilot test but it worked out so well that in 2016 they're adding 11 new buses and they're going to upgrade the existing 10 buses, and they're going to incorporate the lessons that they learned.

**Jerry Lutin:** I think one of the things that you need to look at when you think about automation and technology is how quickly this is evolving. On the left side of this you see a picture of a cabinet. This is a typical electrical equipment cabinet that you would find behind a driver on a bus, and you could see it's literally filled—four shelves—with all of the electronic components that were needed back in 2010 in order to have the bus have these capabilities of keeping in the lane. And down below—behind the bumper—you see a device attached there that was a Lidar unit that actually helped sense where the bus was in terms of keeping it in the lane. Switch to 2015 on the right and you see up there, instead of four shelves, you see four components—some of which are really tiny. I think it's appropriate that they used a dollar bill there—or actually I think that's probably a 10 or a 20—because it does cost a good bit. But all of that fits on one shelf. And on the right-hand side, you see a schematic drawing of a new radar unit that's a side-sensing unit—that's what's shown in the photo there—that replaces the Lidar, which was very exposed and subject to damage, and pretty expensive too. So all these tech upgrades were available in just five years to make the system work even better.

**Jerry Lutin:** And on the left, you see the kinds of devices in 2010 that provided feedback to the operator. The first thing is that you see there in front of the driver is what's called a heads-up display. It's a sheet of glass that was suspended from the ceiling in front of the driver's vision to give them warnings. The other thing that was on the left was an early PDA kind of a screen that also provided warnings to the driver. 2015—that's all being replaced with symbology and LED indicators that are much smaller, much clearer, and much less confusing.

**Jerry Lutin:** And let's talk about how this actually helped the agency. And they were considering-—and they actually do have in the Minneapolis/St. Paul area a light rail line. They were looking at—in certain corridors—comparing the costs of having bus on shoulders with light rail. If you look at the light rail—LRT—the capital costs for the particular configuration they were talking about was 1.7 billion. Bus on shoulder—150 million. Big savings to get a lot of similar advantages of having transit on an exclusive right-of-way. So this is one of the economic consequences of adding technology.

**Jerry Lutin:** We're going to talk about another case study here.

**Jerry Lutin:** And this one is for the Lane Transit District. Very similar in terms of what the capabilities are in terms of lateral guidance for the buses. In the Lane Transit District in Eugene, Oregon, they opened up a pilot in 2007. They have a four-mile line between Eugene and Springfield, they have buses operating on 10- to 15-minute headways, and they had 1.6 miles of dedicated guideway. And you can see in the pictures below, on the left is a lane transit bus operating on a very narrow track. There is grass in the center, and they only needed to have concrete just under the wheels. So it made for a much more environmentally friendly and narrower space-saving kind of alignment. And on the right, you can see a transit stop for that bus rapid transit system. And you'll notice that somebody is wheeling a baby carriage down. The platforms are actually at the same level as the floor of the bus. You don't have to go up or down to get in. Big, big advantage for people with disabilities who need mobility devices.

**Jerry Lutin:** Bus rapid transit issues that they were facing as they sought to implement bus rapid transit. The customers were demanding a higher quality transit system. Getting stuck in a bus in traffic is not really acceptable anymore. They need safer and more cost-effective transit systems. The cost of accidents and insurance is really going sky-high. Insufficient funding. Light rail—as we saw before in the Minneapolis example—it can be very expensive to build light rail, and so we really need to use this bus rapid transit as a way to economize and get a higher level of service. And again, space limitations for bus-only lanes—and you could see how they squeezed in some of these lanes in the previous pictures. However, there was a downside to that. If we were asking the drivers to keep the bus centered, it created another level of stress to keep the bus going in a lane. Same thing was true in the Minnesota example—trying to drive a 10-foot-wide bus on a 10-foot lane was a challenge.

**Jerry Lutin:** So, let's see. What can they do? They tested a Vehicle Assist and Automation—VAA—technology package, and the functions that they tested were magnetic lane guidance for a dedicated BRT lane and precision docking to take advantage of those high-level floor-level platforms. And they wanted to do the testing to determine the potential benefits. Is it really going to work for us to reduce right-of-way requirements and infrastructure buildout? Can we get to a point where our bus rapid transit allows us to emulate rail service? Can we provide smoother and faster travel for our customers? We want to reduce operating and maintenance costs, and, of course, we want to reduce accidents and collisions.

**Jerry Lutin:** So the Vehicle Assist and Automation program that Lane Transit District undertook—they have the 23-mile BRT line. On part of that, for three miles, they installed magnets—and the magnets help provide guidance. You'll see that as we get there. They installed a maintenance yard test track to test the vehicle's performance in keeping centered with the magnets. They were only able to equip one 60-foot New Flyer bus, and we're going to see a picture of that. They put sensor bars in the front and the back across the bottom of the bus. Those sensor bars actually read the position of the magnets. They installed a steering actuator, a computer controller, and a human-machine interface between the computer and the driver.

**Jerry Lutin:** And this is a very complicated figure. It's in your Student Supplement, but I think that it may be worth just going through. We start at the top-left there. J1939—that is an interesting standard we didn't talk about—but J1939 is an electronic standard for diesel-powered vehicles—both trucks and buses and construction equipment—developed by the SAE. And so that provides a standardized interface to a lot of different systems. They also put in, as connected to the J1939 architecture, a control computer; an actuator controller—remember, we talked about the steering wheel was going to be actually actuated by the computer; an HMI controller—two of them—that actually control the human-machine interface; a GPS unit to help locate the bus; a Yaw rate gyro to sense movement; and then down below the horizontal bar are the front and rear magnetometer sensor bars—which is where the equipment was located—and it also had with it a magnetometer sensor board; and then going back, a steering actuator. You really can't see it in the slide, but there is actually a motor attached to the steering column that allows the computer to move the steering wheel right and left. And of course there is a red button that the driver can hit in order to turn the system off, and buzzers and indicators for the human-machine interface. So this gives you a good idea of the kind of stuff that has to be incorporated in the architecture—the logical and the physical spaces of the bus in order to add these kinds of technologies.

**Jerry Lutin:** Now this is a better picture. In the upper one, you see in the person's left hand that cylinder is actually four cylindrical magnets that are stacked together and that go in the hole in the pavement. And then in the person's right hand is actually this magnetic magnetometer sensor that allows the bus to follow it. And in the lower right you can see they were working at night here to try to not disturb daytime traffic. And the red arrows indicate the holes in the pavement where those magnets go, and the bus is following the path of the magnets and using the magnetometers on the sensor bar to keep the bus centered on that path.

**Jerry Lutin:** And the proof of the pudding here—in this case—what you're seeing is the driver's view of the precision docking at the platform. If you look, you can see a strip coming towards you. That is kind of the disabled tactile strip that you see along the platform. And there's a tiny gap between the platform and the bus—and this was achieved uniformly by using the magnetic guidance. And to ensure that a platform and vehicle interface is ADA-compliant, the gap can be no more than two inches horizontally and five-eighths of an inch vertically. That's a pretty close tolerance, and having the automated technology to do that—to maintain that gap—it really is an enormous help in making this service available to people with disabilities.

**Jerry Lutin:** So how did it work out? By placing this operational test in the field and revenue service, it makes the design requirements more stringent because you actually have passengers on the bus. You had to be able to test out the reliability and the maintainability of it. You saw it was pretty complicated from looking at the diagrams. There has to be an emphasis on safety, redundancy, fault detection, and management. The deployment also required them to really have professionals involved in installing the equipment—and the installation had to be done in a way that it would not degrade normal operations. It would have to be done in a way that would allow maintenance to be straightforward without sophisticated and complicated tests. Visual inspection—have the equipment report faults and collect data. And it would also have to be done in a way where faults could be repaired by the existing transit maintenance staff. So they would have to have spare parts available. So these are some of the challenges that they explored in doing this field test.

**Jerry Lutin:** The deployment actually required them handling all of the operational modes of the transit agency. They had to work in heavy traffic scenarios. It had to be able to work in all weather—all traffic conditions. They had to think about how to transition between manual control and automated control. They had to be able to detect and manage all the faults—and of course this is a demonstration—so a lot of things that happen along the way you have to deal with on the fly. You're developing a technology, and the revenue service demands also had to address new issues. So it's a challenge. But they were able to work through a lot of different things—policy, legal, institutional. One of the things that was interesting about this test was that originally it was supposed to have happened in California, but it turned out that the liability issues and the laws in California made it very difficult for the transit agency and the Department of the Transportation to conduct this test there, so it actually went into Oregon.

**Jerry Lutin:** Let's go on to another thing. We've already explored lateral guidance for buses in terms of capacity and for ADA accessibility. Let's talk about something else here in terms of bus platooning. What you see on the right was a picture that was taken—I apologize for the blurry quality, but it goes back to 1997—and you see two buses following three cars, and they were being guided a lot like Lane in Oregon. Back then they were using magnets in the pavement—magnetic nails— and this was part of an automated highway demonstration sponsored by the U.S. Department of Transportation in 1997. It was mandated by legislation back then in 1991—ISTEA. And they took two Houston Metro low-floor New Flyer buses and they equipped them with full automation using, of course, the magnetic guidance. Magnetic nails embedded in the pavement did provide the guidance for these buses.

**Jerry Lutin:** Now, this platooning actually is also very much of interest by the trucking industry, and this illustration shows two trucks—and they are connected here—connected vehicle technology using V2V communications to allow cooperative adaptive cruise control to function for these truckers. And commercial truckers see truck platoons as a way to improve not only safety, but to reduce fuel consumption. And in this case, the picture is showing the claims that Vehicle 1 is going to be able to save 4.5 percent on fuel, and Vehicle 2, which is following and drafting behind the first bus, can save as much as 10 percent in fuel savings. So this is another application.

**Jerry Lutin:** Let's talk about bus platooning in a slightly different way. We talked already in Minnesota about using bus rapid transit as a way to get a lot of the benefits of light rail. There are some differences between light rail. Bus rapid transit ride quality is not as smooth as light rail. Light rail is totally electrically powered. You may have a minimum of eight wheels per car—maybe as many as 12 wheels per car—to distribute the weight. And bus rapid transit doesn't necessarily match potential light rail capacity. The LRT has the ability to form trains. But using automated and connected operations using cooperative adaptive cruise control could enable buses on BRT to improve both ride quality and capacity and could offer the potential for less expensive infrastructure.

**Jerry Lutin:** I'm going to give you an example here of the potential to add peak period capacity at less cost. This shows two New Jersey transit buses—and these are models. This is a concept that we're talking about. NJ Transit hasn't done it yet, but I'll show you why it might be a good idea for them. In this particular example, during the peak period, bus Number 1 on the right is the leader and it has an operator onboard. It is connected electronically to a following bus, which is operating with no driver. And it is purely getting its guidance signals from an automated system and automated steering—automated lane guidance—and it's receiving that from the leader bus. So here, using one driver, you're actually getting to double the capacity, and that can be a key thing. And what happens in the off-peak when you don't need that capacity? You just park it, and the bus continues to operate as a single unit. So it introduces a measure of additional capacity and flexibility for money savings.

**Jerry Lutin:** Where might we apply this? Well, this I'm showing you is one of the most important bus facilities in the country—probably the most highly used. You are looking west on Route 495, which is a six-lane freeway that feeds into the Lincoln Tunnel going into Manhattan. The cars and trucks on the left side are eastbound, and you see there's a dividing barrier between eastbound lanes and the westbound lanes. But on the opposite side of the barrier—which should be moving away from the camera—you see the buses moving towards the camera. They are going eastbound. So that is a contra-flow lane. It is separated from the other lanes simply by rubber stanchions that are put in. And you can see there's one bus behind the other behind the other. So this is the most highly used bus lane in North America.

**Jerry Lutin:** And I want to show you something about how to increase the capacity here. Right now, if you look across the bottom of that chart—the average distance between buses, the average buses per hour, the seated passengers per hour, and the base case based on what we have seen in the peak 15 minutes—this lane has a functional capacity of about 720 buses per hour. And using modern 45-foot buses, that means that that one lane has the potential to move 41,000 passengers—seated passengers—into Manhattan. That gives each bus a headway of five seconds between buses. What happens if we can use cooperative adaptive cruise control? Again, this is not even with steering in this case—we're just talking about maintaining closer headways and having the bus anticipate braking before the driver. What if we could drop that headway average from five seconds to three seconds? We could increase that capacity by 27,000 riders in the peak hour. That is the equivalent of building an additional tunnel—an additional rail tunnel—into Manhattan. That's an enormous capacity that could be achieved if we can start looking at how to apply automated technology to buses. So this is an example here—hasn't been done—but it gives you an example of the potential. And you can see how we worked up to this through some of the pilot programs that were undertaken in Minnesota and Eugene, Oregon.

**Jerry Lutin:** At this point we are now here at our activity, and so we're going to look at the quiz.

**Jerry Lutin:** So the question here is: “Which of the following bus pilot technologies is most reliant on connected vehicle, V2V, technology?” And the answer choices are: A) Automated docking; B) Bus on shoulder; C) Hybrid propulsion; and D) Bus platooning. Think about that for a minute and we're going to show you the answers.

**Jerry Lutin:** Review of the answers now. Which is the most dependent on vehicle-to-vehicle communication? D, bus platooning, because the bus spacing relies mainly on communicating the position of the bus ahead to the bus behind. A, automated docking used—in this example—mainly magnetic guidance, with some supplemental services. Bus on shoulder used mainly radar and GPS. Hybrid propulsion—we didn't talk about that yet. That's for a different webinar. So that was our answers for this particular learning objective.

**Jerry Lutin:** Let's continue on to Learning Objective 3: the development of automated collision avoidance technologies for buses and paratransit vehicles. So we've talked about making buses more accessible, improving capacity, better using highway shoulders. We're turning to a topic totally about safety.

**Jerry Lutin:** The National Transportation Safety Board, which is a group that is independent of the government, issued a report in 2015 on the use of forward collision avoidance systems to prevent and mitigate rear-end crashes. It's important for you to know that the NTSB has no authority to regulate, fund, or be directly involved in the operation of any mode. So their recommendations are purely advisory. They are not being dictated by politics or by funding—but that's important to know that they don't have the authority to implement their recommendations—they depend upon other bodies in the government to do that.

**Jerry Lutin:** Their recommendations and their findings were first of all that currently available forward collision avoidance technologies for passenger and commercial vehicles could reduce rear-end crash fatalities. And their recommendations were for manufacturers to install forward collision avoidance systems on all newly manufactured passenger and commercial motor vehicles. So that would include cars, trucks, and buses. They also called upon the government—NHTSA—to expand the new car assessment program to include graded performance rating of forward collision avoidance systems. And finally, they also called upon NHTSA to expand or develop protocols to assess the effectiveness of forward collision avoidance assessments. So NTSB is trying to push the U.S. government to move forward and more automation for safety.

**Jerry Lutin:** Their findings were—and they looked at some studies that had been conducted—and one in particular for trucks and it involved about 12,000 trucks—forward collisions were reduced by 71 percent for trucks with collision avoidance systems—CAS—autonomous emergency braking, and electronic stability control. And, of course, remember when we talked about autonomous before? So this is a case where the system makes the decision to apply the brakes. Electronic stability control is something that is being required by federal regulation on cars and other types of vehicles. So the NTSB called for immediate action to require all three of these—not just electronic stability control—but collision avoidance and autonomous emergency braking. However, again, there are some problems. First of all, if we buy transit buses with Federal dollars, we have to keep them for at least 12 years, and we like to keep for as many as 18 or maybe 20 years if we can. So that means our fleet turnover, it doesn't happen that rapidly. So it's going to be years before transit would benefit from CAS and AEB on new buses. So the need exists, really, if we're going to be able to use this and make a dent right away, we need to be able to retrofit buses with these technologies. And in order to do that, we really need standards for that—for the performance and for the retrofits. So there's a lot of room here for us to start working on it.

**Jerry Lutin:** Well, let's talk about bus safety. What you see here is a plot of the trend and the rate of bus and paratransit injuries per passenger mile—that's the rate. And for the period 2003 to 2013, it's a good trend—it's going down. And the injury is per million passenger mile—so that's a good sign.

**Jerry Lutin:** But, uh-oh: let's look at this trend. This is the number of injuries. Even though the rate per mile was going down—was improving—the total number of injuries is trending upward in that period.

**Jerry Lutin:** And, also importantly, the casualty and liability expense—this is the insurance premiums and the claims that get paid out to people who are injured—that's been going up at a pretty rapid pace over that period.

**Jerry Lutin:** So let's go on to the next slide. This table gives you kind of a comparison between bus transit and rail transit. We see a lot of attention paid in the press to collisions and collisions in rail transit, and a lot less so in terms of buses. But let's look at the totals in terms of the industry perspective over the reporting period 2002 to 2014. Bus was engaged in 85,000 collisions as opposed to 6,000 in rail. The fatalities are very similar between both modes—about 100 a year. But the injuries incurred in bus collisions—200,000—way more than twice what it was in rail. And the total casualty and liability expenses by mode for rubber tired modes was 5.7 billion as opposed to 3 billion in rail. Both of these numbers are enormous numbers, and they are paid out by an industry that's subsidized. We desperately need to reduce these numbers, and we need to pay attention to what's going on on the bus side.

**Jerry Lutin:** We also did another examination of the magnitude of the problem by looking at transit insurance pool data, and we looked at 232 closed claims with the Washington State Transit Insurance Pool. That organization insures 25 different transit agencies with about 5,000 vehicles. We looked at it for a 10-year period. We found that 100 percent of the fatalities were collision related, and it was collisions with vehicles, collisions with pedestrians and bicyclists. Eighty-eight percent of the injuries resulted from collisions or sudden stops, and 94 percent of the claims—and that amounted to almost $25 million—resulted from collisions or sudden stops. So many of these could have been prevented with collision avoidance systems and autonomous emergency braking. So you can see there's a real business case for that here.

**Jerry Lutin:** We're going to go into the case study of a particular technology that we're looking at right now.

**Jerry Lutin:** The Washington State Transit Insurance Pool received a grant from the Transportation Research Board from a program called Innovations Deserving Exploratory Analysis—IDEA. This is a program that's available to the people in the industry to help solve problems. Thirty-five transit buses were equipped with collision avoidance systems at seven member agencies, and another three at King County Metro in Seattle. So we had 38 buses running around with collision avoidance. We also conducted a comprehensive evaluation and examination of the total cost for the most severe and costly types of collisions—and you can see where this is going. We're going to try to see what's the business case for this? So we wanted to evaluate the potential for collision avoidance systems to reduce the frequency and severity of collisions and reduce casualty and liability expenses. At this stage, we did not include autonomous emergency braking, but we're going to go there next hopefully.

**Jerry Lutin:** This a diagram which shows the collision avoidance system that was installed on the bus. It's manufactured by a company called Rosco that's teamed up with another company from Israel called Mobileye. And what this particular system has is four cameras that are outward looking. One of them is mounted in the center of the windshield in front, one is mounted on a blind spot on the left side, and two are at the back of the bus—because the potential exists for people alongside the bus who cannot be seen by the driver to really get seriously injured from buses turning. It also has three indicators up in front facing the driver, and we'll show you those.

**Jerry Lutin:** And this diagram—this is actually a copy of an operator guide to understanding the system. This is also included in your supplement. And in the picture in the center, you can see three black rectangles with an image of a pedestrian in it. Those three are mounted on the right side, left side, and the center of the windshield, and they display warnings for different kinds of circumstances. If a pedestrian is within two seconds of colliding with a bus, the operator gets a warning: the indictor illuminates yellow. If a pedestrian is within a second of a collision, the indicator turns red and there is an audible beeping sound. And the operator is getting other warnings too. From the center one, there is a circle of dashed blue lines that you can see there, and within that, the driver can get a warning if a driver exceeds the speed limit because the system is also reading signs to detect speed limits. It's also monitoring the distance between the bus and the vehicle ahead. So it provides some very, very helpful alerts and warnings.

**Jerry Lutin:** And this is a close up of that. And you can see within the circle composed to the line segments, there's a green vehicle that's keeping track of the vehicle in front of the bus. If the bus is closing on it too quickly, it's going to turn red and warn the driver you better slow down or you're going to have a rear-end collision.

**Jerry Lutin:** It does not record video. So in order to evaluate the system there were two additional systems that were overlaid on it. So we used additional technology that included additional cameras that were hooked up to a recorder that would show what happens. We also attached a telematics unit to each bus that would send out packets—basically text messages—to a central server every time the system was activated: if you were following too closely, or if there was a pedestrian alert or a warning.

**Jerry Lutin:** This is an example of a frame from an actual video that was captured by the system when it was alerted to the fact that as pedestrians started to run across the street. You see the pedestrians in a crosswalk; the bus in this instance is actually turning left and it actually says that on top. You may have difficulty reading it, but there is a banner at the top that has the bus number, the date, the time, the speed, and it has the GPS coordinates. All of those are generated by the telematics unit. So it gives us a good idea where these things happen. And we get video in order to assess the system performance. And the bus had already stopped here. The warning had taken place, so we weren't going to hit this pedestrian crossing the street.

**Jerry Lutin:** Field testing it, we actually can use this data to see whether there's conditions at that particular location that might warrant some kind of changes. And using Google Street View and Google Earth, together with the GPS location, gives us a good ability to analyze local conditions and to try to help us determine if there are hotspots in the environment where collisions are more likely to take place.

**Jerry Lutin:** We also went on board to make sure that everything was functioning the way it was. This is an indication—this was on a trolley bus in Seattle where a pedestrian warning came on.

**Jerry Lutin:** We were able to check that. We had a timestamp of that picture from the camera that we had. And we were able to compare those results with what the system telematics unit logged, and in this case, we highlighted that particular warning observation. It tells us what the bus number was, the date and time, location. A PDZ-R means that it was a pedestrian warning from the right. And so we were able to confirm that that actually took place. So that's well underway—the collision warning systems.

**Jerry Lutin:** Now, let's talk about the next part of it—autonomous emergency braking. And we're going to have to look at a little physics here—a little curve—and what we have here is a graph, where the horizontal access is time, and the vertical access is velocity: the speed of the bus. The curved line shows the velocity of the bus when it's braking. And the bus actually goes through four different phases when it's braking. The first, of course, is reaction time. And the bus is proceeding at its initial velocity. This is the time that it takes for the driver to respond to seeing something and begin to put their foot on the brake. The next phase we call brake latency also has the operator taking their foot off the accelerator so that starts slowing the bus in terms of the engine. And they put their foot on the brake. These are compressed air brakes so it takes a little bit of time to get the brakes charged up. So all of that takes place—and these are in fractions of a second. But the next phase is called jerk and that is the change in declaration as the brakes engage—and you can see that starts sloping downward. The last phase is pretty much linear and that's when the bus is decelerating at a constant rate. What you can see here is that the bus is going to go fastest—and if we did this to map distance, we would see that the bus covers a lot of distance during the reaction time. So that is where the autonomous braking can help us. It also can help us in the brake latency phase by activating the brakes—pre-charging them. And it also can make the bus decelerate more smoothly during the jerk phase, so that we are less likely to injure any passengers on the bus—especially for standing passengers. So I think this is where the autonomous emergency braking can be a very big help.

**Jerry Lutin:** We need standards and specs. This is a module that addresses standards. These standards don't exist yet. So maybe some of you who are interested—and your career paths may take you into some exploratory work that will help get to the place we need to be. Transit brakes require CAS-AEB technology than cars and trucks. Cars and trucks—the operator and the passengers—are pretty much belted in. That's not true on a transit bus. We have standees. And they could be injured from sudden stops. And, in fact, sudden stops was one of the major parts of the problem in terms of claims. We talked about the fact that buses have to remain in service. We want them to be remain as long as possible. So we have to be able to retrofit the bus with the autonomous emergency braking. And we can't take them out of service for long periods. There are standards that are applied to transit agencies receiving federal government assistance. They don't have an infinite number of spare buses, so they need to get their buses back in service. And so we have to be able to do retrofits in pretty short timeframes. And there is little financial incentive for bus original equipment manufacturers to do the kind of R&D that's necessary. Buses are a niche market compared to autos and trucks. Autos and trucks sell millions of units a year. Buses in the United States—maybe 3,000 to 6,000 buses tops are manufactured. So it's not a large number for a manufacturer to record it. And the buses that we buy typically go through competitive bidding. So we really need to have detailed specifications. We need to be able to tell people what we need and that requires some expertise that's not always available in our industry.

**Jerry Lutin:** The standards are going to have to address some unique bus characteristics. Blind spot locations alongside the side of the bus—you noticed what we did earlier in the collision warning—we actually had to have cameras in the back of the bus on each side to detect pedestrians alongside the bus where they would be in blind spots. Component replacement and maintenance requirements are going to have to be able to be done by transit agencies. We're going to have to understand the force of this acting on seated and standing passengers. They're not belted in, so we need to be able to apply braking consistently, evenly, and we're going to have work on those standards. Operator training and workload. We have found that to some extent, some of these collision warning devices can be distracting to someone, and so we need to be able to be sensitive to the human machine interface and the workload that the driver faces. And what's different between buses and cars and trucks is that because of the fact that we have to stop and pick up passengers, we are always going to be in an environment where pedestrians and waiting passengers will be very close to the bus. So the system has to be designed to account for that. And we have to look at where the sensors are placed on the vehicle so that they don't get damaged and they can provide the right kind of visibility. And of course, we have to think about the vehicle lifespan. So those are some of the issues that are going to have to be confronted as we look at the development of standards for collision avoidance systems and autonomous emergency braking.

**Jerry Lutin:** We're going to go into our next activity.

**Jerry Lutin:** We're going to ask you, "Which of the following statements is true?" And the answer choices are: A) Casualty and liability expenses for rail transit far exceed those for bus transit; B) Driver reaction time is not a factor in avoiding bus collisions; C) National Transportation Safety Board does not require forward collision warning systems on all new vehicles; and D) Transit buses are currently being delivered with autonomous emergency braking.

**Jerry Lutin:** Let's turn to the answers, and the correct answer is C. The NTSB does not require forward collision warning systems on all new vehicles. Don't forget, the NTSB recommends, but has no authority to require it. A is incorrect. Bus casualty and liability expenses are 80 percent higher than rail. It was over 5 billion compared to 3 billion. Driver reaction time is a factor. That's incorrect because the bus is moving at the highest speed during the time when the operator needs to react. And D transit buses are currently being delivered with autonomous emergency braking—and that's incorrect. AEB is not currently available for transit buses. I'm recording this in November of 2016. You may be listening to this in 2018 or 2020. I'm hoping that when you listen to this, this statement will no longer be false because we want AEB on buses.

**Jerry Lutin:** All right. We're going to turn to the next learning objective. Learning objective No. 4. This one is a real fun one because this is really looking out in the future: The potential for AV/CV technologies to support first mile/last mile transit connections.

**Jerry Lutin:** We're going to talk about a case study that is actually going on in Europe.

**Jerry Lutin:** And this was a study that was recently completed in 2016—the CityMobil2 demonstrations. And this was a European Union project to pilot test automated road transit vehicles. And they pilot-tested driverless shuttle vehicles in a number of cities across Europe. We're going to show you some of those. It was funded at 15 million euros, which is almost $20 million in U.S. money depending upon the currency exchange at the time. Two sets of six vehicles were supplied by two vendors—EasyMile and Robosoft. So we had 12 vehicles. They were all battery-operated. They typically operate at low speed—eight to 15 kilometers per hour, which is five to nine miles an hour. The vehicles are little buses, seated six, and they also had room—between four and six standees. And they used Lidar—which we've already talked about—and GPS—globally positioning systems—for guidance.

**Jerry Lutin:** This graph is also in your student supplement if you want to come back to it. They conducted three different types of demonstrations. The first were large scale ones. Some of these went on for about four months each: Lausanne in Switzerland; La Rochelle, France; and Trikala in Greece. They had small scale demos which went on for about two months each in Antibes in France; Oristano, Italy; Vantaa in Finland; and San Sebastian in Spain. And they also had some smaller showcases—Bordeaux, France; Leon, Spain; and Warsaw, Poland. Some of these we actually have some statistics on the number of stations served. They typically had anywhere from three to four of the vehicles, in some cases up to six. The routes were a couple of kilometers, and they carried some impressive numbers of people here under automated control. So this was a pretty extensive demonstration of these technologies.

**Jerry Lutin:** This is one of the two vehicles. This is the EasyMile EZ10 vehicle. It is electrically powered, and in your student supplement, you will find some of the specifications for the vehicle.

**Jerry Lutin:** This is what it looked like on the inside. There are two rows of seats facing each other—six seats. On the left, you see there is a tablet mounted on the dashboard. Presumably, that allows you to indicate what stop you want and it gives passenger information.

**Jerry Lutin:** This is the Robosoft RobuCITY vehicle. Not as sexy looking at the EasyMile vehicle. If you take a close look, it's got an open window on one side with a rolled-down shade for in bad weather. But if you look at the top, you can see something white protruding there. It's a Lidar sensor. There's some GPS sensors on top. And there's somebody—one of the monitors—sitting inside looking at the vehicle. But it doesn't have a steering wheel or brakes—not in the vehicle. This, I think, is the future of public transportation.

**Jerry Lutin:** They were required to have people overseeing the system, and this guy's title is official driver—and where is he? He's sitting at a desk monitoring what goes on in the vehicle. So the future of transit is the bus driver telecommutes to work—and this is in Trikala, Greece. There is a very impressive video online and I encourage you to look it up on YouTube—the Trikala demonstration.

**Jerry Lutin:** And this is one frame that I pulled from it. It is one of these vehicles operating under automated control at night in a lane on a street with traffic crossing the lane—with pedestrians and bicyclists—and it's a really impressive part of the demonstration. So I think these operate at low speed but they are, I think, going to take root. And even though the European demonstration has concluded, there are several startup companies that are in the process of taking that technology and bringing it to commercialization. And you're likely to see some of those demonstrations with similar vehicles be conducted in the U.S.

**Jerry Lutin:** So at this point, we are now at our activity.

**Jerry Lutin:** The question is, "Which of the following was not true of the CityMobil2 demonstrations?" And the answer choices are: A) The program was funded at about 19.5 million by the European Union; B) Two different contractors each built six robotic vehicles; C) The vehicles traveled at low speed and carried passengers; and D) The vehicles required exclusive rights of way with no pedestrian or vehicle crossings.

**Jerry Lutin:** So let's see what the correct answer is here. We want to know what was not true of the CityMobil2 demonstration? So the correct answer was D. The vehicles did not require exclusive rights of way; they shared the roads with people, bicycles, and cars. A was true. It was about 19 million in U.S. equivalent dollars. True, there were two different contractors. C, the vehicles traveled at low speed and did carry passengers. So those were the answers for this particular quiz.

**Jerry Lutin:** We are now going on to Learning Objective 5. This is the final learning objective for this webinar. And in this we're going to talk about the fundamentals of rail transit system connected/automated operation for safety and capacity.

**Jerry Lutin:** And again, we're going to start out with a case study, because people are actually doing this.

**Jerry Lutin:** This case study involves one of the two technologies that we're going to talk about. The first is called communications-based train control—or CBTC. And this is being implemented at New York City Transit, which of course is the largest rail transit system in the United States. In order to understand communications-based train control, you really have to have a little understanding about the way transit has been signaled for the past 100 years.

**Jerry Lutin:** And that is by a technology called fixed block signaling, which is the most common form of railway signaling, and it's been in use for more than a century. And in that sections of rails—steel rails on the track—are separated by electrical insulators, and we can use the steel train wheels and their axles to complete an electric circuit through the rails as the train passes from one section of rail to the next. The insulated sections of rail are called blocks. The purpose of this technology for signaling is to ensure that only one train at a time is in the block. So when a train enters the block, electricity passes through the track circuit, and it eliminates signals like traffic lights telling the oncoming trains to stop, slow, or proceed. So it's very much like traffic signals, but it is controlled by electric currents going through the rails.

**Jerry Lutin:** In New York City, the system was built over 100 years ago. And what we're showing you here is an illustration of what they called a control tower, or an interlocking. What you see on the back there is a long flat surface—vertical surface—with lines on it, and those lines represent the tracks. And the little dots that are illuminated represent trains that are in the blocks in this section of rail that indicates where they are. So all we know from this technology is that a block is occupied. We know the train is in there. We have no idea how fast the train is going. We have no idea how long the train is. We don't even necessarily know which direction the train is going in. We just know where it is. So it gives us a little information, but not a lot. The other thing that you'll notice is that there are Xs between the horizontal lines representing the tracks. Those Xs represent crossovers and places where the trains can switch from one track to another. How is that controlled? In the very front of this, closest to the camera, you see a row of levers, the operator can pull those levers and turn them, and that is connected through electrical current—and oftentimes though pneumatic tubing—to the switches on the track, so that the tower operator can allow the train to go from one track to another. And the fact is that if one switch needs to be aligned a certain way, the next switch has to be aligned to correspond. The levers are interlocked so that when the operator pulls one switch, it automatically pulls the other switch to align it in the right direction. That's why these became known as an interlocking. This particular piece of technology here has been in use since the 1930s. This is the history, and this is what we are looking to improve using modern communications technology.

**Jerry Lutin:** And this is kind of a diagram of it. If you look at the lower figure, you see two subway cars, and you can see how they're on a track and you can see that there are lines separating them. Those indicate the blocks—the insulated sections of rails. So you can see that where there is a car in the track, the red text indicates occupied. That kind of corresponds to the signal that would be seen by a train coming up to that track section. It would get a red stop signal. And not only that, a couple of sections before that would have a yellow signal indicating "Oh, there's a train up ahead, you better slow down." So that's what that is. These intervals were fixed, and so you really could proceed at only one design speed. You had to have a fixed interval. And with communications-based train control now, we are using electronic signals emanating from various ways from the trains to allow you to have more capacity and to have greater flexibility. You can operate at different speeds. You can also alert track workers. So it's a big improvement in terms of safety and capacity.

**Jerry Lutin:** What are the key elements of a radio-based, communication-based train control system? What's the architecture? Well, it transmits train performance data and continuous train position and speed, so we're able to know how fast the train is going. We can also know how long it is because that could be important, too. It enables dynamic adjustment of train spacing. It creates a virtual block, rather than one that is actually fixed by the sections of rail. We used three different kinds of radio networks: a backbone network that communicates to the control center and also links up various wayside components; we have a radio network which connects to the vehicles; and we have a train-to track-side—a wayside network—which actually uses transponders and short range DSRC, similar to what we talked about in the connected vehicles, to be able to locate the train as it passes a device along the wayside. It also has another system on board the train called automatic train control, which uses the wayside technology to control the speed and the braking. So that gives us a lot more capability to control the train in terms of safety.

**Jerry Lutin:** This is all highly regulated in terms of standards. The Institute for Electronic and Electrical Engineers—IEEE—has developed the standards for communications-based train control, and it is a worldwide reference technology standard—IEEE 1474.1. So this has been a well-defined system that's available. Another part of it actually also depends on Wi-Fi and local area networks—IEEE 802.11 A, G, P, and N—which is your typical Wi-Fi, and they have standards for that. And that also is used in communications-based train control.

**Jerry Lutin:** What are some of the benefits? In New York City, they have already implemented this on the Canarsie line. At the time this webinar was being recorded, they are installing it on the Flushing line, and they are about to go on to the Queens Boulevard line next. The technology allows more trains per hour, and if you've ever ridden a New York City transit subway in the rush hour, you know that increasing passenger capacity is pretty important. It provides more reliable service—more efficient use of its track and car fleet. It allows the system to recover quickly from delays and restore consistent wait times. It keeps the signaling system in a state of good repair and enhances safety. You know, this stuff that I showed you earlier has been in service since 1930. It's starting to break down more frequently, so replacing it with newer electronic technology is something that's going to help keep the system in a state of good repair and enhanced safety. It gives you really a great tool to improve track worker safety because you can program a not-to-exceed speed in a work zone. Make sure that trains are not proceeding too quickly if track workers are out there. And it has the ability to provide real-time travel information to the customers which, as we know, is very important. And the result of this was when communications-based train control was installed on the Canarsie line in 2007, ridership went up by 27 percent. That's pretty amazing.

**Jerry Lutin:** Let's change our topic now. We're going to go into the very last topic, which is applied to transit—Positive Train Control. This is a reversion—to some extent—of communications-based train control, but you need to understand some of the differences. Positive train control applies more to commuter rail operations, and what you see on the left is New Jersey Transit. That's a New Jersey Transit commuter train. They operate over the same tracks as Amtrak does and freight tracks, and freight also can operate over many of the tracks operated by commuter rails. In 2014, there were 23 different authorities reporting service, operating almost 4,000 vehicles—that's passenger cars and locomotives. They had 275,000 passenger trips and 178,000 revenue miles. So a lot of people are riding commuter rail. And it's growing. And so positive train control is an important aspect.

**Jerry Lutin:** What is it? How does it differ from communications-based train control? PTC describes technologies designed to automatically stop a train before certain accidents caused by human error occur. And this is part of the official definition. This technology was mandated by Congress. And it has to be designed to prevent train-to-train collisions. It has to prevent derailments from excessive speed, unauthorized incursions by trains onto track with maintenance activities, and movement of a train through a track switch left in the wrong position. So this is what the capabilities of this technology had to be. They actually don't necessarily replace existing train control systems. For railroads that have their own signal systems out there, positive train control can be constructed as what we call an overlay system.

**Jerry Lutin:** This technology was mandated by the Rail Safety Improvement Act of 2008, and it was created because of a horrific train accident that happened in Chatsworth, California on September 12, 2008. A train very much like the one you see in the photograph, which is a diesel locomotive and three passenger cars—this was the Metrolink in Los Angeles. One of these trains collided with a Union Pacific freight train, because they share the tracks with the freight. Twenty-five people were killed, 102 injured, and there was $12 million in damage. The cause was the Metrolink engineer was texting on his phone at the time. Congress therefore passed a law; they didn't want this to happen again. They mandated that railroads—and this applied to commuter railroads and freight railroads and Amtrak, and all of the major railroads in the U.S.—install positive train control by December 31, 2015. For a variety of reasons, that didn't happen. And faced with the entire railroad system in the United States being shut down because the railroads would have been fined if they operated past that date, Congress extended that deadline to 2018.

**Jerry Lutin:** How does it work? Well, this is a diagram that kind of gives you a visual impression. Let's start with the locomotive. The locomotive has an onboard system and it's got a computer. It needs to know how to apply the brakes and so on. You can see there that it also has a dashed yellow line. That is the radio reception from GPS. GPS—where it's available—can provide some location referencing for trains, although GPS isn't the be-all solution because it's not accurate enough to tell you which track you're on, and it doesn't necessarily provide you the location signals you need if you're in a tunnel. There is, above it, you see radio network 220-megahertz cellular. This is a wayside radio network that communicates with the trains at the 220-megahertz spectrum. And it also is linked through a hardwire—maybe fiber optic or other things—back to the back office on top. You notice the cloud there, which also represents the cloud storage of stuff. The train communicates with the wayside network. The train also communicates to transponders that are short range in the track. And you see two curbs ahead of that, and those are kind of the things that actually are computed based on the information the train gets about where it is, combined with a mapping that it has onboard to know if it has to slow down for a curve. And there are also the wayside signals that still present visual indicators to the locomotive engine. So this should kind of give you an idea of all of the linkages.

**Jerry Lutin:** The next slide that we're going to have for you shows the architecture. And the architecture is important because this is mandated by federal law. And there are actually a couple of different ways to get it. Although the federal law covers railroads nationwide, the railroads operate under very differing conditions. In the far west, most of the traffic is freight traffic. They're going over long distances—sometimes in areas where there's no electricity. Sometimes they didn't even have signaling for long stretches. Amtrak in the Northeast corridor operates at high speed—very dense traffic, a lot of tunnels and bridges. So they have a system called ACSES, which stands for Advanced Civil Speed Enforcement System. The freight railroads generally use something called I-ETMS, which is Interoperable Electronic Train Management System. And there are the four parts to the architecture. Starting from the upper left—the Back Office—and that is the central control for the railroad where all of the traffic is managed from. Then there is Wayside, which are units along the track. There is Maintenance of Way, and this is particularly important to communicate with employees because they're out there often working on the track and they need to communicate with the back office. They need to communicate with the trains on the track to make sure that safety is paramount. And finally, there's the Locomotive, and so each locomotive has its on-board software. It has a lot of radio equipment. It has interfaces with the braking. It also has an event recorder. And all of this is connected through the different kinds of communications links. And they include private wireless, cellular carriers. It includes the 220 backbone. It includes Wi-Fi. And a lot of fiber optic and cable and other means of communication. So that's the glue that holds this all together.

**Jerry Lutin:** This was not an insignificant challenge for the U.S. railroad industry. The railroad industry estimated the price tag at $13 billion. They had to physically survey and geo-map 82,000 miles of track. They needed to map 460,000 field assets—mileposts, curves, grade crossings—places that we needed to know about in order to create the electronic model necessary for positive train control to work. They also had to put radios on 22,000 locomotives and install all of the other necessary systems. There were 32,600 wayside interface units and new radios connecting locomotives, train dispatching, and signals and switches. Some of these required antennas on the right of way, and some of those antennas required environmental impact studies. So that was one of the other problems in meeting the 2015 deadline. Twenty-six hundred-plus switches, another signal replacements at 15,000 locations, and the whole system required new radio spectrum that had to be purchased, actually, for the railroads to use it—and the back office systems as well.

**Jerry Lutin:** So are there standards for PTC? Yes, there are—and something even more than standards. Unlike most other ITS standards, standards for positive train control are based on federal law. The Rail Safety Improvement Act of 2008 mandated that the Federal Railroad Administration of U.S. DOT issue the rules for PTC, which actually constitutes much of the standards. The key technical mandates for this were: all PTC systems must be interoperable. Any railroads, locomotive can operate on any other railroad's track using the same signaling and control systems. This is one of the key ways that PTC differs from communications-based train control. We do not expect the New York City subway cars to run in Philadelphia, or Washington, or Baltimore, or Miami, or Atlanta, or anywhere else. They do not have to be interoperable under CBTC. You can design it specifically for your system and not worry about it. But whether you're operating in the Canadian Pacific Railroad or the Burlington Northern or the CSX system—even though you may be running most of your freight from Chicago to the East Coast, and somebody else must be running their freight from Chicago to the West Coast, your locomotives have to be interoperable everywhere, and their locomotives have to be able to talk to your control center if they come on to your tracks. The core objectives—and this was written into the law—must prevent train-to-train collisions, over-speed derailments, incursions into work zones. So this was written into the law.

**Jerry Lutin:** And what you see here—you don't have to read it, but I just wanted to give you an idea of what a standard is going to look like when it's written into the law. And this is in your student supplement. These are the chapters of the law for positive train control that actually deal with standards and requirements, including field testing, implementation, the safety planning, training, and all of the various kinds of activities that need to go into implementing positive train control systems—a stack of papers.

**Jerry Lutin:** Although there's that huge stack of papers, that wasn't all that was needed in order to do this. The Association of American Railroads has actually engaged in the development of a manual of standards and recommended practices. And the AAR standards don't replace the positive train control of standards by the feds; they supplement it and augment it. And it's written in six parts: it deals with the System Architecture, the Locomotive Electronics/Train Consist—the consist is the train cars and locomotives together; we call it a consist. The Wayside Electronics is part three. The Office Architecture is also universally agreed upon on on many American railroads. Electronics Environmental Requirements. And the Data Management and Communications. So you can see this is heavily standardized and regulated. And the standards are absolutely necessary if you're going to have that kind of interoperability among railroads.

**Jerry Lutin:** We are now at the stage of our last activity for this webinar.

**Jerry Lutin:** And our question is, "Which of the following statements is true?" And the answers are: A) Positive train control standards are voluntary; B) All communications-based train control systems must be interoperable; C) Communication-based train control systems allow only one train in a fixed lock at a time; or D) Positive train control systems and communication-based train control systems can be overlaid on existing fixed block signal systems." So which of these is true?

**Jerry Lutin:** And we'll go to the answers. The correct answer is D. Yes, you can overlay both CBTC and PTC on top of as an overlay to your existing block signaling system. A is not true. They're not voluntary. They're required by rulemaking and by the law for PTC. Again, all CBTC systems do not have to interoperate. We don't necessarily expect Boston subway cars to run in New York or Philadelphia. CBTC systems do not use fixed blocks. They're an overlay, and they provide a way to get more trains in a block than one in a safe way. That is the last quiz.

**Jerry Lutin:** Let's just basically summarize quickly where we've gone. This has been a long webinar—a lot of new stuff I think you learned. First, the relationship between connected vehicle and automated vehicle functionality, including terminology, and what's an SDO? A standard development organization, and which standard development organizations are active in the connected vehicle, automated vehicle space. We saw there are a lot of them, and they're still working out who is responsible for what. Two, Learning Objective 2 was that we saw the potential to improve safety, access, and capacity by using automated guidance for operations on shoulders, for docking at platforms, and for bus platooning. Three, we saw that the development of automated collision avoidance technologies for buses and paratransit vehicles can improve operational safety and can save lives, reduce injuries, and reduce costs by avoiding collisions and braking autonomously. Four, we took a look at the European CityMobil2 demonstrations, which showed the potential for automated transit systems to provide first mile/last mile service in mixed traffic with pedestrians, bicyclists, and autos. And five, we saw that positive train control systems and communications-based train control systems can improve safety capacity and system reliability through automation and connectivity.

**Jerry Lutin:** Thank you very much for completing this module. I hope you really enjoyed listening and got something out of it. It was a pleasure for me to present it. Please give us your feedback. We want your thoughts and comments. We want to know what we can do better on this. So with that, I'm going to sign off.