Module 6: AI Applications in Autonomous Vehicles and Transportation

Video Transcripts

Video 1: Module Overview

In this module, we're going to cover the applications of artificial intelligence to autonomous vehicles and transportation. We're going to talk about why it makes sense for all of us to understand and to study the AV industry? How your company can benefit from AV developments? How to choose the right level of automation for different autonomous vehicle use cases?

We will understand how does an autonomous vehicle see, compute, and act using AI capabilities? What we're dive into what infrastructure is needed to accelerate AV adoption? And, finally, we're going to look at how AVs will transform the movement of people and goods? So, that's the spectrum and the journey that we will cover in this module on autonomous vehicles and transportation.

Video 2: The Importance of AV Revolution

Let's begin by understanding what autonomous technology means or what is an autonomous vehicle. Autonomous technology is any technology that's installed in a motor vehicle that has the capability to drive the motor vehicle without the active control or monitoring of a human otto, operator. So, it's essentially vehicles that can drive themselves and make the, all of the decisions which as braking, steering, acceleration to safely, and effectively drive a vehicle. There'll be some pretty provocative statements made by CEOs and business leaders in this domain.

Elon Musk made a statement that, "That people may outlaw driving cars because it's too dangerous. You can have a person driving a two-ton on death machine". Marc Andreessen is saying, "That people are so lousy at driving cars that algorithm don't need to be much better. You know he suggests every time you go to the D.M.V. you look around. you're like. Oh, my God, I wish all these people were replaced by computer drivers".

Of course, you need computers to be perfect. They have to perform better than human beings. But, this raises the issue that does a lot of human error. Does a lot of mistakes that humans make in driving, that cause a lot of damage to the economy. There are three big areas that are impacted safety, society, and mobility. An interesting and scary statistic is that 94% of crashes involve human error. 1.2 million deaths worldwide are caused due to vehicle crashes. Almost 37,000 people died on the roads in 2016 in the United States, and 2.4 million people were injured. Two out of three people will be involved in a drunk driving crash in their lifetime. In society, there's almost $600 billion in harm from loss of life and injury.

In terms of mobility, there are three million Americans who are 40 and older that are blind or have low vision. Almost 80% of seniors aged 65 and older live in car-dependent community than when they can't drive, they lose their economic independence and their physical independence. There are 42-hour wasted in traffic each year per person.

So, when you add up all of these statistics, you start to realize the scope the magnitude of the AV opportunity which is why we see billions of dollars of venture financing chasing investments and AV. Some of the most highvy, highly valued startups of all time have been in this sector companies like Lyft, and Uber, and DD, and so on. So, that's the AV opportunity. Let's look at why you should care about the AV industry.

First of all, the AV industry is a leader in AI development and implementation. So, what we can do is to transfer knowledge from this domain to other industries including the industry that we are in. It also affects all of us as a consumer; AV's will transform how we move across vehicles, planes, and ships. As a decision-maker in business, it will transform how businesses managed their inbound and outbound logistics. It will disrupt business models, and it'll have broader implications for jobs in transportation and trucking. If you're a government representative, or executives, or a city administration leader, accountable for city infrastructure and transportation, autonomous vehicles will transform how cities are built, how public transportation and semi-public transportation operates.

So, I cannot think of an industry that has broader impact on each of our lives and is also at the forefront of AI development. One of the questions that you should ask that business executives should ask related to how AV developments will impact their business. You'll need to think about ownership structure. Who's going to own the autonomous vehicles? What are the different models for ownership? Will it be subscription or asset ownership? What are the business models? Will they be subscription-based business models, transaction-based business model, as a service business models? What are the societal implications in terms of jobs, in terms of regulation, and in terms of ways in which we think about making autonomous vehicles safe? What will the infrastructure that will be required for autonomous vehicles? As vehicles communicate with infrastructure, we all talk what V2 acts or vehicle to infrastructure will have to put sensors into road.

We will have to create, you know, a whole vast network of sensors and infrastructure that can provide data and communicate with autonomous vehicles. We'll have to look at the domain, and more where will AV's operate, will they go on highways? Will be on suburban areas? Will they be on land? Will they be in sea? Will they be in the air? And what will be the impact on mobility? Mobility impact for seniors, mobility impact for commuters, mobility impact for cargo. So, as you can see that a wide variety of questions that you need to ask related to autonomous vehicles.

You also need to visualize the various disruptions within the transportation ecosystem. Traditional business model will be appended. There will be lot of disruption that will happen to vehicle ownership to the crash economy, which is the insurance industry, think about in it, an autonomous vehicle. What will you insure against what? So, whose fault is it if an autonomous car is in a crash? How will insurance be priced for autonomous vehicles? City revenues, what happens to parking? What happens to violations? What happens to public transit, transit, and jobs? What happens to taxi drivers? What happens to truckers? What happens to other people involved in the transportation and delivery business? So, the transportation ecosystem will see a lot of disruption related to who owns vehicles. How do you manage risk and underwrite risk? How do public utilities and cities generate revenues from transportation and what are the implication on jobs?

There are also implications that autonomous vehicles have beyond the transportation industry. As businesses and consumers, we're all customers of transportation and, therefore, will be affected by these developments. Businesses will find that there are new revenue streams that can create new and innovative methods for delivering products and services such as drones and last-mile delivery. Expanded geographical coverage and hard-to-reach areas. Imagine delivering medicines to sheep farmers in the outback in Australia.

Using autonomous vehicle as channel for new form of engagement, infotainment, and services. Think about the fact that if you are no longer having to drive a car, you can we entertained, you can be productive, you can do all sorts of interesting things to convert your commute time into uptime.

You will also have to think about the lower costs of autonomous vehicles. How you can develop asset light logistics model using transportation as a service? How you can reduce labor cost and liability cost in transportation? And, how you can build just-in-time supply chains that use the increased availability and on-demand nature of autonomous vehicles to drive down delivery costs. So, the autonomous vehicle revolution has implications not only for the transportation industry for, but for every industry both as business executives and as consumers.

So, here's the bottom line. Autonomous vehicles will reshape the movement of people and freight across all modes of transport, land, sea, and air. Individuals, for instance, will own fewer cars. They may be able to live further from work and they'll be able to spend in vehicle time more productively. Businesses can manage inbound and outbound logistics with autonomous vehicles. They can offer new forms of delivery and they can disrupt existing transportation- related services and business models.

Video 3: Levels of Autonomy and AV Efficient Frontier

Let's now look at the different levels of automation and discuss a concept called the AV efficiency frontier, which allows us to find the right or the appropriate level of autonomy for a specific use case. Autonomous vehicles are defined in terms of five levels of autonomy. The first level is driver assistance. This is where the autonomous or the AI capabilities are used to assist the driver in doing things like acceleration and breaking. In level two, you start to get to partial automation, where there is some functionality that is autonomous, but the driver must remain engaged. Level two is where Tesla has been since October of 2016.

Where the car will steer, accelerate, and brake, and keep distance in traffic without human intervention. But, the driver always has to be alert and ready to take over control. At level three autonomy, you get conditional automation. The driver is not required to monitor but must be ready to takeover, under certain exceptions. And, this only operates in a very specific set of driving conditions or operational driving domains. Level four is high automation, where you actually turn over the driving to the AI algorithm but, perhaps, not under all conditions. And, perhaps with some fail big, fail-safe mechanism.

Level five autonomies full automation where the driver doesn't even need to be present, let alone take control. So, those are the five levels of autonomy as we think about autonomous vehicles. So, what this means for a driver is that at level one, you got driver assistance, and this is what we call ADAS or automated driver assistance, advanced driver assistance systems. So, they will sometimes assist with one function but not with multiple functions. At level two, ADAS will control both the steering, and braking, and the acceleration, but only under some circumstances.

At level three, we get to ADS or automated driving systems that perform all aspect of driving but only under certain conditions. And, the human must be ready to take back control. At level four, which is high automation. The ADS drives in many circumstances, and the human may not pay attention in those circumstances. And, in level five, the ADS drives and all circumstances on the human who's just a passenger. In fact, the human may not even be present, in case it's carrying cargo. So, the big leap that we make is when we go beyond level three autonomy, the level four, level five.

Why is this a big deal? It is a big deal because the moment we get to L4 that is the first level at which not only you can take your hands off the vehicle, or you can also take your mind off the vehicle. So that is really the transition, where you are creating what we call a disengagement boundary. The disengagement boundary is the idea that now human being doesn't need to be involved. This is why L4 and L5 are so difficult to achieve because of all of the regulatory and ethical and legal considerations of letting an autonomous vehicle drive without human supervision.

So, let's define these autonomy levels a little bit more broadly. We will give us different set of definitions for these autonomy levels. We'll call them L1 as assist, L2 as augment, L3 as a debt, L4 as assume control, and L5 is automate. So, these are sort of the five ways in which, we will think about the levels of autonomy, and to select the right level of autonomy for your use case. Now, let's introduce a very important concept called the autonomous vehicle efficiency frontier or the AV efficient frontier. The AV Efficient Frontier is a framework to determine the appropriate autonomy level.

So, the idea here is that the optimal level of automation for a specific AV use case is not level five automatically, it may be a lower level of autonomy because we need to factor in the trade- offs that you must make at each level of autonomy as we're going towards higher autonomy levels, we're creating more value but, you're also creating higher costs and risks. So, need to balance off the costs and wrist with the value that's being created.

So, this efficient frontier, AV efficient frontier, is inspired from the efficient frontier concept from financial portfolio management, which is the optimal portfolio that offer the highest expected return or a defined level of risk or the lowest risk for a given level of return. So, what the AV efficient frontier allows executive to do, is to assess and to value the benefits of autonomy against the risks and costs of autonomy to pinpoint the right level of autonomy for a specific autonomous vehicle use case. Let's dig deeper into what we mean by value and risk.

If you look at the value drivers, there are a wide variety of value drivers for autonomous vehicles, reduce transportation time because a shorter weights, reduce capital cost of transportation assets because these assets are being used more efficiently, reduce labor costs because we have fewer drivers. Lower insurance cost because we are eliminating human errors and accidents, reduce fuel costs because we're eliminating human safety and support and control system.

So, we can make vehicles lighter, increase asset utilization because of asset sharing, and 24- hour operations of autonomous transportation systems, increased productivity by converting downtime to productive time during commuting. Those are the value drivers against which you have the cost drivers. And, this includes the cost of computational resources to process all possible corner cases and scenarios. The cost of infrastructure needed to interface with AVs. The cost of potential liability due to loss of cargo or loss of human life if an AV makes a mistake.

The cost of network externality to create a vehicle to vehicle communication re, redesigning and retrofitting legacy vehicles with AV capabilities. The cost of regulatory compliance to deal with new laws for AV's. The cost of idling of AV's that are being used to reposition and do backhaul trips in order to go back to their owners. And the cost, massive cost of retrofitting, fitting legacy systems with AV hardware and software. So, when we look at these value drivers and cost drivers, we can then, array them onto a two-dimensional framework to define the AV efficient frontier.

So, the optimal autonomy level for a use case maximizes the ratio of the value to the cost analyst. So, let's look at the application off the AV efficient frontier for different use cases. By the way, the optimal level of auto, autonomy will lie on the diagonal, which will be from L1 through L5. So, for instance, when we look at in-city mobility of drones, taxis, and ride share. You might find that you are L4, or L5 is the optimal level.

But, on the other hand, when you have autonomous garbage collection or anonymous shipping in inland waters, we might use level two or level three autonomy, which has assisted in tolerance. So, what we can see here is that based on the value relative to the cost and risk, you can define the appropriate level of autonomy for any AV use case, which will either be L1, L2, L3, L4, L5. We will all lie on this diagonal between value and risk. So, that in summary are the, ill the levels of automation and the AV efficient, efficient frontier, which weighs value against costs and risks to define the appropriate level of autonomy for a specific AV use case.

Video 4: State of the Industry

Let's now look at the landscape of the autonomous vehicle industry and look back into history as to how this industry has evolved. The turning point perhaps was a set of three competitions organized by the US Defense Advanced Research Projects Agency or DARPA. They ran the first challenge in 2004, the DARPA Grand Challenge. In this, challenge no vehicles completed the autonomous vehicle course that was created for them. This was followed by the DARPA Grand Challenge in 2005, which consists of navigating 175 miles through desert terrain and less than 10 hours without human intervention; five vehicles completed this course.

This was followed by an even more difficult challenge in 2007, where the vehicles had to cover 80 miles in urban areas in less than six hours, and they had to follow all of the traffic rules. And, six vehicles ended up completing this course. So, these challenges spurred innovation in the autonomous vehicle industry and started off a race that continues to this day. So, where are we at today? Perhaps, the leader in terms of the number of miles driven and the length of miles that can be driven without the driver having to engage is Google's unit, Waymo.

Waymo has run self-driving cars over five million miles in 25 cities. And, they've also done billion miles in computer simulation. So, this is company launched by Google and they are perhaps, the most advanced terms of the experience that they have. UBER has been working on autonomous vehicle capability for some time. And, they had a setback in 2017, when there was a crash and UBER vehicle that, being tested in Phoenix, killed a pedestrian. They have resumed testing in 2018. You know, after a lot of modifications to the system by changing the operations, the technology, and also the organization so as to make the AVs safer.

So, they have resumed testing now in San Francisco and Toronto. So, UBER is investing very heavily in autonomous vehicles. The one that has, perhaps, the only autonomous, semi- autonomous vehicles in the market today is Tesla. Tesla announced autopilot and released it in October 2018; this allows Tesla cars partial autonomous capabilities. Since they've launched autopilot in 2015 and the second version of autopilot in 2018, Tesla has been able to track billions of miles of real-world driving but continuously learning and refining as AI models.

So today, Tesla offers you enhanced autopilot platform that has its eight cameras, and 40 extra computing power of the first-generation systems includes ultrasonic sense, sensors, radar, and cameras that feed appropriately neural network. And, the advanced machine learning algorithms allow these cost to collect and process the data in milliseconds. So, I personally own a Tesla, and I've been using autopilot for several years now and it works pretty darn well. Many other OEMs are getting into the act two. Audi is launching the Tronic. General Motors has a project called Cruise.

Volvo is working extensively on autonomous vehicles, including autonomous garbage handling trucks. Nissan is working on this too. And, Mercedes-Benz and Ford have also announced initiatives. So, pretty much every OEM, major OEM is involved in the autonomous vehicle race. Now, these traditional OEMs are pursuing different autonomy level efforts. They are usually at the L4 or the L5 level. Ford is going to market for the shared mobility or transit fleet.

Volkswagen is working on private AV's and autonomous buses and trucks. GM is pursuing a shared mobility fleet approach using the screws, ah, startup that they haven't funded, and there are new entrants like Tesla and Nio that have capabilities ranging from L2 all the way to L5. In addition, many of the automotive tier one suppliers such as Bosh and rideshare company such as Uber are also participating in the AV economy and the AV ecosystem. One metric for how advanced the capabilities of any of the players are what is, what is something that we call the disengagement rate.

So, disengagement means when is self-driving mode stopped due to system error or when a human need to intervene. And, the metric that we look at the disengagement rate per 1000 miles, which means these are test miles in public roads. So, we're, as you can see from here, Waymo is way ahead of the game in terms of the most test miles and the lowest disengagement rate and their disengagement rate is running at 0.2 per 1000 miles. That means in two out of 0.10000 miles is the frequency with which a driver needs to intervene.

So, GM Cruise is next but at, at a third of the miles, after which the test miles on public roads drops pretty dramatically. So, as you can see, Tesla and Waymo or perhaps we're ahead of the game in terms of the test miles and disengagement rate. Is you expand the border AV ecosystem, it is very, very diverse. There are services like route planning, parking, carpooling, after-market repair. They're safety and security access acc, accident detection, emotion, fatigue, distraction avoidance, cybersecurity.

There are intelligent and assistant technology diagnostics, predictive maintenance, usage- based insurance sensors, infotainment, displays, voice assistance solutions. There's infrastructure companies that look at intelligence sensors, telematics and an, an infrastructure for autonomy. And, this is also happening across modes three wheelers, two wheelers, public transport, flight, trucks, freight, boats, ships. So, that AV ecosystem is robust, it's deep, it's broad, and billions of dollars of private venture money, and private equity money is funding these start-ups.

However, many important challenges remain the AV to human hand-off. Human drivers trust the technology too much. And, sometimes they don't monitored roadway care, carefully enough to safely take control. And, this is called a, caused a couple of deaths in particular, in the case of Tesla. There are technical limitations, cameras and sensors are not good at gathering data and adverse weather conditions. Software algorithms are not as sophisticated as humans in interpreting all visual data. There are environmental inconsistencies, shifts, and inconsistencies in weather, in terrain, in road material, in signage practices, in construction zones.

There's also the need to develop graceful fail-safe and degradation mechanisms, where there's any sensor failure, there should be an override; there should be a way a failsafe mechanism in case any sensor fails. Security challenges because AVs rely on connectivity, which allows people to potentially hack into these networks. So, you need to be more security and controls. And finally, this idea of corner edge cases where you have illogical, weird, unusual behaviors, and obstacles, and human actors, and environmental situations an algorithm need to account for all of these edge cases.

There are strange things like, if an autonomous vehicle follows all the road say, safety, and traffic laws, they drive too slow for the drivers who are speeding, and they run into these vehicles. People will start jaywalking more if they know that the autonomous vehicle and not going to hit them on a red light. So, there are many challenges, but one of the most fundamental philosophical challenges is the moral dilemma that is proverb, commonly called the trolley problem.

So, trolley problem is the ethical choice that AVs need to make and need to be trained with when confronted with a sudden and a complex situation. So, way this trolley problem has talked about is that there's a runaway trolley, that's going down a railway track ahead of the railway track, there are five people tied up and unable to move and the trolleys going straight for them. You as the decision-maker are standing some distance off next to a lever if you pull the lever the trolley will switch to a different set of tracks on which one person is tied up.

So, what is the dilemma here do nothing and the trolley kills five people on the main track or pull the lever and divert the trolley onto the side track where it will kill one person. How do you make that decision? Is not an easy decision. The same concept applies to autonomous vehicles and the decision that they must make when confronted with such situations. So, this might be a choice of pedestrians, or this might be choice of people in the way AV or people on the crosswalk. Unless we sort out all of these ethical decision-making challenges, it will be difficult for us to reach the full levels of autonomy. What we're going to do next once we've understood the AV landscape is they're going to unpack the AV ecosystem and look at the impact on mobility within specific areas off the AV ecosystem.

Video 5: Dissecting the AV: Steps and Decisions

So, let's now dissect the autonomous vehicle in terms of the steps and the decisions that an AV needs to make. We'll unpack the AV by breaking it down into three steps. Let's look at a typical L4 system, level four autonomy systems. There are three stages in decision-making that the autonomous vehicle needs to go through sensing, computing, and acting. What it does in this? It has a suite of sensors, and high definition, imagery, real-time computational power, and complex algorithms that allow the AV to act in a safe and reliable manner. So, sensing takes place through sensors and maps.

Computing takes place through hardware and AI algorithms and software. And, acting takes place in terms of decisions and actuation of the car's systems. At the sensing stage, what the AV needs to do is perception and localization. Where am I, and what is around me? In the compute stage, it needs to understand the scenes and understand the objects and it needs to decide the path forward. What is going to happen next? What are all of the objects and actors in my, in my environment going to do?

What does the pedestrian going to do? What does the car ahead of me going to do? Where should I go as a result? And, the third step is acting, which a decision-making control, which is what is the right decision that I need to make? Where should the vehicle go and what does the driver state. So, these are the three stages of decision making that an AV needs to go through. Now, how does the AV's sense? An AV senses in lots of different modalities or ways or sensors.

And AV has LIDAR, which is light detection and ranging. It's a survey technology. It measures distance by illuminating a light with a target with a laser light. It also has a radar. Radar is an object detection system that uses radio waves to, to determine the range, the angle, and the velocity of objects. It has ultrasonic sensors, which are object detection systems that emit ultrasonic sound waves and detect the return to determine distance. And, then there are passive visual, which is passive cameras and object detection algorithm to understand street signs or what is visible from the cameras.

Now, these sensors all have very differing capabilities, and there is a very interesting concept in autonomous vehicles called sensor fusion. So, sensor fusion is the idea that you need to put together inputs from multiple types of sensors, which are complimentary in order to create a 360 degree and a more robust picture of the environment. So, what does the AV see? And how does the AV see? So, each of these sensors sends a different data point to the AV, which allows it to read the scenes, and all the actors in it, the traffic signals, road condition, other vehicles, pedestrians, weather patterns.

And there are variety of AI techniques that are used to make the AV make sense of its surroundings. We use deep recurrent CNN's or which are called RCNN's to infer directly from a sequence of images. What are the objects in the environment? So, we can automatically sends and learn feature representation for visual objects through these convolutional neural networks. And, it also implicitly models sequential dynamics, which is video sequence detection seeing what is the sequence of video images than what might happen next.

If you really think about what an AV is? It is like a gigantic data center on wheels. The compute capacity of an AV needs to be powerful enough to handle onboard computing task, and it needs to be well-connected enough to interface with multiple networks and devices. So, this is an egg, example of edge computing, where you will actually need to do a lot of computation in the vehicle because of the low latency you need to make decisions quickly and you cannot move this data back and forth to the cloud at the speed at which you require to make decisions. So, an AV generates an enormous amount of data.

Intel estimates that an AV can generate four terabytes of data in 90 minutes of driving. And this is the amount of time a person spends on their car each day. So, multiple images, radar, LIDAR, time-of-flight, accelerometer, telemetry, gyroscope sensors generate data stream that need to be analyzed in order to perform the calculation and adjustments to safely navigate the AV. And, these calculations all need to be done in real-time because there's no time to upload this data to a central server. So, essentially, the AV is like a datacenter that operates autonomously; it just operates on wheels is like an edge device in a cloud network.

So, what does the AV process? Once it takes all this impulse, an autonomous vehicle uses deep learning, computer vision, trajectory prediction, and motion planning algorithms to help make sense of its surroundings and determine how to reach its intended destination. So, this includes scene understanding. Computer vision and object detection algorithm process actors and objects around the vehicle and identify them as a vehicle, a pedestrian, a cyclist, and obstruction, a traffic light, and an I assign a unique trajectory prediction to each actor or each object.

For example, a pedestrian moved at a different speed and with a different probability than a cyclist or other vehicle. The AV also needs to do path planning by combining trajectory prediction algorithms and routing and motion planning software, as well as map data, vehicles status, and operational activity. It determines what route the vehicle should use to reach the intended destination. How should move along with that path while factoring and traffic rules and spatial buffers that it needs to maintain? The AV then acts decisively within splits seconds. A modern car has many control systems that functions in many ways like microservices do in web development.

Think of an airbag, brake, cruise control, power steering, audio system, power windows, door, mirror adjustment, battery, recharging system for electric cars. All the system need to be able to communicate and read states from one to another. So, essentially, there is a bus, which is the platform or a network where any system in the car can listen and send commands to other systems. So, this bus integrates all these com, complex components in an elegant way allowing for many of the modern features we love in vehicles today.

So, current driver-less vehicles are using electro-mechanical actuators to control steering, braking, and acceleration. Now, potentially, another way to accomplish is, this is by using drive by wire technology, instead of using cables and hydraulic pressure, there maybe other ways of providing driver with direct physical control over speed and direction of a vehicle. By using electronic controls to activate the breaks, control the steering, and operate other systems.

So, that is how an AV acts by processing the signals and then transmitting the signals to all of the physical systems either through hydraulics or by drive by wire. Finally, how the AV takes decisions. In decision-making, AI techniques make real-time decisions such as increase the speed, decreases speed, change lanes navigate to a stop. Facial recognition algorithms can process data such as body pose, the blink rate, blink duration, pupil diameter, and drowsiness to evaluate and factor the driver's state into decision-making.

And the AV also takes action by controlling the vehicle control systems to execute the supplied motion plan by actuating the vehicle steering, braking, dawn signals, throttle, and gears. So, this is the end to end view of how an autonomous vehicle goes through the steps of seeing, computing, and acting. And, as you can see, it's a very complex combination of electronic systems, electrical systems, mechanical systems, hardware, software, and machine learning, and deep learning algorithms.

Video 6: AV Infrastructure Needs

An autonomous vehicle does not operate in a vacuum. It needs infrastructure around it that can support autonomous vehicles so that they can reach their fullest potential. So, let's unpack the infrastructure around an autonomous vehicle because this has important implications for city planners and for infrastructure providers. So, what AV's will end up doing is they will end up expanding the scope of the infrastructure that is needed and they will also outline some new capabilities that will be needed to be developed to build smart infrastructure. For example, roads, lanes, and traffic lights can actually tell the AV about road conditions and traffic conditions.

How can vehicles talk to each other? So, this is the vehicle to vehicle communication. And, also how can we use next-generation cellular technologies like 5G, which are very high speed and low latency network to create new applications for autonomous vehicles. So, there is a variety of very exciting and interesting infrastructure developments related to AV's. So, the overall vision here is what we call V2X, which is vehicle to everything. So, vehicle to everything connectivity provides an additional layer of information to the autonomous vehicle, to the pedestrian as well as to the infrastructure.

So, this can be used to support crash avoidance and provide driver assistance. So, the users here maybe motorcycles, and bicycles, and construction workers but also micro-mobility solutions like electronics, electric scooters and mopeds. Cellular-to-vehicle or C-V2X solutions are also being tested globally use, utilizing the 5.9 gigahertz band, which is a very high- frequency band that are also very high-speed data network exchanges over very small distances. So, what we can do by enhancing the infrastructure is it can quicken the adoption of AV's by providing inter-operable technology and guidance to automakers and technology companies.

So, let's look at various aspects of this infrastructure V2V vehicle to vehicle. So, here the idea is that vehicle to vehicle communication can dramatically increase roadway safety with potentially to ell, eliminate almost 90% of light vehicle to light vehicle crashes, and about 85% of they're associated economic cost. This is like you know, to put it very jokingly my car saying to your car, "Hey! You're too close for comfort," and they're able to talk to each other and slow down to the increase the distance. This develops using direct communication using a high-frequency band, which is 5.9 gigahertz brand or between vehicles.

The neat thing about this is it does not require any telecommunications infrastructure is almost like Bluetooth for your communicating directly and you don't need cell towers to function. So, the FCC has allocated there's 75 megahertz of spectrum or intelligent transportation services, and this is called dedicated short-range communications or DSRC. And, yes rules have been established for license in this. So, DSRC systems will provide a short-range wireless link to transfer information between vehicles and roadside system.

And, you only have to imagine how popular Bluetooth has become to think about how this might become a very interesting use case or communication between vehicles, but every vehicle will need to have a receiver and will need to be retrofitted. The implications are V2V are that once you have a channel like this, you can do incident alert. You can do notification. You can do automated rerouting. You can reduce congestion. You can do a swarm reaction.

For example, if there is a pileup we've seen pileups in, in right bad road conditions, then you have fog or snow. You can actually have swarm reaction to slow down on all the cars in a, in a, in a sequence so that you avoid these pileups. You can also do dynamic wireless recharging of electric vehicle, an automated dispatch of emergency services. So, a wide variety of scenarios or vehicle communication. The next type of communication is V2I or vehicle to infrastructure. This is done by creating road side units. These are sensors that are placed alongside roadways that are capable of communicating with vehicles and infrastructure to improve the situational awareness of roadway conditions.

So, you might have a variety of sensors here that will enhance the maintenance of roadways, bridge, and tunnel surfaces. For instance, there's a pothole you know, ability to create high contrast and consistent traffic control devices such as road signs, and traffic signals, lane marking, smart roads with built-in communication capabilities, smart traffic signal, than streetlights, and weather sensors that give whether, ve, vehicles more precise information about prevalent conditions. No need for a sign that says, the bridge becomes icy before the road.

The bridge will automatically tell there the vehicle I am iced over. So, beacons and chip-based identification for b, officials, construction workers, and emergency vehicles that automatically alert or auto, AVs to their presence. So, this is the vehicle to infrastructure use cases. There are a number of other opportunities that V2I vehicle to infrastructure will unlock. It will provide better experiences to citizens and create new av, avenues for operational efficiency and growth.

Congestion prediction, optimizing traffic management, and incident response, smart parking services, where the parking will alert you to say that I've got a spot. You can come here. That's the closest spot, automatic traveler information services, intelligent waste management where garbage trucks are routed intelligently, environmental sensing; you know weather monitoring. And more efficient operations by improving transportation planning and design, intelligent traffic signals, smart lighting solutions, smart tolling services, variable and dynamic road pricing based on traffic, dynamic lane capacity dynamic, speed limit management so that you might not have a fixed speed limit.

You can vary speed limits based on traffic. So there are variety of applications that vehicle to infrastructure may unlock. However, this requires investments in infrastructure by governments and by local authorities. So, in order to future-proof cities, you can have a variety of use cases. AV use cases for smart city solutions. And, again we can apply the efficient frontier to come up with smart city use cases and what we see here are a variety of use cases that are arrayed on different levels of autonomy so that you can way the value that is created by that use case against the cost to come up with the appropriate levels of autonomy.

For example, highway truck platooning, you know, which is a very interesting application where you're actually having trucks very close to each other running on a highway, there level four might be the appropriate very high level of automation you might use. So, by looking at the efficient frontier, you can look at the different use cases and find the optimal level of autonomy for that use case. So, here's an example of a case study. And this is Columbus, Ohio, in the United States.

So, Columbus is seeking to define or help define what it means to be a smart city and become the US first city to fully integrate a breadth of innovative technology including intelligent transportation systems, connected vehicles, automated vehicles, using what they call the smart Columbus operating system and other advanced technologies into the transportation network. So, the heartbeat of the smart Columbus program is what they call the smart Columbus operating system, which is a web-based, dynamic, governed, data delivery platform built on a federated architecture.

There are a number of projects that are taking place within the smart Columbus portfolio. This includes connected vehicle environment, multi-model trip planning where you can connect people who are different modes of transportation, common payment systems, smart mobility hubs, prenatal trip assistance for pregnant women, event parking management, truck platooning, and connected electronic autonomous vehicles. So, this is a very interesting case of how one city which is Columbus, Ohio, has taken the lead and visualizing different use cases for smart cities and smart infrastructure.

Video 7: The Autonomous Movement of People

Let's now look at the autonomous movement of people. After this, we're going to study the autonomous movement of cargo and goods. So, first, let's start with people. So, what we're going to focus on now is the impact of autonomous vehicles and the related infrastructure on the mobility of people. One obvious outcome of autonomous vehicles is increased accessibility to transportation services. This gives people greater freedom to explore, greater freedom to work, and greater freedom to experience everyday life.

Think about the vast number of people who are either visually impaired or cognitively impaired, you know or had no longer have the reflexes because of age that they can drive themselves. These people can now have access to transportation as a service with autonomous vehicles because you no longer need to be a driver in order to be a passenger. So, there's a very powerful empowerment idea, that AV's can provide freedom to people. Even for the people who do drive.

What autonomous vehicles will do is they'll reduce the cognitive load because you don't have to worry about the vehicle, and you don't have to worry about the road. I have already observe this when I've been driving my Tesla. When I have the autopilot on, I don't have to stay second to second focussed on what the next vehicle is going to do. I can actually look around and enjoy the scenery. I can actually read billboards. I can have a conversation. I can potentially even be on the phone. And, that is because I am freed from making the continuous cognitive decisions in, in, in driving a car.

So, without having to worry about the vehicle, you can have a safer ride. You can have automated diagnostics; you can have safety redundancy. You can also like the Tesla is able to do remote upgrades and new feature enhancements. If you don't have to worry about the road. You can have a better commute less stress. Think about how much stress can be eliminated in driving. Driving is perhaps one of the most stressful things we do every day. In the vehicle now, instead of just driving, we can do work; we can be entertained, we can have meetings, we can watch movies, right.

So, you can have personalized in-vehicle infotainment, and you have the opportunity and option to live further away from work because now is my downtime, commuting is actually productive time. So, that is the benefit of lower cognitive load. Another very interesting application is the shift in private ownership. There will be many different scenarios of future vehicle ownership. All in all, there's possibly going to be lower private ownership paired with greater reliance on micro mobility, and shared mobility services. So, for example, a family of three have several options.

They may replace the traditional car with L4 or L5 level of autonomy for self-use only, or they may actually use these autonomous vehicles for self plus mobility service deployment. I can rent out my car to other people my autonomous vehicle. Or I can completely replace traditional car with a shared mobility service using transportation as a service. So, all in all, we will have fewer vehicles on but more vehicle miles traveled. There are some very interesting semi- private alternatives that are emerging and three cities that are testing different forms of autonomous ride share are Dubai, which is using air taxis and drones for air taxis.

Singapore that is looking at ai, road transportation and Amsterdam that is looking at water. So, for an, for an note on Amsterdam in their, in the city is Centrum districts where residents currently leave trash on the curb or collection large trucks create congestion, and pollution, and noise. They've created this concept called the Roboats, which is a roboat board that can serve as a floating dumpster to carry the waste away and 70% of the district can be served in this way because in Amsterdam, you know there are many canals. So, the garbage can actually be picked up from the canals through these roboat waste haulers as opposed to trucks that congest of the cities.

Another very interesting application for moving people is to drive retirees autonomously. So, this is a fascinating case study for a company called Voyage. So, Voyage has a fleet but this fleet is level four autonomy and not level five autonomy. Why level four because the voyage fleet stays within the boundaries of a tightly defined retirement communities. What is the benefit of doing this by restricting what we call the ODD, the operational driving domains to this community, you can map the roads very precisely, your speed limits are lower, your traffic patterns are more clearly defined than in a metropolitan city area.

So, Voyage approach makes it possible for them to deliver a self-driving taxi service to a community within a matter of months. So, Voyage deploy, the diploid is self-driving fleet at the villages in San Jose, California. A 4000 strong retirement community is able to summon a voice self-driving taxi using a smartphone app and this service is particularly valuable to customers with mobility limitations that prevent them from walking to an event or reaching a bus stop down the street.

They've also recently deployed their services in the villages community in Florida, reaching 125,000 residents living in a community spread over 750 miles of road and 40 square miles of land. So, what is really interesting here is that I believe that mobility or autonomous vehicle mobility is going to come to these restricted domains. And, I think a retirement community, the Voyage approach is a much smarter idea than letting a car lose with level five autonomy in any street, anywhere, under any conditions.

So, I think that in the near term for the next few years, opportunities like Voyager make more sense because you are creating a boundary or a sandbox within which you will have freedom. I call this freedom within a framework. So, these are some applications of moving people autonomously. And, we've talked about a variety of mobility scenarios and concluded that sometimes, it is actually level four autonomy that makes more sense and not all the way going to level five autonomy.

Video 8 – Autonomous Vehicles: Mobility of Freight

Let's now turn to the impact of autonomous vehicles and related infrastructure on the mobility of freight, on the mobility of goods. So, as you think about autonomous vehicles across all modes. There's a transformative set of opportunities for the supply chain both in terms of greater cost efficiency and better customer experiences. And, I sometimes joke that people are the worst kind of cargo because cargo doesn't complain, cargo doesn't unionize, cargo doesn't get tired, cargo doesn't need to be air condition, cargo doesn't need to reach its destination most efficiently.

So, actually, I believe that cargo applications moving goods presents a more attractive near- term opportunity than moving people, which are subject to much greater risk and more regulatory constraints. So, as you think about logistic applications, you can map these to the AV efficient frontier by weighing the value and cost against the risk for three different kinds of applications. First mile, long haul miles, and last mile. So, first mile is from the warehouse or distribution center.

The long-haul miles are the highway in-between, and the last mile is the last step of delivery. So, these automation scenarios will vary and in fact, some of the most interesting L4 and L5 applications are in last-mile delivery where you're starting to see, for instance, Walmart actually running distribution delivery from its warehouses to stores to the last couple of miles using autonomous vehicles for delivery. Long haul miles, there's a wide range of scenarios for highway driving, including things like platooning that we're going to talk about.

And in terms of the first-mile application, you might have distribution close to the distribution centers that can also be impacted using autonomous vehicles. So, these are the three types of logistics applications. First-mile, long haul miles and last-mile and each of them have unique use cases and unique positions on the AV efficient frontier. Let's look at a few specific vertical examples the mining industry. First mile applications and mining. Mining is perhaps the most advanced early adopter for autonomous vehicles.

For a variety of haulage activities, autonomous haulage, autonomous drilling, blasting assistance, bulldozer assist, loader assist, haulage assist functions. So, they've been using technology for things like autonomous blasting, autonomous bull dosing, autonomous loading, fatigue monitoring, and collision avoidance. Rio Tinto, for instance, has moved 1 billion tons of material in Western Australia's Pilbara region with a driver-less fleet. Vehicles of operators 700 hours longer than a year with 15% lower unit cost.

So, from the AV project at Rio Tinto in Australia, what we find is that the autonomous haulage system allows material to be used, moved more efficiently and safely. You leading to a huge increase in the productivity, and what you can do is to operate all these haul trucks using a central supervisory system and one central controller rather than a driver. And, these trucks because they use predefined GPS courses they can autonomy, automatically navigate and, and, and haul a crossroads and intersections because they know the location speed and direction of all other vehicles at all times.

Same thing is happening in agriculture. In agriculture, we have labor shortages, costs increases, and we really need to bring more efficiency and improve the yield. So, what you can do now is to have true 24 hours, round the clock operation that empowers farmers to manage their operation from a tablet on-the-go. Each unmanned farm vehicle is equipped with a series of hardware and software components that allow user to toggle between manual and robotic control.

These components work with existing by wire, mechanical, or hotdralic, hydraulic control systems all linked to a central command station, which allows a single operator the summer stanley, simultaneously manage multiple vehicles across a farm operations. So, these multiple machines which are manned or unmanned can operate in a field to accomplish tasks efficiently. So, these autonomous solutions divisions of companies like John Deere and Caterpillar are working to build the next generation of semi-autonomous and autonomous applications in farming as well as in construction.

Now, let's look at long-haul miles via road. The three important use cases here are load balancing, platooning, and terminal management. So, in load-balancing, what you're trying to do is to manage your fleets and your logistic team to optimize the utilization of the team and to balance the load across the different trucks and the operators. In terminal management, what you're doing is efficient scheduling and staffing at terminal by communicating with the AV to basically figure out when it's going to arrive at the terminal and how the unloading will be managed? But, one very interesting use case that I'm going to dig a little deeper into the idea of platooning.

So, platooning is the notion that I can stitch together or I can actually have a whole range of trucks very closely spaced because they're communicating with each other and you can, youcate, and the ideal platoon is that the draft that is created by the truck in front of you reduces the fuel cost. So, a study done by the North America concert for freight efficiency found that 65 miles per hour fuel savings across a two truck platon, platoon are 7.254%, 4.5% for the lead truck, and 10% for the follow truck.

And platooning also enabled connected braking, which automatically maintains a safe distance and reacts faster than a human. So, those are some fascinating applications for long- haul miles we erode. Long-haul Miles by sea is even more attractive. Think of the fact that long-haul of cargo by sea is a very boring job. It requires days and weeks of being out in the high seas, where you're doing very little and your ship can be pirated or your people can, need to be fed, they need to be maintained, they need to be air condition. So, there's a lot of development work going on in creating autonomous shipping, particularly for the high seas.

The Yara Birkeland will be the first fully electric and fully autonomous container ship with zero emissions. So, this is, in a, in the R&D stages and Rolls Royce is working actively to build this as well as Yara is working to build its own ships. And Yara is farther along with Rolls Royce following closely with its own autonomous shipping applications. So, there are a number of benefits of autonomous shipping, including higher fuel efficiency, no need for braking, alerting the ports to the arrival, better coordination, and in fact, reduced piracy because you can't pirate an autonomous ship.

There is also a very interesting application of long-haule plus last-mile AV's by air. There's a company called Zipline that has built the fastest and most reliable delivery drone as part of its autonomous logistics network. There are drones have already flown over 1 million kilometers making over 16,000 life-saving deliveries via autonomous drones. The way it works is doctors were placed demand on, on-demand orders through a simple app for a medicine that they need and when they need it. Medical products are stored centrally at Ziplines distribution centers and there are flown quickly to any destination.

And, they move along at over 100 kilometers per hour and they provide these vital medicines faster than any other mode of transport. And, these drones can fly our remote mountains rivered, rivers, washed-out roads, deserts. And, there is no local infrastructure required within 30 minutes of medical supply can be delivered from the sky by parachute and recipients actually don't need to interact with the drone. So, imagine the application to Indonesia, which has thousands of islands; imagine the application in Australia wherever the outback and desert.

So, for life-saving medicines, this is an example of how drones can be a very effective way to deliver medicines. And, finally thinking about the automated last-mile deliveries, you know, various companies are in late-stage pilots for autonomous delivery vans, autonomous drones, even sidewalk box and micro-mobility solutions. And, these might become common place over the next five to seven years even to deliver your pizza locally. So, this is a wide range of applications related to moving goods by land, by sea, and by air in a variety of scenarios.

Video 9: End-to-End Application: Smart Ports

So far, we have looked at various use cases for autonomous vehicles and moving people and on moving cargo. We're going to conclude with a look at an end to end application, where can start to see how these use cases get stitched together into a very complex end to end application. And, we're going to look at the operation of a port, or the idea of a smart board using artificial intelligence. What this requires us to first understand is what we call E2E logistics, end-to-end logistics.

Imagine, when you order your product online that information needs to go to a warehouse from which the product got shipped maybe from China by sea, which then may land at a port and be transported by rail freight, and rail head goes to road freight, and from road freight maybe air freight, and from there we might have customs clearance, and then you might have supervision and then delivery to the person. So, as you can think about this, the end-to-end logistics is a very, very complex chain of events that needs to be optimized and supervised.

And what this also sensitizes you is to the fact that as you build AI applications with larger and larger scope, you got better and better as use. Because here, optimizing only one part of this chain is not going to be as powerful as optimizing the E2E or end-to-end logistics. Alright, let's dig specifically into what happens at a port. What are the key-port operations and how can we map these to the AV efficiency frontier? So, there are elements of the port infrastructure, which is the Anchorage, the Berth, and the port Terminal, and there are a number of port processes that are involved in processing a vehicle.

The vehicle arrival, the anchoring, the navigation to the berth, the berthing, the terminal operations, which includes the unloading, and so on. The deberthing when the vessel leaves, navigation out of the port, and departure. So, this is the sequence of events that needs to be optimized and there are number of AI use cases that are embedded within this port operations ranging from autonomous shipping to port call optimization which is when should you actually call on the port to autonomous berthing using autonomous driving to be able to find the port who connected multi-modal logistics networks.

For example, here connecting your ship to the rail head or to truck or automatically alerting the trucks that the cargo has arrived by ship. So, there are variety of use cases that you can array on the AV efficient frontier. So, port operations is a very rich area for applying artificial intelligence because there are so many processes that need to be coordinated and so much information that needs to move between entities like the port operations, the vehicles, the shippers, and the destination. So, let's see how this is all being put into action in the Port of Rotterdam.

Rotterdam's port was established in 1283 almost 800 years ago. You know, when a small fishing village was created at the mouth of the Rotter river is the Europe's busiest port by Cargo tonnage. It's throughput with almost 500 million tonnes and processed over 150,000 vehicles, and 30,000 sea-going vehicles, and 120,000 inland vehicles. So, the head of the Rotterdam port says that we're taking an action to become the smartest port in the world, because they understand the speed and efficiency is critical to their business and they are trying to stitch together all the data, a real-time information on the infrastructure, water and air to improve the service that they provide to everyone who uses the port and to embrace the connected and autonomous shipping of the future.

So, Rotterdam is at the cutting edge of deployment, deployment of artificial intelligence, and automation for port operations. So, what are the ways in which they're doing this? They're taking a multi-step approach here, alright? So, what they want to do is to make the supply chain and the port more predictable and efficient as they talk to each other. So, AV's across modes of transport and the right infrastructure to support them will facilitate this dialogue. So, the first step here is to digitize individual entities, equip them with the technology to at an, enable autonomous control, real-time communication, et cetera. Next stage is to integrate across entities.

Leveraging what we've talked about earlier in this module V2V, vehicle to vehicle and V2I, vehicle to infrastructure capabilities to integrate and get vehicles to talk to each other. So then, what do you want to do is to move back from the port to the traditional supply chain and then getting that supply chain plugged in and connected to the port. And, finally think about going global and creating ports, that are getting boards to talk to each other. So, this will allow for efficiency like route planning, and timing, and management of traffic across ports, globally. So, this is the step-by-step approach that Rotterdam has followed in automating it's port operations starting with individual entities, and going integration across entities, connecting supply chain and finally going global.

Video 10: Key Takeaways

So, let's summarize where we've been in this very complex and a very exciting domain of autonomous vehicles. I talked about the fact that autonomous vehicles are fascinating because they are close to maturity and commercial introduction, there are also very important because they affect every one of us, as passengers and as executives managing business, and the transportation of goods. In the short term, there are many challenges for autonomous vehicles regulatory challenges, safety challenges, the trolley problem, ethical challenges.

So, even though millions and thousands of people are injured and killed today by human beings. But it is not acceptable for software and AV's to even kill one human being. So, that places a very high bar for level five autonomy. And, what we started is to think about in this context is that as we look at the use cases for autonomous vehicles, there is a tremendous opportunity for a strategic shift and disruption in business models and in operations for three entities; government, businesses, and end consumers.

As AVs become more reliable across all modes of transport, there will be enormous implications for ownership of cars and assets. People will own fewer cars, they will live further away from work, they will spend a vehicle time more efficiently and differently. Businesses will change how they manage inbound logistics, and outbound logistics and new business models for delivery will emerge that will disrupt existing transportation services. However, before you jump on the AV bandwagon, you need to think carefully about appropriate autonomy levels.

We introduced a very important framework called the AV efficient frontier, which helps you to identify and define the appropriate target autonomy level, which balances the value and the benefits against the costs and the risks of achieving that level of autonomy. And what we find and what we've illustrated is that in many cases it may not be level five autonomy that you're looking for.

A lower level of autonomy may generate optimal impact within more controlled environment and lead to higher returns and faster time to market. So, think not just about ultimate autonomy, think about appropriate autonomy. That is the best way to navigate into the future of autonomous vehicles.