THE BROOKINGS INSTITUTION

AUTONOMOUS CARS:
SCIENCE, TECHNOLOGY, AND POLICY

AN EVENT FROM THE BROOKINGS INSTITUTION,
THE MAYS INNOVATION RESEARCH CENTER AT TEXAS A&M,
AND THE TRANSPORTATION INSTITUTE AT
THE UNIVERSITY OF FLORIDA

Washington, D.C.

Thursday, July 25, 2019

Welcome:

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Center on Regulation and Markets
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Introductions:

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KOROK RAY
Director, Mays Innovation Research Center
Texas A&M University

Keynote Speaker:

KENNETH M. LEONARD
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Engineering Presentation 1: Autonomous Vehicles, Traffic, and Humans:

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Engineering Presentation 2: Smart Infrastructure:

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Keynote Speaker:

DEREK KAN
Executive Associate Director, White House Office of Management and Budget
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Panel 1: Policy Issues:

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MARJORY BLUMENTHAL
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Panel 2: Public and Private Sector Collaboration:

TANYA SNYDER, Moderator
Reporter
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JOYT CHADHA
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BARUCH FEIGENBAUM
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P R O C E E D I N G S

MR. LOONEY: Thumbs up, okay. Well welcome to Brookings and thank you very much for being here. I'm Adam Looney, I'm the Director of the Center on Regulation and Markets here at Brookings. We've very excited to bring you today's events in collaboration with Texas A&M and the University of Florida. We'll be gathered here today for most of the duration of the day.

I wanted to remind you that today's event is being live-streamed, and so there will be people joining us from their homes and offices. You should all have a hard copy that describes today's program and the bios of all the participants. I just wanted to emphasize that there are two panels this morning, there are two panels this afternoon. There are two featured speakers. And in between I wanted to encourage you to join us for lunch at the conclusion of the first two morning panels, and then for a reception that begins immediately after the last panel.

And I want to begin this program with another introduction, which is an introduction for our co-hosts from the University of Florida and Texas A&M. Dr. Lily Elefteriadou, the Director of the University of Florida Transportation Institute, and the Barbara Goldsby Professor of Civil and Costal Engineering. And Dr. Korok Ray, who is the Director of the Mays Innovation Research Center at Texas A&M and a Professor of Accounting at the Mays Business School.

Do you want to say a few words of instruction? Then come on up. And thank you all for being here.

DR. ELEFTERIADOU: Good morning everyone. On behalf of the University of Florida Transportation Institute I want to welcome you to this very exciting workshop, Autonomous Vehicles, which is going to focus on technology, science, and policy.

As you know, this is a very exciting time in transportation, and we have been partnering with industry, with academia, with the public sector, to develop and deploy advanced transportation technologies. Florida is one of the largest states, the third largest in

the US, and has been for many years a pioneer in transportation infrastructure. And of course no surprise, they're now at the forefront of deploying advanced transportation technologies.

So looking forward to the discussions today and the panels. And I want to thank our collaborators, Korok and Adam, for putting together this event. I also want to thank Anna for organizing the event. Thank you. Welcome.

MR. RAY: Howdy. It's great to be here, thank you everyone for coming. This is an exciting time for all of us. I feel like it was just yesterday when a few years ago I was in my office coding in Python to gather some data for my research in economics. And about an hour later I was on an abandoned airfield at Texas A&M with Shiva, and he was in the backseat with me, also coding in Python, to navigate an autonomous vehicle. It really showed me how technology has truly penetrated our lives. And in this conference I hope we can talk about the technology and also understand all the opportunity it can bring.

So thank you all for coming. I want to especially give a shout out to John Cannavo and Anna Dawson who did an excellent job coordinating this, we couldn't have done that without them. And we really look forward to all the exciting discussions today.

I believe this is going to be a little bit of a mix where we'll have science in the morning and policy in the afternoon. I spent a decade of my life in DC, and I always felt like there could be more science to some of the conversations, so this is our first attempt at that.

So I hope you enjoy the experiment, and I look forward to meeting everybody later today.

MR. LOONEY: I don't know if I could pull off a howdy in the same way. Welcome, Texas.

Well it's my pleasure to welcome our first speaker, Ken Leonard. Mr. Leonard is the Director of the US Department of Transportation Intelligent Transportations Systems Joint Program Office. He spent more than 30 years in Federal government and in

the private sector, including at the Federal Motor Carrier Safety Administration and the Federal Aviation Administration. He's a recognized leader in the field of Intelligent Transportation Systems, and he brings a unique perspective to what has to be accomplished to do research, develop capabilities, and implement successful intelligent transportation strategies.

I'm very excited that he's here to open our program. And so please join me in welcoming Mr. Leonard.

MR. LEONARD: Good morning. I am Ken Leonard, I am the Director of the Intelligent Transportation Systems Joint Program Office. And for nearly seven years I've had the great pleasure to work on an exciting portfolio including some of the most fascinating topics in transportation science, technology, and policy. The JPO vantage point allows us to look at intelligent transportation issues through a broader multi moto lens.

I'd like to start by thanking the Brookings Institution, Texas A&M, and the University of Florida for sponsoring this event. I'm honored to speak on a topic that's at the top of USDOT's innovation agenda.

The USDOT has worked to develop the tremendous promise of connected and automated vehicles to solve some of transportation's toughest challenges, to reduce or eliminate the six million crashes, three million with injury, and almost 40,000 fatalities on the nation's roads each year.

We partner with a broad coalition of industry, academics, Federal, state, and local agencies, safety advocacy groups, and others to support safe development, testing, and deployment of intelligent transportation technologies. We're working together to bring connectivity to our roads, to create connected transportation ecosystem in which our cars, our infrastructure, and our mobile devices communicate to yield quantifiable safety benefits and an improved system efficiencies.

Why? Because connectivity is a problem worth solving. Connected vehicle technologies have tremendous potential to reduce congestion, expand our individual

mobility, maximize system efficiency, all to improve the quality of our lives and, most importantly, to save lives.

Innovation, and specifically ITS innovation, has the power to transform our lives. We're on the cusp of monumental changes. We see the maturing of past research in connected vehicles as they move from demonstration to marketplace. And as we see a new wave of emerging technologies such as automated vehicles, artificial intelligence, robotics, fueled by the power of connectivity, data, advanced analytics, to machine learning.

We believe in the power of demonstrations and early deployments of technologies to identify and overcome barriers to realizing ITS technology's full potential. Our demonstrations reduce risk and pave the way for widespread adoption.

Three of our largest connected vehicle pilot deployments in New York City, Tampa, Florida, and across the State of Wyoming, are implementing applications tailored to meet each of those region's unique needs. The three locations are bringing together more than 10,000 connected light vehicles, trucks, traffic signals, and pedestrian devices to their communities.

Our pilot successfully demonstrated site to site equipment and application inner operability to show that they can operate as designed anywhere in the country, regardless of which competing manufacturers build them.

In addition to inner operability, we've worked out some of the cyber security challenges. Since the inception of our connected vehicle program we understood the potential vulnerability of information sharing among vehicles, and we incorporated the concepts of privacy and security by design from the outset of the development of our communications protocols for DSRC on 5.9. This is a critical design concept that is overlooked at great peril in the rush to utilize spectrum for transportation purposes.

We also funded the development of a Security Credential Managements, or SCMS, proof of concept demonstration which secured vehicle-to-vehicle and vehicle-to-infrastructure communications. This system is now available via the commercial

marketplace to support deployment. In fact the US has over 80 ongoing and planned deployments of connected vehicles. We know vehicle communications must be effective, affordable, ubiquitous, and interoperable to meet transportation's goals.

As communities begin to deploy connective vehicles, DOT remains committed to protecting the 5.9 Ghz spectrum for transportation communications essential to public safety today and in the future. Connected vehicles are just one example of our research and investment in an advanced automated transportation eco system to improve the quality of life for everyone and to achieve our vision to transform the way society moves.

We're making progress not only in connected vehicles, but in automation as well. In three successive years, from 2016, '17, and '18, we released substantive policy documentation on automation. Our Federal Automated Vehicle Policy Guidance document explored big picture questions around automated vehicles such as legislative authorities, certification issues, and impacts.

Our Federal Automated Vehicle Policy 2.0 clarified the voluntary self-assessment process and emphasized motor vehicle safety. The number of firms submitting self-assessments has grown to 17, and it's a number that changes almost week to week. And while we've always remained committed to motor vehicle safety, we have expanded our discussion of a more robust and multi-moto approach.

And released in 2018, AV 3.0 advances DOT's commitment to supporting the safe integration of automation into the broad multi-motoal surface transportation system. It reiterates approaches to safety that were established in prior guidance, provides new multi-motoal safety guidance, and outlines a process of working with the Department as the new technologies evolve.

Preparing for the future of transportation, Automated Vehicles 3.0 establishes a clear Federal approach to shaping policy for automated vehicles based on the following six principles.

First, we will always prioritize safety. USDOT will lead efforts to address

potential safety risks and advance the life-saving potential of automation and seek to strengthen public confidence in these emerging technologies.

We will remain technology neutral, adopting flexible technology policies to promote competition and innovation, and achieve safety, mobility, and economic goals. We will modernize regulations. USDOT will modernize or eliminate outdated regulations that unnecessarily impede the development of automated vehicles and that do not address critical safety needs.

Fourth, we will encourage consistent regulatory and operational environments. DOT will build consensus among state and local transportation agencies and industry stakeholders on voluntary technical standards and advance policies to support the integration of automated vehicles throughout the transportation system.

And we will proactively prepare for automation. We'll provide guidance, best practices, pilot programs, and other assistance to help our partners plan and invest. But we won't assume universal implementation of any particular approach.

And finally, we'll work to protect and enhance the freedoms enjoyed by Americans today. We embrace the freedom of the open road, and we envision automated vehicles operating alongside conventional, manually driven vehicles and other road users.

These three policy documents are just the tip of the iceberg. And we've taken many steps to advance the science and technology of connected and automated vehicles with our research and deployment funding and convening activities and events. And I'd like to share about a dozen of these activities with you.

In 2017 we hosted a round table on data for automated vehicle safety to explore voluntary data exchanges to accelerate the safe deployment of automated vehicles. As a result of that round table we've created a minimum viable product for automated vehicle works on data exchange with a number of states, and multi-state pilots are anticipated soon.

We hosted over 1,000 stakeholders at a public listening sessions summit on

automated vehicle policy in March of 2018 to seek input and broadly engage the public. USDOT modes have published requests for information from stakeholders and we've analyzed thousands of comments that we've received.

Several modes have engaged with their stakeholders through face-to-face national dialogues and public listening sessions, some just as recently as last week at ABS in Florida. And we're assessing national issues, developing technical guidance, supporting research, adopting programs, policies, and creating a national community around automation.

One of our most important partners in solving automation issues is Congress. And in response to the Omnibus 2018 Appropriations Act, we developed a plan that communicated our management and research demonstration plans, as well as coordinated across the Department on over $100 million in additional funding going into automation.

As part of the Omnibus, in December of '18 the Department published a NOFO, a Notice of Funding Opportunity, for ADS demonstration grants. These grants will provide up to $60 million in funding for projects that test the safe integration of ADS on our nation's roadways. We received a lot of interest in the grant funding opportunity, and the application closed in March. We expect to announce awardees soon.

We're also partnering with the Department of Labor, the Department of Commerce, and the Department of Health and Human Services to conduct comprehensive analysis of workforce impacts and operational safety issues for commercial drivers. They're introduced through automation technology.

We held an event in March to gather stakeholder input and we're in the process of developing a study and will publish a report this summer. Our goal is to provide information to policymakers and the public to help the nation prepare so that we can all benefit from the introduction of new technologies such as automated trucks.

NITSA, FMCSA have issued advanced notices of proposed rulemakings on

the removal of unnecessary regulatory barriers to the safe introduction of ADS vehicles in the United States. Both agencies are seeking comments at this stage to ensure that all potential approaches are fully considered. As the agencies move forward with these regulatory actions, we encourage you to submit comments to the Federal Register Dockets, comments on both AMPRMs are due July 29th, so just around the corner.

The Department has also sought public comment on proposed exemptions to Federal standards and how the public can be protected as new transportation technologies emerge.

In March NITSA issued two requests for comment in response to petitions for the temporary exemption of the Federal Motor Vehicle Safety Standards, FMVSSs, submitted by General Motors and NURO respectively. The comment period closed in May, and NITSA's reviewing the comments that they've received.

Federal Highways has developed the Carma Platform to encourage collaboration between transportation systems management and operations strategies and automated driving technology, focused on how infrastructure can move traffic more efficiently.

And three awards were made for truck platooning projects to assess in-service truck platoons delivering commercial goods via fleet operators on their common delivery routes, to understand how truck platoons will operate in a realistic operational environment. Results will inform state and local decision makers that develop truck platooning regulations.

And lastly, but certainly not least important, in April and June of this year we held two public sessions on the 5.9 Ghz safety band. The safety band is critical to ensuring connectivity that enables cooperation through secure, uninterrupted, below agency, inner operable, proven communications. Protecting the 5.9 Ghz band radio spectrum, the safety band, is of critical importance to the Department. It's uniquely capable of supporting safety applications that prevents or significantly reduces the severity of vehicle crashes in a

manner that's not available through existing vehicle technologies.

The safety band is already used by state and local transportation departments for vehicle to vehicle and pedestrian collision avoidance as well as emergency vehicle priority. The safety band also enables applications for red light warnings, reduced speed warnings, curve speed warnings, spot weather impact warnings, and other safety critical applications.

As technology advances inner operability remains central to enabling universal vehicle to everything capability and benefits. USDOT must ensure that the safety band is protected for traffic safety. The Department is technology neutral, but we're not technology agnostic. We believe that technology must perform. It must deliver on the promise of safety, safety is our highest priority, and transportation technology using the 5.9 safety band must demonstrably achieve it.

At the same time we encourage the automotive industry, wireless technology companies, and other innovators to continue developing multiple technologies that leverage the 5.9 Ghz band of spectrum for transportation safety benefits.

So as you can see, we've been pretty busy. USDOT is moving forward with both connected and automated vehicles, we're committed to engaging stakeholders to identify and solve scientific technical and policy issues, and usher in a new era of transportation. The Department will work with partners to integrate connectivity and automation across the transportation system, enhancing mobility for seniors, people with disabilities, facilitating freight movement, and increasing productivity. The DOT's actions represent just a step in the right direction. We know that it's a long road, but one that we must take together. Connected vehicle technology is proven and in deployment.

Despite its promise and the progress that's been made, automated vehicle technology is still in its early stages of development. The public has concerns about the safety and security of this new technology. These concerns must be addressed because without public acceptance we know automated technology will never reach its full potential.

Ensuring that we establish common methods to evaluate the safe performance of emerging ADS equipped vehicle technologies is critical. DOT and industry are working to assure the safety of ADS equipped vehicles. The Department supports automation in a safe and secure environment where innovation can thrive and the American public can be excited and confident about the future of transportation. The promise and safety of automated vehicles is only possible if we all work together.

So in conclusion, and in advance of your discussions today, let me thank you again for your work to advance smart transportation. So thank you.

DR. ELEFTERIADOU: Good morning again. This first part we will focus on the technical and scientific aspects of autonomous and connected vehicle technologies. First I'll start with an overview of those technologies and their deployment.

My background, just to give you an idea, is on traffic engineering, my expert in traffic flow theory and civil engineering.

Dr. Carl Crane is a Professor of Mechanical Engineering at UF, he's been working on autonomous vehicles for several decades. He's developed both surface and water vehicles, autonomous vehicles, and he'll discuss the technology and sensors for autonomous vehicles, along with deployment challenges.

Next Dr. Sherrilene Classen is a Professor and Chair of Occupational Therapy and she's an expert on fitness to drive issues and driving simulators. And she'll discuss the interactions of technologies with humans, and particularly perceptions by older drivers.

Dr. Sanjay Ranka is a Professor of Computer Information Science and Engineering. He's an expert in computing and machine learning, and he'll discuss transportation related data management applications that are under way.

First let's start with the status of the transportation system in the US. And Ken mentioned the more than 40,000 fatalities in the US this past year. This graph shows how the number of fatalities have changed since 1975, along with the fatality rate per 100

million VMP. As you can see, both numbers have been going down. And even though vehicles and the infrastructure have generally become safer, the vast majority of these crashes, 94 percent, are due to human error. So the promise of autonomies to reduce these substantially or even eliminate them.

You have seen various tests by Google, Uber, in the news, and now there are more than 1400 vehicles being tested by more than 80 companies across the US. We see more and more shuttles, such as the one shown here on the screen, which is the one in Gainesville.

So as you can see, the vehicle is going really slowly. It's really frustrating if you're behind it but it is because it's mapping the route. And during that time, I don't know if you caught that, but there was a bicyclist zooming by, and the vehicle just stopped. Wouldn't it be nice if all our vehicles could do that? And this by the way, was not staged, this is something that just happened while the vehicle was mapping the route.

This shuttle is going to be part of the original transit service in Gainesville. We're waiting for approval from NITSA, the vehicles themselves are in Gainesville. But we hope this will give us great information about interactions with the public, how people might use autonomous cells.

Now let me take you back to when vehicles were first invented. That's what they looked like. So we didn't get to where we are overnight, it took about more than 100 years to get to the transportation system of today. And at that time acceptance of vehicles was very far from universal. There were significant objection, significant safety issues, no rules of the road, no stop signs, no traffic lights. And at the time of course horses were prevalent with problems, manure, mistreatment of the animal, and so on. So mixing the two was a challenge. The horses were getting scared of the cars.

So this little invention was introduced. It's a horse head so that horses wouldn't be spooked. Of course that didn't work. But in some ways we face similar issues today with humans accepting autonomy.

How will conventional vehicles and drivers operate their own autonomous vehicles? Will they cut them off because they can, because they can trust that an autonomous vehicle will stop? How will the autonomous vehicle interact with pedestrians and bicycles and scooters, which are very prevalent on the UF campus?

So the concept on this slide is kind of similar to the horse head. Now we want to make the vehicle look and act like a human driver so the pedestrians and other human drivers can understand what the intent of the vehicle is. So if the vehicle is approaching, are they going to stop for me to cross if I'm a pedestrian? In the autonomous vehicle logic also wants to know is the pedestrian standing on the side of the road getting ready to cross, or are they just waiting for something else?

So in my field, in traffic engineering, we use this graph in introductory transportation engineering courses. And it shows the three major elements of the transportation system, the vehicle, and its characteristics, the driver, the traveler, and then the infrastructure and the environment. So each of these affects and is affected by the other elements, and all together contribute to the performance of the transportation system.

So the speeds that we observe are a product of all these. The capacities are a product of all these. So as an example, when you have a heavy truck, it's traveling much slower when you have a steep upgrade. So the combination of the vehicle characteristics and the infrastructure result in particular performance. Each of us as humans, we react differently to the different designs. Some of us are more cautious, some are more aggressive, some of us we want to keep longer distances, shorter distances. So this variation that we have from human drivers also affect the speed, the travel times and the safety.

So how do these fit within this system? How will different travelers use and interact with AVs, with autonomous vehicles? How will different vehicles from different manufacturers operate under different highway designs? So when we're introducing autonomous vehicles we have to consider all three elements. We have to consider the

variabilities in driver behavior, both in using a particular autonomous vehicle and driving, as well as interacting with a pedestrian or as a bicyclist.

So here is a graphic, this type is commonly used to describe autonomous vehicle operation. So an autonomous vehicle maps the terrain. It has several types of sensors by which they're able to look at obstacles and navigate through the highway network. Now these are detected with the bigger sensors, then the vehicle's logic decides how it's going to move, whether to stop, and whether to change lanes.

But imagine this scenario on this slide where you have an autonomous vehicle which approaches a crosswalk, and there's a pedestrian already on the crosswalk, there's a bicyclist further ahead. And this can be seen by the sensors. But there's another pedestrian standing there. And its view may be somewhat obstructed by the sensors on the vehicle. So can the vehicle detect the pedestrian, first of all? And even if it can detect it, can they determine the intent, whether the pedestrian is getting ready to cross?

When we have a human driver, the human driver can communicate that non-verbally with the pedestrian, determine the intent, allow them to motion them to pass, and so on. And this becomes a very difficult problem, especially considering the viability in driver behavior. So different individuals will behave very differently.

Now imagine this environment. Freeway congestion, and then an autonomous vehicle operating in it. In this environment you'd have very frequent lane changing as vehicles are trying to get to the correct lane for their destination. And so when you have an autonomous vehicle under this environment, the autonomous vehicle has to recognize the intent of other vehicles changing lanes.

Second, you have a distance that the autonomous vehicle needs to keep with the vehicle ahead to maximize its safety. If that distance becomes too long then the space that this que occupies with conventional vehicles becomes much longer. If it's too short it may cause rear end crashes. So the vast majority of autonomous vehicle crashes that have been recorded so far are due to human error or of a conventional vehicle crashing

into an autonomous vehicle, because they don't react quickly enough. The human driver doesn't react as quickly as the autonomous vehicle.

So autonomous vehicles do have the potential to significantly improve safety and mobility, but there are risks in their deployment. And those deployments may be derailed if we start increasing delays and crashes. So the wrong type of deployment, when the technology's not ready or well thought out, will backfire.

Let me show you now an example of how we're approaching this problem to avoid these pitfalls for deployment of autonomous connected vehicles. We have a partnership at the University of Florida with the Florida Department of Transportation and the City of Gainesville to build the I Street, which is a real world test bed. And its objective is to test, deploy, evaluate, several different advanced transportation technologies.

Gainesville and the UF campus where this is deployed are ideal for this type of testing because there is significant pedestrian, bicyclist traffic, there's scooters. We have an extensive transit network. We have relatively low speeds, and good weather. Also Florida is very welcoming to autonomous and connected vehicles. So the Florida Department of Transportation has funded the deployment of communication devices for connectivity along several corridors, including corridors around the UF campus. And those allow vehicles that are instrumented to communicate with infrastructure.

So what I'm showing in this slide is a system we're developing for optimizing signal controls, so the operation of traffic lights and the way that the green is allocated to the traffic approaching the intersection while at the same time advising arriving vehicles that are able to receive this information what their optimal path is, or their trajectory.

So the autonomous vehicles approaching the intersection, as soon as they reach the communication range, they receive very specific information on the path that they should follow, and they can execute it. We've been doing experiments now for a couple of years and we've developed the hardware and software to be able to do this.

With connected vehicles, which are also part of the mix, if they have the

ability for connectivity then they can also receive information on optimal speed. And right now we're working on an app where we are able to have even conventional vehicles with no connectivity be able to receive information on optimal paths, advisory speeds, in essence.

This picture shows how we use radar and other sensors. This is at an intersection on the UF campus Stadium Road and Gale Lemerand. You see our football stadium there on the left. So that intersection is instrumented so that when the vehicle is connected it can receive an optimal path, which is the green point there.

So when we first detect a conventional vehicle we estimate its projected path. We optimize signal control. And then as the vehicle moves we reevaluate the path and adjust the signalization if the vehicle was slower or faster than what we predicted.

So with initial simulation experiments and for a fully autonomous simulation environment, but with communication with the infrastructure, our experience shows that we can reduce delay by 20 to 70 percent, depending on the demand. Of course that number goes down when you have mixed traffic and lower market penetrations. We start to see a significant difference when we get to about 20 percent market penetration.

So a system like this cannot function if it doesn't have communication with the infrastructure. And to be able to take advantage of such systems we have to have collaboration on both the public sector and industry, academia. And so I Street is approaching this as a collaboration with our partners, Eftason and the City of Gainesville. Because if we don't get this right, if we don't make a difference, then congestion will get worse and deployments for autonomous vehicles will backfire.

So this map here on the right shows our ongoing deployments around Gainesville for I Street. So I invite you to check out our work on I Street. You will hear some more with the next three presentations, and we look forward to working with you to improve mobility and safety.

Thank you. And with that I'm going to get Dr. Crane here for the next presentation.

DR. CRANE: Well, thank you very much. We call her Dr. Lily, so she's a fantastic leader of our efforts down in Florida.

So I was asked to try to do some -- I was watching that clock there, a 15-minute overview of autonomous technologies to a group of experts in a wide variety of topic areas, which is usually a recipe for disaster. So here goes.

A little bit of the over -- I'm glad you started with the old cars. I hadn't seen the horse head, I thought that was great. Background. I've been in Florida a long time. I'd been in the Army before I got to Florida, and like in the Army, every three years you transfer and you're just -- so my three years got up, I was like great, I've been there now for like 35 years, so I guess it's not going to happen.

But over that time we've done a lot of autonomous vehicle work for the Air Force, for different projects that they had. And then in the mid-2002s DARPA had their Grand Challenges and the Urban Challenge. I was going to say we participated in all three.

The Grand Challenge, if you're not familiar, was they gave along a desert route latitude/longitude of a whole bunch of points so about 150 mile long path, and whoever could do it the fastest would get, well they upped it to a $2 million prize. And the first year, shoot, five vehicles got about five miles, and five got about a mile, and five self-destructed at the starting gate. And they were the best 15 out of 43. We were in the middle group, we got about a mile. My goal is make sure we get out of sight of the starting gate, and then whatever happens, happens.

But the second year though definitely, it was about a year and half later they redid it. And 43 teams, they put 23 in the race. Five completed, and the fastest was Stanford, and they got the $2 million prize and kind of led off to Google, Waymo, and all that. We got about 14 miles and our GPS went out. Well our GPS, which is supposed to broadcast corrections to a few centimeters level accuracy had an eight meter error in GPS, and the entire vehicle was a single point failure vehicle. So I can't say that I was disappointed, that's not the right word. But that was actually our high water mark, I think.

And it was really exciting to see that happen. So now I used up all that time on the first slide.

What I want to do today is just show, you know, sort of a basic overview of what's going on with autonomous vehicles. And I don't have to spend a lot of time on this chart. But what really jumps at me is that orange word "deaths." And when you see that and it's next to that blue line and it's going way up high, you say "Oh, my goodness, this is terrible." But it turns out that that's actually vehicle miles traveled. And one of the other increasing one is population. And if you go to the very bottom line about deaths per billions of vehicle miles traveled, there's been real improvements. And I think a lot of the safety factors that you had mentioned. I'm going to get a new car this fall and I'm going to get everything I can on it because it's amazing what they've got up there.

So there has been big improvements, but there can be better. So if I look at the basic problem for, you know, one autonomous vehicle, basically all you have is your instantaneous sensor data, and you have whatever operative or map data that you have ahead of time, and that's all you have. And from that, again, in every instance you have to get your throttle, steering, braking, whatever you want to get to come out of it.

And for the instantaneous sensor data, you know, one is localization. Can you get some idea, you know, a typical GPS might be, you know, for meter accuracy, it's not too bad. You can do better than that with some other technologies. Identify static objects, the terrain, where is it smooth, where are the curves, and then lane markings. But the moving objects are the big one, the other vehicles and pedestrians and things like that, how do we do it.

The main sensors that are out there, I think I've said the accelerator pedal, I gotta go a little faster. The main sensors that are out there, LIDAR, you know, is very popular, you shoot the laser and you get this point cloud, you get this point data. And the advantage is 80 meters is easy. We've got one sensor that claims I saved 300 meters that we used, oh, the Urban Challenge, that's the city street DARPA competition, I forgot to talk

about.

But you might miss the target. The beams, you know, it's not continuous, reflections due to rain or things like that, or certain materials don't reflect the material, you know, the beam that well.

Our vision is great because it's passive, you're not sending any signal out there, but again, lighting and weather conditions and something as simple as the stripe in the road going under a shadow of a tree can cause some issues sometimes.

Ultrasonics, I know we started way back with some of our Air Force work, we were moving very slow, it was construction equipment, and ultrasonics is the poor person's sensor. They are inexpensive, but short range, and all you know is in this cone of area there's something out there but you're not sure where.

And radar is, you know, probably one of the best as far as bad weather and things, so that you can get it out there. But again, it's not pinpoint sort of like a laser beam as far as locating where something is out there.

This is our Urban Challenge vehicle, so that was a competition DARPA did out at an Air Force Base that was closed in Victorville, California. You had to drive on city streets. Again there was a $2 million prize, but it was a bit more subjective this time. Instead of who did the 150 miles the fastest, it was clear who the winner is. This time, so first place was Carnegie Mellon got $2 million, Stanford got $1 million second place, Virginia Tech third, got half a million dollar prize. If I was to ride in one of the vehicles, maybe I shouldn't say which one I would want to ride in.

So this is our vehicle, it's a Toyota Highlander that we did. We have a lot of single beam radars down at bumper level, you see Sick, it's a German sensor, pronounce it Sick. I don't know. Sends out a single beam, so on the bumper level there's sort of a plain of beams that are out there. And if you look at this top-down view, there's an L shape right in the middle, has a number 36 next to it. That's what from the top view, but that's another vehicle. So you've got to interpret that as a vehicle. Some of the other objects, you see how

we grouped them together anyway, our buildings and things, the vehicle itself is that rectangle, it's not labeled, in the middle.

And then as you move forward, this is some of the technology where the prices have come down now. This is a Velodyne 16 meter LIDAR that we use quite regularly. And you see how it's angled on the left-hand picture so that it swings 16 beams 360 degrees. On the left of the blue dot thing, all that mess up there are the trees because the back side of the LIDAR is shooting up there. But on the right-hand side we see the 16 beams as they're sweeping across the road. So again, you don't get continuous total data but you get all these points as indicated by those blue dots.

This is a 16 beam LIDAR as we put on our vehicles when we're driving around campus, so again, you get a lot of information. The problem becomes how to interpret that fast. And the 64 beam LIDARs are very popular. When these first came out though I think the 64 matched to the price, I think it was $64,000. Yeah. But you get a lot of data. And you can say "Why is that important?" Well, we're going to get to that.

What about the operary information? All right. We're going to have maps, so how are we going represent those maps. Are they going to be point clouds, are they just going to be -- well let's just show the options.

This is the map that we had for the DARPA Urban Challenge. It was a texted file. And if you look down the list here, you can see about halfway down on the left it says "Number of lanes, two." And then two lines below that it says "Lane 1.1, number of weight points 4." And down at the bottom of the left-hand column you can see four pairs of numbers. Those are latitude/longitude of certain points. And then it says "End of Lane 1." And then in the right-hand column, Lane 1.2, so it's Segment 1 lane 2, has six weight points. And you can see the lat/long. And the fifth line it says "Exit, 1.2.4, and then 3.1.1. That means that you can exit or you can transition from Segment 1 lane to .4 to Segment 3 lane 1.1.

So that was our world, that's all we had. And from that then, you know, we

planned routes to -- oh, we were given a mission file so you go points 8, 11, 20, you know, in a certain order. So you had to plan your route with that information.

So do you have a map like that, or do you give entire point clouds? So this was us driving down one of the roadways in Gainesville with a 16 beam LIDAR and just one single path. And you can even see the wires in the power lines. And it's a lot of information, but it's all available.

Or do you take all that information and try to condense it down so you can make a Boxall representation so it's sort of line Minecraft representation. So on the left you see all these boxes. And on the right we did some classification. This is something for the Air Force, we were looking for tree trunks and not people. And the purple we identified as tree trunks, except for the one image.

So if you had instantaneous sensor data and you have some type of map data, how do you decide what to do? I'm not going to dwell on this slide, but one of the biggest things we did on our Urban Challenge vehicle was how do you decide what behavior to do. Again, it was to go from that sensor data, which is the blue thing on the bottom, to throttle breaking. I'm going to zip through that one.

Okay. What can you get today? And I have to apologize to some of the other vendors, this is a Tesla video, but General Motors has some great stuff, a lot of the people have great stuff. So if you were to go to the showroom today and buy something, you can basically be on like an interstate and do lane changes, stay in your lane, stay behind a vehicle. Some of it's kind of cute, you know, tells it to pull out of the garage and come get ready to go. And, you know, automatic parking, you know, it's been out there quite a while. And the last one is emergency braking. And those are, they're really good things, and I'd love to have that in my car, but it's not an autonomous car.

So again, kind of rushed through in 15 minutes, and you go from what's available to buy today, go to some of the esthetical topics, maybe some of the things that keep us up at night. And then go back to the LIDAR. So the problem with the LIDAR is how

do I take, for example, this point cloud. So on the left are all the points that were hit, I believe there are 16 beams here. Somebody was about two and a half meters away, you get a lot of data. And you can see on the right-hand side, you can hardly see the dots at 17 meters. And 17 meters isn't that far but you don't get that many hits. So how do I identify that as a person?

So this is from a TED talk from Chris Urmson from Awaymo. One of the approach was they generated all these data of actual people and have stored them, and then you compare, you know, the point cloud that you have with the models you have and identify.

And then this is one, I just wanted to show a case. I don't want to say things that keep us up at night, but let's see if can I get this to play. Play, play, play. Okay, so let's play. There's an intersection indicated by those orange lines. And the mouse was wiggling by a person there. And this is the raw data, and we classified now. There's the person, and the person's about to walk across the road. And you can see we're getting great point hits. The sensor is located at the intersection of the blue/green/red lines. And as they walk across, look how it disappeared. Now if you look at the raw data there's still data there, but our algorithm said there wasn't enough points to classify that was a person. So that's a problem. And it's not a problem that's going to go away. Now on Tuesday the student ran in, hey I got a new video, I've got that case solved. And I didn't bother to put it in the presentation because we'll have a new problem tomorrow anyway.

But those are the kind of things that cause, you know, trouble to get out of there.

So we're going to go to issues. Like I say, it has to work 100 percent of the time. Nothing works 100 percent of the time, but that's not the real issue. When the system realizes it's having trouble it has to be able to turn over to the human, you know, in enough time, things like that. So the whole system has to work 100 percent of the time, let me put it that way.

I worry about, and maybe this is what I should have said, the stuff I worry about, sensor of performance, important environmental conditions, false positives/negatives. This is one I think Dr. Classen's going to talk about, is things like this. If I'm in the vehicle, do I want the vehicle to explain to me what it's doing? I'd feel better if I see this map and I see little boxes around the other vehicles, that it's identified them and I'll feel better. I'm not grabbing the wheel though. And then the communication issue, I think that's going to be a really big plus vehicle to vehicle. Legal/ethical issues.

So what I'm going to end on is I got two videos. And I think this is from Vietnam. Intersection of the present. Maybe it's efficient, they're all moving, nobody is stuck. So we go from that. And I found this, it's at low resolution and the reference, it was from France. Here we go. They put a lot of time into this I believe. And it goes on for a little bit longer. So, you know, that's definitely not what Gainesville looks like today.

So thank you for your patients. Again, I tried to give a shorter, quick, shotgun overview of the technologies that are out there. And we're going to turn over to Dr. Classen now for the next.

DR. CLASSEN: So after all of that I feel very compelled to represent and to present the human perspective to be able to see how folks are experiencing all of these exciting growth and challenging times as we are really standing in the transportation revolution.

I'm an occupational therapist, so what ODIS are doing is we are interested in the person, the vehicle, and the occupation. Or, those meaningful tasks that each one of us have to do to be able to survive, to strive, to thrive, to live meaningful lives, and of course to drive.

So from that perspective I'm going to talk about a study that we've conducted at the University of Florida to look at older adults' perceptions of autonomous vehicles. So I'm going to use the scientific outline to be able to frame my presentation. So it's going to be a true scientific presentation.

And a little bit of background in terms of older drivers, or older adults. So we know that the demographic shift in America is happening. And about 20 percent of the US population is over the age of 65. And that is to increase in the next 10 years, so that we will have one out of four drivers will be over the age of 65.

Despite the fact that older drivers have issues with medical issues, declines as a result of the normal aging process in their cognitive, their visual, their motor, and their sensory functions, as well as being on complex medication regimes. And that causes that they are at a higher risk for crash related injuries and fatalities. Despite that, driving is still the preferred mode of transportation among this population. So autonomous vehicles might hold excellent opportunities for these drivers to offset some of the health as well as the safety issues.

Recent perceptions were measured by survey only where older adults were asked about autonomous vehicles, survey only. So we thought well, if we can use the surveys, but if we can also expose older adults to some of these autonomous vehicle technologies, what will we see? And the expectation that we had going into the study was that their attitudes, their perceptions, their values, and even maybe their early adoption thoughts may improve as a result of exposing them to some of these technologies.

So what we did is we exposed them to a driving simulator that was programmed at the SAE Level 4. And we also exposed them to the autonomous shuttle, the one that Dr. Lily showed in the previous presentation. So obviously because we are working with human subjects, we had to go through ethics approval and received a full IRB approval, that's the Institutional Review Board approval from the University of Florida. And we developed a repeated measures crossover design, and I'll say a little bit more about that in a second.

We recruited the participants from the northcentral Florida area, but with a concentration in Gainesville. And we included folks if they were at or older than 65 years of age and if they had valid driver's licenses. And the exclusion criteria pertained to their

performance on the Montreal Assessment, cognitive assessment and using the indicators of that particular assessment to understand cognition and cognitive declines.

We had a variety of measures that we used. And I'm not going to go over all of them, but on the left-hand side you can see some of them pertain to chemical tastes, looking at safe shifting as well as user perception surveys. And then also the driving habits questionnaire which basically calculates or describes all the drivers' habits. And the life space questionnaire to help us to understand how older people are moving in their home, outside of their home in the neighborhoods, or do they even cross state lines as well.

So, let me just go back to this one. On the right-hand side you see the RTI high fidelity driving simulator. So in this simulator it's got a full car cab, and the older driver would sit behind the wheel with a research assistance in the passenger seat. These life-size images that's being projected on the actual screen. And, folks, the experiences are very immersive experience with very high what we call physical and emotional fidelity. Meaning that the believability of this situation is really high.

On the bottom is the transitive easy mile, easy 10 autonomous shuttle that's also been programmed at the level for the SAE standards, and that's the shuttle that we've used. In this particular shuttle we had six older adults at a time in the shuttle, and we had a research assistant as well as the safety operator accompanying the older drivers. And because of not having the actual NITSA waiver to run the shuttle on the public roads we conducted this study in a bus depot in Gainesville.

So after folks enrolled in the study, they completed all of the base line measurements that I've mentioned in the previous slide in visit one. And then they were randomly allocated to Group One and Group Two because of the crossover design.

So for folks in Group One, they were first exposed to the simulator and then they were exposed to the shuttle. And after each one of these exposures we actually used the AV User Perception Survey to look at their perceptions prior to exposure, exposure after the simulator, and exposure after the shuttle, to see if there's any changes.

And in Group Two we flipped the order of the exposure, and they were exposed to the shuttle first and then the driving simulator.

So we collected the data by trained research assistants, and we entered that in a red cap system that adheres to all of the privacy and the confidentiality policies at the University of Florida. And our analysis was conducted with statistical software, SPS version 25. And today I'm going to give you a preliminary look into the data that we found. We haven't completed the study yet, we are enrolling 105 older adults, and this is 69 older adults that's completed the study. So please see this as preliminary data. And of course we cannot make any causal conclusions as a result of that.

I just want to say something about the user perception survey. When we started the study there were no user perception surveys that actually asked the questions that we wanted folks to answer so we had to design our own user perception survey. So this is still undergoing psychometric testing and so it's in development as well.

But some of the things that I would like to highlight is that we basically have 28 questions on the table over here -- the pointer is not working, but you can see that there's a total of 32 questions, 28 of them are all questions pertaining to perceptions, values, beliefs, and experiences with autonomous vehicle technology. And then we ask four open-ended questions such as the disadvantages or the advantages of autonomous vehicles.

So all of these items derive from basically the dimensions, which is in the top left-hand corner. So we look at questions pertaining to trust, safety, control, experience, etcetera. And all of those dimensions are basically conceptually imbedded in some of the existing models that's at the bottom there, there are seven existing models. So as I say, psychometric testing is continuing with this particular survey. But this is the survey that we used for the study.

So if we are looking at the results. So this is some of the demographics of our participants. So for shuttle first exposure we had 20 women and 18 men. And the women were a little bit younger than the men in comparison. So 73 was the mean age, 77

the mean age of the men. And that pattern pretty much held for folks who were exposed to the simulator first as well.

If we look at the gender distribution we had so far 29 men, that's 42 percent of the sample, and 58 percent female. And that's a pretty good representation of the current demographics for gender, according to the Florida census statistics. In Florida it's 45 percent male and 55 percent female. If we look at racial distribution, so we had 87 percent of the folks that self-classified as Caucasian or white, nine percent classified as black, and four percent classified as other.

This is an interesting slide in terms of the actual education. So Gainesville being a college town, and much of our recruitment occurred amongst the older adults in Gainesville, you can see that 73 percent of our participants had either Bachelor's degrees, Master's degrees, or Doctorate degrees. So that is totally of course skewed in terms of the general population. We also had 23 percent of our participants having a technical school, some college, or an Associate degree, and four percent of our participants had a high school diploma or a GED. So a little bit skewed in terms of education. So we worked with a very highly educated group in the study so far.

All right. So I'm going to show you the results of the entire group before the actual exposure to any of the technology, and then exposure to the shuttle and the simulator.

So a brief orientation here is that on the YXs you will see the user perceptions. And we measured that with what we call a visual analog scale. And so that's a scale that is numbered from 1 to 10, it's exactly 100 millimeters, and we use that as numeric data to be able to measure the perceptions of older adults. And on the X axis we have the baseline condition, the shuttle condition, as well as the simulator condition.

So the variables on the right-hand side pertains to the social influence, the intention to use, and the cost. And all of these, if the graphs is going up it shows that older adults are more favorable to each one of those conditions.

So you can see that was the case for being exposed in the shuttle as well as in the simulator, although there was a dip when folks were exposed to the simulator. The outlier here is the intention to use, where the older adults were really more positive after they'd been exposed to the simulator, and the intention of course is to use autonomous vehicle technology.

For the actual next three variables, this is pertaining to how media influence people as well as their trust of autonomous vehicle technology and the controls. Do they want to take control over of the vehicle or would they rely on autonomous vehicle technology. You can see that the graphs are pretty much telling us the same picture. At baseline, you know, they are lower. Once they get exposed to the autonomous shuttle, sharp increases, and then to the simulator we see that the graph is decreasing again.

And then our last four variables pertains to authority, excuse me, that's pertaining to trusting the National Highway Traffic Safety Administration's safety measures, perceived usefulness, perceived ease of use, as well as safety under each one of those cases. Again you see that folks felt much more positive to these four variables after they'd been exposed to the shuttle versus being exposed to the simulator, but still the simulator had an effect.

So if we then looked at what happened in the groups. So if we look at Group One, you will see that they were first exposed to the simulator and then to the shuttle. Now I don't want to be saying that we can make causal inferences, but we did look at statistical significance, and that's outlined in the red font over there. And we also looked at effect sizes to tell us how big the effect is.

And what we learned from this first table on the left-hand side, is that the older adults' trust increased quite a bit after they'd been exposed to the shuttle last, as well as their perceptions of safety after they've been exposed to the shuttle last.

And then for Group Two where they've been exposed to the shuttle first and then the simulator, we see that the intention to use increased. So we think it's because in

the simulator they were sitting behind the steering wheel, it felt like they were an operator of the simulator, where as in the shuttle they were more passive as a passenger.

Okay. So my take home messages, you know, overall analysis, exposure to AV technology positively effects older adults perceptions to this emerging technology. Perceived safety shows the highest percentage points of increase after being exposed to the autonomous shuttle, and then intention to use shows the highest increases after being exposed to the autonomous shuttle -- excuse me, to the simulator.

The Whitten Group analysis showed us that trust and safety significantly increased if they were exposed to the autonomous shuttle last, and intention to use significantly increased after being exposed to the simulator.

So our next step of things to do is of course to complete the study and to look at gender and age and time effects as folks are being exposed to this technology. This is also laying the foundation for us to further look at folks who are disabled, those with dementia, the disadvantaged, the deskilled, as well as those with degenerative disease such as degenerative neurological disease. Because we do believe that transportation, like Mr. Leonard had said, does not just need to be affordable, effective, integrated and ubiquitous, but for these special populations it also needs to be accessible, acceptable, adaptable, and available. And so, you know, we hope to further the work in that area.

So I want to acknowledge our funders as well as our stakeholders, and then each one of the project team members, specifically Justin Mason, our post-Doc, Dr. James Russel, who did much of the data collection, Virginia CC Opeco, one of our collaborators, Jason Rogers, and our research assistants, Melissa Varara and Casey Clark. So thank you so much for your attention.

DR. RANKA: So I think we are slightly ahead of schedule, right, so maybe I can take a few more minutes? All right.

Good morning, I'm Sanjay Ranka, I'm a Professor in Computer Science. I do mostly artificial intelligence for transportation and healthcare.

So what I'm going to talk about today is the world is changing, where in the past most of the data on transportation was collected by the government or third-parties like Google. But now with autonomous cars, all the car companies are also going to be having data, and that's the new player in the market.

And the key goal is to able to create a symbolic relationship, and in my mind the way to do that is make things more real time. Because at some juncture all the cars that you are driving around, we have to interact with pedestrians and other vehicles. And the more real time information which you can provide to them, the more amenable they are going to be to able to use it. And obviously that's going to improve both safety and operations.

What we're trying to do is we're trying to build a data store. Again, try to be able to access that in real time, to be able to achieve a variety of applications, both from monitoring, from evaluation analysis, be able to do predictive modeling, being able to do optimization of a variety of issues in signals and corridors. And also support planning and investment.

Again, the key goal obviously is to both manage traffic condition and improve safety, but make everything data driven. And also be able to support our vision, movement of goods, services, and people.

With that challenge I'm going to talk about some of the projects which we are working on on trying to make the projections smarter and more real-time. The goal is, at a very high level, to be able to compute everything on the edge, as they call it, right near the signal, as close to the signal as possible, because you want to make it real time. And then be able to assimilate key findings and push that through a centralizing monitor like a cloud so that you can do more longer analysis there. Clearly the important part here is to be able to be sole sufficient and be able to use a variety of sensors which are available to you today and which will be available to you in the future. And that's what we are working towards.

So one of the projects which we are working on is what I call smart

intersections. So right here basically is that you have an intersection, a typical intersection in any city, which has local controlled data, there are local controls is under the roads, which give you data about every vehicle arrival. We want to be able to use other cameras, like video cameras, which are called fish-eye cameras, sitting on top of the intersection, and in the long term be able to use LIDARs and other sensors to be able to collect information in real time about all that's happening on the intersection, store it in a sensible form, keeping track, making sure that we obviously worry about privacy issues. And then be able to understand what's going on at the intersection in terms of an anonymous behavior or in terms of near misses, to be able to provide feedback to the designers as well as architects of intersections on what designs are actually more effective and what signal timing planning are actually more effective to improve both operations and safety.

So what we're trying to do is we're trying to develop these real time skillable systems which can actually collect data from roof controllers as well as from video. First I'll talk a little about the roof control of it and then I'll talk about the video analysis. To be able to collect the data in real time, to be able to run all these algorithms for detection and everything else in real time, and then be able to push that information back to the autonomous vehicles in real time for this to be effective.

So we are developing a system for understanding what's happening at the intersection, both at the intersection level and at city level. We work both the City of Orlando and City of Gainesville, collecting permission from all the signals which they have data for, to be able to analyze it. And I'll show you some of the results from a broader perspective, and then go back to the intersection level.

So for example in this particular case we can actually process one vehicle feed in less than an hour. And that's our goal. Our goal is to make everything as real time as possible so that the information which is gathered is captured and processed and analyzed and sent back to the vehicles and the pedestrians. We can actually take all the data in a given city, rank all the intersections in terms of their performance so that traffic

engineers can understand what's going on in every intersection and get a broader picture of – I'll give you an example of this. Where essentially what it'll do is it'll rate, if you look at one, it shows the different categories of intersections, whether the fixtures are not working properly or they have capacity issues, or they have timing issues. Again, the intent basically is to provide a traffic intersection with a good perspective of what's going on in that entirety so that they can make changes in real time in some cases, or a case on a daily basis.

So they can select all the information about what's going on in the city for any given day, be able to figure out the week day or weekend behavior, to say hey, this is where my problems are during the week days and the weekends, understand what's happening in the morning, what's happening in the evening, so they can plan the traffic signal timings better.

Again, the goal is to make the infrastructure smarter so that they can impact whatever the conditions and autonomous vehicles.

This one kind of shows you that the behavior changes by the hour, and how you plan for that. Also be able to do a change detection automatically to say where the change is happening so you can focus on those changes.

This kind of gives you an idea in terms of a broader infrastructure. What I'm going to talk a little bit about is how do we do real time video analysis to be able to understand what's happening at the intersection and, again, be able to generate messages on the fly and be able to support in a few years information through the autonomous vehicles about what information is useful for them, what's happening in the city or whatever unit it's in, and our intersection can be changed without directly.

So this one kind of shows you again real time processing of an intersection in Gainesville where traffic is coming. We're tracking different kinds of objects. In this particular case I'm showing you in real time all the cars, the greens are a bike or a motor bike, and the yellow is pedestrian. So all this tracking is happening in real time. Also this kind of gives us a good synopsis of what's happening at the intersection. We collect this

data in real time and then process it to understand behavior. You see this is just playing again and again.

What this data does it give us information about all the vehicle categories on that particular intersection. So it would be color coded for different directions, the light, all the categories are marked so that the light ones where they start and the dark ones where they end. And this shows you the behavior at that particular intersection. Again, the goal is to be able to analyze this and be able to rate all the intersections in terms of their safety and operational quality.

This shows you the behavior on the right-hand side based on different phases, generally every signal has six to eight phases. And each phase has different traffic behavior. In some cases people are going east/west, some cases people are going north/south. And then be able to also understand what's happen on a given phase because traffic sometimes moves in a fashion that two directions can interact with each other, so we can actually show that. We actually then are able to analyze also all the pedestrian traffic through the intersections to see how many people are actually jaywalking on the intersection, how many people are not following the paths. And again, we can do this from morning times to evening times.

A very interesting part which we do is we look at autonomous behaviors, right? So for example these are all the categories here which show the way that you are crossing on the red light in a given hour. The key goal of all this is that once we can analyze this data, we are able to then predict behavior and then be able to use that for better intersection design. And in some cases then the end goal is to, if you look at the left, there's a pedestrian walking, crossing the traffic and goes back, right? So we want to be able to capture that kind of behavior and be able to warn all the traffic on that intersection to say hey, there's a pedestrian crossing where they should not be crossing, be aware of it.

So these kind of real time messaging and real time processing is very important to improve the safety in the long term. And the goal is that any object which can

actually communicate at the intersection should be able to get that piece of information.

Here's another example. If you look at the behavior of this particular pedestrian, they come there with the red light, doesn't want to wait, comes back, and jay crosses. So we want to be able to track all this behavior in real time and be able to send this information to all the vehicles on the intersection.

We also want to be able to detect near misses. So if two vehicles are coming very close to each other we want to be able to say hey, there's a potential problem there. And the key challenge of course there is that you're dealing with esthetical cameras which have distortion of all kinds, they see better near and they don't see very well far away. We have to be able to take care of that. And then again, be able to find out. So here's an example on a target, you see there that the vehicle stopped in the front so the vehicle behind braked. And if it didn't brake there would probably be a crash. And the vehicle could possibly brake in this location because there was actually a fire truck behind which was beeping, so the vehicle in the front stopped in the middle of the intersection and the one behind went further.

Another example of that, if you look at these two vehicles, they come very close to each other but that's normal behavior. Because they're just passing each other in different directions. They came very close to each other but they're in different directions and that's not a near miss, so we have to be able to detect one, things which are real misses versus "the false misses" if you will..

So we do this analysis by collecting the data in real time. And then part of our project, and Lily mentioned this, to be able to do this in the competing project where we will have all these video cameras at 10 to 123 intersections, we'll collect the data and be able to essentially share the data with the smart and connected vehicles in real time of what's going on in the entire network. Be able to analyze the network itself, detect all the incidents which are happening on the different parts of the intersection off their network, and relay that back to autonomous vehicles and be able to optimize it at the network level.

We also do other work on the infrastructure site where we understand why looking at vehicles which are passing on highways to be able to say what commodity are they carrying. One of the interesting parts of understanding behavior on highways is to understand how commodities are getting transferred in the State of Florida. And obviously this can be extended to the entire nation by essentially looking at the type of object and logo detection of what company it is. So if it's Wal-Mart we know what kind of goods they are carrying, if it's Fed Ex we know what kind of goods they are carrying. So we can understand in real time how goods and services move around in terms of freight planning and everything else.

The other thing which we do is we look at highway videos to understand how vehicles enter and exit ramps, how does that impact speed of the different vehicles which are coming in, to be able then to understand what kind of ramp changes need to be made or what kind of designs are better than other ones, to be able to be effective.

This is my team, there are four faculty involved in this project and eight or nine Ph.D. students. We effective double up every aspect of these techniques. Our work is supported by NSF Services Smart View Project, I'd like to acknowledge them. Also this is a recent study which showed the importance of different levels in terms of improving transportation, it just came out six months ago. And UF as a whole is focusing on the top five here, which can actually have a real impact in terms of improving traffic performance.

Thank you.

DR. ELEFTERIADOU: Thank you. Do we have a few minutes for questions, I believe. Yes, please.

MALE SPEAKER: Thank you for visiting us. We're an academic institution so we'll give academic reactions to what you've said. Four quick ones.

For your presentation, what you've discussed about improvements in autonomous vehicles at intersections could be done now. Nothing preventing that from happening now. So it would be useful to think a little bit about the political economy of why

is it we aren't doing these things now and we need autonomous vehicles to get them done? I'm not saying you answer it, but it might help to sort of motivate what's going.

I'll go quickly through the three other ones. These are largely for motivation.

On your presentation you show the sort of stylized facts about the declines in fatalities for VMT. Nothing obviously to dispute about that. The issue is why. You know, we're really not so sure about that. I mean one can speculate about improvement in vehicles, but it's very hard to show that kind of thing. I would suggest that an equally compelling explanation is the increase in congestion that's occurred at the same time because people are going slower, it's simple physics. Point being, that's a benevolent way to reduce traffic fatalities, is congestion. And the point that I would make is that we're sort of running out of good ways to save lives. And that's where autonomous vehicles comes in, because that's going to be a little accelerated with decline, and that's a good thing that's going to happen.

On yours, you didn't have time probably to go into detail, but it will help to know more about the people in your sample. In other words, what was their accident experience? Had any of these people been in accidents? Do they know people who've been in an accident? How much VMT they drive every year, they care about safety in the vehicles they buy. Going into this, this would be an interesting comparison. Are there groups of people who we think, because of their own experience to vehicles and so on and so forth, are going to be open to the benefits of autonomous vehicles and safety as compared with others who aren't at all similar to those experiences, who obviously would be very, you know, hesitant to believe that for a variety of reasons. Might be interesting to sort of point all that out.

DR. CLASSEN: I will comment to that by saying that we do have that data. And so that will be analyzed as we are done with --

MALE SPEAKER: Yeah, that'll be important I think in terms of the people who resist it.

And on yours, the thing I'm thinking is long run. Is the road network going to change because of autonomous vehicles? Remember, we have built this network based on non- autonomous vehicles. And I'm seeing all these intersections and I'm thinking, yeah, we have that because people couldn't get close to their destination and they gotta walk across city streets. So maybe traffic patterns will change, maybe we'll realize, you know, these kinds of intersections are bad, roundabouts are better, or for that matter we'd even want these kinds of things. You know, it doesn't hurt to start treating now the changes in the network that will come about because of autonomous vehicles, and start speculating. Obviously you can't do any of this now, but I think we're going to learn a lot as we go into this and we're going to see both pedestrians and the network changing. So those are suggestions, our view.

DR. ELEFTERIADOU: Thank you. With respect to your questions, if I got it right. Yes, we can start doing this now. One of the issues is the chicken and the egg. The vehicles need to be instrumented, the infrastructure needs to be instrumented in order to communicate, and I think that is what is unique with what's happening in Florida is that both are happening at the same time and that allows us to start getting those benefits.

DR. CRANE: I was just going to say about the congestion. Okay. All I want to say about the congestion was that's a very good point that I hadn't thought of, but it's definitely not what I want to see happen. But that's an excellent point. Yeah.

DR. RANKA: As we know, intersection unfortunately doesn't change overnight, right. So all these highways and road networks are built over decades. So I know that these things are going to stay for a long time. We have to work with whatever we got right now. And of course as we learn more, as you're pointing out, they will evolve. But probably take several decades before that happens.

DR. ELEFTERIADOU: Any more questions? Yes?

MALE SPEAKER: Urban planner. Strikes me, this is fascinating. The big data revolution is giving us tremendous resources, but where do we draw the line between

rational human behavior and irrational human behavior? Because theoretically and totally unacceptably you can have, you know, collect the entire, you know, data on the entire history of one pedestrian who is apparently trying to cross the road. You know, the mental history, is he out of an institution, might he have a relapse, does he have something in the family recently? Yeah, we have the data about that, yeah, his wife has behaved -- where do we draw the data? Where is the human responsibility in that? And not ours, in yours as scientists, but ours as individuals? Thank you.

DR. ELEFTERIADOU: I think one of the points Sanjay was making was the real time information and warning. And so being able to recognize and predict intent, that's I think where that technology can be very useful.

DR. RANKA: But, you know, add to what Lily just said, the doctor can only tell you what you need, good for your health, if you still want to do stuff which is bad for you, at some juncture we can only prevent other people from not getting impacted.

MALE SPEAKER: Thank you. I just saw an article on line where the Attorney General is ordering that software always be created with a back door so that government can access it. Of course anywhere there's a back door in technology, hackers can misuse it. What are the provisions for encryption security in autonomous vehicles? Will they have no back doors so that no hackers can intrude?

And to follow up on the previous gentleman's point, we probably all remember of the Geico commercial where the squirrels are like high fiving each other for tricking a car running off the road. What happens when 15 year old kids see autonomous vehicles come along, decide to kick a soccer ball across the street and watch what happens?

DR. CRANE: The second part, I think that's already happening, you know. These are just anecdotal stories that I've read on line. But people challenge the autonomous vehicle, they'll drive right in front of it because they want to see what it does. And that's a problem.

The encryption part I'm probably going to have to pass to Sanjay myself because the level that I've been at is just got to get it to work. And that, you know, becomes kind of my secondary concern. But, boy, if it is hacked into it could just be chaos. I don't know, do you have any comments?

DR. RANKA: Yeah. You know I don't really know much about the security of autonomous cars themselves, but on the infrastructure side we are making sure that whatever we actually collect we throw away as soon as possible. We don't, like for example, the video coverage I talked about, we just need it for five seconds, and after that we process it and at that juncture the video is useless for us. We just wanted to get immediate information about what is going on. We obviously are very careful about privacy issues, and we encrypt all the information which we keep. We analyze it, that even if you were able to get to it, it's useless for you. Because our goal is not to track people, our goal is to understand behavior.

FEMALE SPEAKER: Thank you. My question's about the connected infrastructure and the infrastructure pieces. Because I know in the autonomous vehicle community there's an actual competing theory, including one that's being tested right now in Florida at the Villages, where they want to be completely independent. They don't want this connection. They don't want to have to depend on the infrastructure being there doing what it's supposed to. They want the vehicle to be smart enough and the mapping to be good enough.

So I want to sort of talk to you about if you take on what this debate is about connection versus true autonomy.

DR. ELEFTERIADOU: Yeah. This is a very interesting just competing approaches. In my view you need to have both to maximize safety and to avoid making congestion worse.

I don't think it can be done without the connectivity, just purely with autonomy. The information that you can get with connectivity supplements very nicely what

autonomy is able to do. So in my view the two have to work together.

DR. CRANE: As I say, it all started like 2007 was the Urban Challenge, and you didn't want to rely on anybody, it had to just be you. And part of that though is look at the impact across the infrastructure. So we had no impact on the infrastructure, and yet you could get it to go.

But the benefits are if there's other vehicles, especially pedestrians is one of the projects we're doing now, is that if I can be told that from sensors at the intersection or from other vehicles or whatever, that information's just really going to help me. So again, when we started, well there is nothing, so we're just going with the current infrastructure. But I think anything that's added is just really going to be a benefit.

MALE SPEAKER: So a good segue way for my question is so if these autonomous vehicles are relying on the connected infrastructure, and as we all know that things break at one point in time. Where is a line that you will draw in terms of how autonomous systems are supposed to be just self-sufficient like because otherwise people will start taking shortcuts and, you know, build systems relying on the infrastructure that may fail and may get some potential hazard.

DR. CRANE: I was just going to offer my opinion is I think it ought to be self-sufficient, and anything I get in from some of the other sources is a bonus for me, it's going to make me better. But I think it's going to have to be, and as it all develops too, I mean we're in northcentral Florida, and you don't have to go very far to be out to not much -- well, I'll take that back, to, you know, minimal things. And I think self-sufficiency is going to have to be with us for a while.

DR. RANKA: So by definition most autonomous systems are failsafe. That means they will work independently, maybe at a lower quality than expected if the information is not there, and the goal is that they have become more efficient as more information is available. But the intent always is that things should work even if everything else fails.

DR. ELEFTERIADOU: Yeah. I think there has to be redundancy. I also think that the deployment will be facilitated if both work together to supplement the information that the autonomous vehicle has right now. For the examples that I showed, for example where you don't have line of sight to obstacles, but having information from the infrastructure allows you to get that.

Okay. Over there.

FEMALE SPEAKER: I'm sorry I was late. Thank you. I was wondering about a timeframe. A lot of people say this is going to happen much later than what we think. And maybe this is another group, but supposedly the 5G network is very important. And China's way ahead of us, and we're arguing with Huawei and are we going to use them or not use them. Supposedly it'll be a security risk.

And also trucks. Now those are high paying jobs, truck drivers. Are you just doing vehicles now or will they be doing trucks later? I've heard there'll be one lead in truck with one person and then autonomous behind it. And I'm wondering if a young person, not I, but if the young people want to get into this field, what's their best major in college, or what should they be studying?

DR. CRANE: I just tell our students that the whole area, in the last part, is a mix of mechanical, electrical, computer science, and that you can major in any of those, but you're going to learn about all of those. So it's a blend. Maybe it needs to be a new major, I don't know.

ER. ELEFTERIADOU: Yeah, it's traditionally the transportation systems has been under civil engineering, but you see here the collaboration that happens at the research level, and we want to bring that also for the students so we have transportation across different colleges, across different departments, and it becomes so much more important now with advanced technologies at the forefront.

DR. CRANE: It's funny, you go to different -- well, an electrical engineer is going to say it's all electrical, they're number one, and the computer person --

DR. RANKA: I would say that the world is changing where you could take one profession and work there for 35 years and you'd retire. I told my two daughters, just learn how to learn. And after that you'll do fine.

DR. ELEFTERIADOU: All right. We are officially out of time. I put up take aways from this session from the different presentations. And we welcome more discussion.

Thank you very much.

MR. GOPALSWAMY: Good morning. Howdy.

My name is Swami Gopalswamy. I spent several years in the automobile industry, primarily the areas of control, design, and development. And for the last few years I've been with Texas A&M University working on connected autonomous vehicles.

So before I go on with what I'm going to talk about, let me introduce my colleagues and co-panelists. Dr. Darbha is a professor in the Department of Mechanical Engineering also at Texas A&M with focused on controlled theory and applications, including, of course, autonomous vehicles. He has been working on vehicle platooning for over three decades and has developed some fundamental (inaudible) that provide insights into platooning and connected vehicle operations.

Dr. Rathinam is an associate professor in mechanical engineering also at Texas A&M University. His research interests include autonomous vehicles, aerial, ground, and underwater autonomous vehicles, (inaudible) algorithms. Somebody asked in the last session, what kind of education would make sense to be in this space? Just to give you an example of Dr. Rathinam, he has his bachelor's and master's in mechanical engineering, a master's in electrical and computer science, a Ph.D. in civil engineering, and his Ph.D. thesis work was on aerospace. (Laughter)

Okay. It is a great pleasure for me to be here to introduce the concept that we've been calling -- let me just see how I should -- okay. So, the concept that we are calling the infrastructure enabled autonomy and the idea is how that leads to autonomy as a service and what implications could be thereof.

We believe it is a new paradigm for autonomous vehicles and the primary goal would be to ac celebrate the deployment of autonomy, autonomous transportation. So let me start with this. Why are we working on autonomous vehicle? Many people have already addressed that before, and so I don't want to belabor that point. There are tremendous benefits in terms of the potential for lives saved, number of crashes that can be reduced, the economic savings, the fuel savings and so on and so forth. Obviously, great, great benefits.

But we always look at the fine print. The benefits accrue with the corresponding penetration of autonomous vehicles in transportation. You need to have 90 percent of penetration to kind of get the fabulous benefits that we are hoping to get. And for example, in the U.S. alone, we have 250 million automobiles, both commercial and personal cars and trucks on the road today. And the question is, how do we hope to get the kind of penetration that we need to really get the benefit that we all hoping that we will get? And so that's really the thought process behind what I'm going to be talking about today.

We talk about the penetration of autonomous vehicles, and let me kind of do a quick rundown of what people have been thinking, and I want to do this by using the famous Gartner Hype Cycle for emerging technologies to kind of quickly walk through what people have been thinking.

In 2011 -- I don't know if people are familiar with this hype cycle but essentially it just talks about the various emerging technologies that are there and the different phrases of enchantment and hype about this technology before you kind of -- you go into the (inaudible) and finally kind of get into the plateau of actual meaningful deployment.

Okay. So in 2011, autonomous vehicles did not have a space here. In 2011, we suddenly started having autonomous vehicles, and as we walk through, you can see at the peak of its hype around 2015, and whoa, it started going down on the trough. And, in fact, in 2018, I think -- I don't necessarily agree with that but the Autonomous Stuff

technology was split into two parts for different levels of automation and one was continuing to be in the hype cycle but the other one is going down (inaudible).

So the point is, as I said, we have 250 million vehicles on the road. How do we expect to accelerate the penetration of autonomous vehicles? Because that's the only way we can actually get the benefits that are being touted that we hope to get from autonomous vehicles.

So I come from the automotive background, and so I have an acute sense of what it takes, or I have an acute awareness of the realities of complex code because as you can see, mechatronics, the modern automobile in general is a mechatronics system. The autonomous vehicle is much more of a mechatronics system and the complexity is all big into the software that goes into these vehicles.

So we have in a typical modern car, 10 million lines of code. The complexity is humungous. The number of subsystems, number of engineers working on it, number of suppliers involved, the distributive nature of the development, so the complexity is really enormous, and this is just for regular modern cars, not necessarily autonomous vehicles. And if you just look at some of the headlines, you just have to do a google search. And this idea is almost a couple of years back, there have been dramatic failures across the globe in terms of software-related failures, and when you have software failures in mechatronic systems, they are systems that work not only the software that works with mechanical systems and that which has interaction with human beings, the cost impacts are humungous.

So I'm not going to belabor the impact of the complexity except to say that we really need to think about how soon do we really expect the people to be taking -- for us to be seeing 90 percent penetration? Even 10 percent penetration, 25 million vehicles on the road, I expect that we probably will have 20,000 to 30,000 vehicles in the next 10 years in a very limited kind of fashion.

So here's my explanation. I want to say how to think about this.

So if you look at the driving functions that we do today, you can look at the -- let me see if I can get a pointer on this. Yeah.

Okay. So the typical modern vehicle, you have a driver aware system that is developed by the automotive odium. They help you, once you press the car -- I mean, the gas pedal, it translates that into how much acceleration you need to get, how much braking you need to get, how much steering you need to provide. You have the decision-making -- before that you have the situation awareness. The driver is you. You would see what's outside. You look at your dashboard, kind of make an assessment of the situation, and do your decision-making. And then you use, in order to drive, additional information that comes from outside.

The distribution of the responsibility amongst these functions, the responsibility really translates to liability to a large extent, is as follows. The automotive odium takes care of the green box. The human driver takes care of most of the decision-making and situational awareness. And you have some exclusions from the odium onto the decision-making by providing some supporting ADAS functions, advanced driver assistance systems, such as lane change, obstacle avoidance, and so on.

The information comes from third-party players, such as GPS, cloud services, et cetera, and there are infrastructure providers, infrastructure primarily being information infrastructure providers who would facilitate the transfer of the information to the vehicle to do the driving. And this is a balance, a distribution of responsible data that's evolved over time and we understand what it is. We care comfortable with it and this is kind of where we are right now.

If you wanted to move to a new paradigm of completely autonomous vehicles, what this changes to is the following: The automotive OEM really takes it a responsibility for the entire driving. And this is where I believe there's going to be a big pause in the introduction of autonomous vehicles in a big way. They have already seen many accidents of that nature if it were to happen for a large company selling millions of

vehicles, it's going to be a big, big liability for them.

So I feel like this will provide a lot of big pauses, and so at least, we will have 20 to 30,000 vehicles. Maybe on a least basis they're owned by the OEM and provided under very limited circumstances. And that does not bode well for a goal of 90 percent penetration.

So what is our proposal? Our proposal is to separate this intelligence that's going to be needed for autonomy -- for autonomous driving from being only in the vehicle to being separated between the vehicle and infrastructure. Take advantage of the infrastructure in a very fundamental way and that would reduce or at least distribute the liability and that is kind of what we want to propose as a concept as an additional in-panel development along with the existing approaches for autonomous vehicles.

So the idea is that we have the traditional driving that is taken care of by the automobile OEMs that will continue to remain there, but the situation awareness will come from the infrastructure. When I say from the infrastructure, I mean primarily from the infrastructure. And the decision-making will be done by third party units that reside between the driver aware system of the vehicle and the situation awareness on the infrastructure to help make the autonomous driving decisions.

So the core concept is what it considers a separation of issues and expertise. The automakers will focus on the drive-aware capabilities and make it even more perfect. They can, of course, bring in more advanced driver assistance systems but then the infrastructure will become smart and start enabling awareness. And when I say smart infrastructure, what we mean by that is that the perception and the contextual awareness are synthesized, will be synthesized using off-board sensing. So you have roadside units that will have sensors that will generate, that will be looking at -- so you essentially have ice -- not ice on the road but placed on the infrastructure. They will be looking at the road from above, getting -- generating the situation awareness information. Sending that wirelessly to the vehicle. And in order to do that we leverage connectivity. That's the -- there was

another question sometime back, which one should be used? Should it be connectivity or should it be autonomous driving? We believe it has to be a combination of both. There have been significant improvements both in connectivity as well as autonomous capabilities in the recent past and we really need to bring them together.

And what this allows us to do very interestingly is this allows us to do on demand automation, and I'll talk about that later on because that actually suddenly opens up a possibility for funding this infrastructure investment required that would not be otherwise possible.

Here is a cartoon that kind of describes our concept vision. So you have the specialized corridors that we will call as the infrastructure enabled autonomy corridor. This will have roadside units. They may look like streetlights but in reality they are multi-sensor smart PATT. Multiple sensors that can essentially look at your road and generate situational awareness information. And, of course, you don't want to collect all information and send it blindly to the vehicles, but you have -- it's computing. Computing right there on the edge to abstract that information to the minimally required mode of information that can be sent optimally to the vehicle in a wireless fashion. Then that information then comes into the vehicles which have the driver aware capability, the smart connect device inside, which can talk on the one hand to the infrastructure. On the other hand, to the vehicle's drive (inaudible) system, and use the information to generate autonomous driving capabilities.

Once you have that information, it does not have to be used only for autonomous driving. You could imagine a plethora of uses for such information. It could be sent to a bicyclist or a pedestrian on their smartphones or a smart watch to give them warning signals of what's happening on the roads. You can send it to manually-driven vehicles such as diagnostics and information so that they can drive better as humans.

So this is the fundamental concept that we have been trying to promote as infrastructure enabled autonomy. And let me first walk through a few slides that explain how we have bene taking this concept at Texas A&M University.

So we started by actually having a clarification on the concept by doing a theoretical explanation of the risks using a probabilistic characterizations on the falls and risks associated with distributing the intelligence. So we demonstrated that the risks get distributed according to the -- based on the proposed redistribution of intelligence where we assume that there's a clear partitioning of the functional and physical interfaces. Dr. Rathinam and I actually co-authored a paper on this, and the paper reference is right here.

So that's kind of laying the theoretical underpinning for why we would want to work on this concept.

The next one was our iteration zero work. This was where we said, okay, let's now do a virtual simulation of this concept to see if we can demonstrate that things could work. So, we had a simulation of an autonomous vehicle with a three -- and some of our students are working on it right here actually in this room. We have three cameras, three roadside units that are simulated and the vehicle goes through each of these cameras and the vehicle is able to detect -- I mean, the camera system is able to detect the vehicle, localize that, send it wirelessly. And for wireless communication we use DSRC units. And the reason we use DSRC's unit is not because we have a preference for the DSRC or 5G, we are actually communication agnostic, but we were donated 30 DSRC units for free by (inaudible) operation. And that's the reason we use that.

But the idea was that the fact that we could use the DSRC implies that that's actually one of the lower bandwidth communication capabilities and we have been able to successfully use that to demonstrate our system and the implication being that if 5G had to come on board and if you adopt 5G it's just going to be that much easier to do it. So that's the iteration zero.

The iteration one was development of a prototype at our RELLIS campus.

Is this the recent presentation that I sent you? Sorry. Okay. This is -- okay, I just lost the title of the presentation. I don't see it anywhere here.

Okay. So this is their first iteration. And essentially what we have is we

have a RELLIS campus. This is all a military Air Force base that we are using. It's got seven-plus miles of concrete runways that we use as our innovation proving grounds at Texas A&M. It's called the RELLIS campus. And that's where we did our initial prototyping experiments. You can see this mobile trailer that has polies sticking on top of it. We have a camera mounted on top of it. We have wires coming down. We have a laptop serving as the Edge computer and this is the autonomous vehicle that we use to evaluate this capability. So that was the first iteration zero.

Then the iteration two -- before that I want to show a couple of more videos because -- let me -- yeah. So this is how it looks like. For example, this is the trailer. The camera is somewhere here. There is an Edge computer here that communicates to the vehicle wirelessly through DSRC. And you can see from the camera we can actually track the vehicle and localize the car in terms of -- in the runway and send it to this vehicle.

Yeah. This is what I want to show.

This is Texas A&M research. So we have to have the hat. But this is our very first experiment where we were just doing simple lane changes and so on.

This is the RELLIS campus that I just mentioned. It's a 2,000 acre old -- sorry, not old -- 2,000 acre military airbase repurposed for advanced technology research. We have seven-plus miles of connected concrete pavement. We have traffic intersections, specialized roadside units, and 5G connectivity in the plan. And this essentially becomes our smart city environment that we want to work with.

So if you look at the IEA development, how it has moved up to now, on the iteration two we have built a 450 meter course with four roadside units. These are essentially luminaires, streetlights on which we have mounted the cameras. And we -- let me see if I can -- yeah. And this is connected through a wire to the Edge computer at the bottom. We are still using the laptops for now because we are still in the development phase. But this can be now made to switch between DSRC or 5G or any other communication method. And we have used this for a variety of testing. And that's kind of --

some of the testing is what you will be seeing later in the presentations also. And so we have four of these light units about 50 meters between each of them. And these are not powered so we actually had to have generators for each of those even though we are doing our experiments. But this kind of is the beautiful landscape that we get to work with.

So some recent tests. So this is multiple views. You can see the first camera tracking the vehicle and then there's a handoff that happens at some point when the vehicle comes into the view of the next camera and then there's an overlap period. And after the overlap period is over, the second camera, second roadside unit takes over and they are constantly processing the information, localizing the vehicles, sending that information back to the autonomous vehicle.

The autonomous vehicle has a multiple set of sensors because it is being used for a variety of research purposes. But for this particular project they didn't use any of the onboard sensors. So they used the light exclusively on the information coming from the infrastructure because that's kind of what we wanted to demonstrate.

So what I want to say is this -- the concept obviously needs really early stages, but we have already been able to show enough progress that we feel compelled that it's now really time to take it to the next stage.

So the technical value proposition is that the multiple sensor smart PATT, you can get much higher, reliable, and precise information because you know the ground route on these roadside units. So you know the ground route. You can have markers on your road. You can have reconciliation between different roadside units. Within a roadside unit you can have multiple sensors that are fused with each other. And not only that, you can also have the ability to award occlusions. So if you are driving today, if your view is blocked by a vehicle -- a truck or whatever other vehicle that might be in front of you, you really cannot do much. And the same thing applies to sensors that mount on the vehicles. You can only do so much with the sensors that you mount on the vehicles. And this is exactly where sensors, the different vantage point dramatically changes the clarity of your

situational awareness.

And then the fact that you have increased computational time, you can do much more in terms of understanding what is happening to your traffic. You can spot potholes. You can identify traffic jams. And most importantly, every vehicle will have the same sort of belief states. Shared belief state that is common between all the vehicles so they know how to try to respond to each other. And mind you, I am talking about a scenario where it is a mixture of manually driven vehicles and the IEA-driven vehicles.

Now, this is an interesting part. What this whole concept allows is it provides a new paradigm for doing autonomy. The deployment model. How exactly are we going to do autonomous vehicles?

So my expectation is the following. I will be driving a vehicle that looks like a normal vehicle. I would be driving it in general as I usually do except when I go to these congested areas that have an IEA corridor, my commute time for example that I spend one hour every day, that's when I say, no, I will actually want to go to this IEA corridor. The corridor will interrogate me as soon as I enter there. Say do you want to be driven autonomously? Of course, there has to be a registration process prior to that. (Inaudible) that's done. So it interrogates, it says, do you want to be driven autonomously today? And if I feel like it I say yes, I want to go here. And it drives you autonomously. And at that time, because the vehicle is in complete control, you can actually go to sleep. And if you are asleep when it comes close to the destination, it will park you and you wake up and drive when you are ready to take it.

And you get charged by the mile. And that's the key point. So because autonomy does not have -- and I do not want to be driven autonomously every time. I want to be driven autonomously only under some conditions. I value autonomy only under some circumstances and the value of autonomy for me is different, and therefore, ideally I would like to pay only for the autonomy when I really need it. I don't want to pay for all my sensors and costs up front. Here is an opportunity where I pay for my autonomy as a service. I pay

by the number of miles that I travel autonomously.

So this I think provides an opportunity for monetarization of autonomy. And this only allows private infrastructure players to come into this space because there's going to be tremendous investment cost associated with instrumenting roadside units every 50 to 100 meters with sensors and having connectivity. Yes, of course. But there is also an opportunity to monetize the usage of that. And that's kind of really the opportunity that we want to talk about.

So it's not only a technical value proposition. So there's a value proposition for a large ecosystem. We believe the automotive odium will be happy because they don't have to deal with taking on additional liability while they still remain in this space of autonomous vehicles. Private infrastructure operators, tollbooth operators, cellphone operators, cell tower companies, lighting and urban infrastructure companies, a whole slew of companies suddenly get an opportunity to participate in this autonomous ecosystem. Device makers, the people who make the sensors. The people who make the integration of the sensors that go on to the roadside units, opportunities for them. And the application makers. So when you have a smart connect that gathers a whole bunch of information, the number of applications that you can have is limited only by your imagination. I believe that there will be a whole slew of people who will be making different types of applications, leveraging the information that comes in while you're driving.

Now, of course, law enforcement, infrastructure/maintenance, traffic management, a variety of users can easily be seen. And of course, society at large because we believe that this would actually accelerate the penetration of autonomous vehicles at least in specific corridors. So on a corridor by corridor business, you can dramatically improve the penetration of autonomous vehicles, thereby reaping the "promised benefits of economy."

So that's kind of where I want to stop. I mean, there are many open research questions. And we don't have anything solved. I mean, we have ideas, and we

know the problems exist. We are working on them. But really, there is a lot of work still that remains to be done. We have demonstrated the core functionality at Texas A&M but we want to increase the complexity of the scenarios that we will be demonstrating. We want to increase the scope of the work we are doing. We want to go from 40 meters to a two mile loop. People are working on resilience with respect to cyberattacks to communication failure. There are a variety of opportunities for doing research on pricing models, perhaps elastic option-based price models. Dr. Caroke is an expert on that. Then there is a Goldman Private Investor Partnership models that need to be looked at. There are legal risk and regulatory environment implications that need to be discussed. A variety of business models. I'm not going to go through all this.

And last but not least, the issue of privacy. How do we ensure that in having thousands of cameras all around the road does not infringe on people's policy?

So I say with that I leave and I'm going to pass it on to Dr. Rathinam.

This is just -- yeah.

(Applause)

MR. RATHINAM: I have been a faculty member at Texas A&M for 10 years. So the first time, the first year at least when I was, you know, I would come to the lecture room. I would start talking. I would go to the board, write equations and all that. It was an undergraduate class so after, you know, some of the classes, the undergraduate students came to me and said, Professor, please. You know, you can say whatever you want. Just say howdy before you start anything. (Laughter) And we are all good. So I'm going to say howdy and start my presentation.

I'm going to talk about infrastructure-based advanced driver systems, economic systems. So we have already heard a lot of presentations about introduction to autonomous presentations and the IEA concept.

I just want to first acknowledge the support by the Safety Transportation Research Center, which is funded by the U.S. Department of Transportation. And also, we

work closely from the researchers from the Texas A&M transportation industry. And, of course, all these students who are here, Abhishek, Vamsi, and Kenny, who do all the work. We are just present; right?

So I'll just move on to -- so I think we have heard from the previous presentations at least the road infrastructure is going to significantly benefit both advanced driver assist systems, which is what is called as ADAS on autonomous vehicles. And in particular I'm going to talk about proof of concept demonstrations of the IEA concept that Dr. Swami was talking about for different applications first. And then I'm going to talk about the need for common standards. So this is something I think Ken, earlier in the keynote speech mentioned that we need common standards for evaluating autonomous vehicle technologies and taking it forward. So that is something I'm going to talk about. I'm going to maybe focus on lane departure warning systems because that's closely related with infrastructure.

So before I move on to the actual slides, I want to give you a short of intro video on all the testing that we do. So we work on a wide variety of problems from platooning, car platooning, truck platooning, lateral control, vision-based control, many other things. So this is just a summary of what you have done. So here, this is a promo video and all the frames that you see, the car frames that you see were all taken when the car was was in the autonomous model.

(WHEREUPON, a video was played.)

MR. RATHINAM: And I am not really a fan of this music but they said it's a wide audience so I just said, okay. Why not?

Anyway, so I'm going to talk about this in two parts. The first part I'm going to talk about the roadside camera unit which we have installed on each of the four poles that Dr. Swami was talking about. And how we use that information for some of the applications. And then we're going to talk about lane markings, which is an integral part of the lane departure warning systems that at least are available in some of the high-end cars.

So first, in fact, just to give you an idea, deep learning algorithms have been

used, or at least have been significantly developed over the last few years, and you can use them to identify objects in the road and you can actually use them to also identify -- classify objects into cars, emergency vehicles, policemen, and all kinds -- pedestrians and all kinds of things. And you can actually sort of tailor the rest points based on what kind of vehicles you identify.

So this is just a short clip of having some of these deep learning algorithms trained on the datasets that we have. And you can actually classified them into emergency vehicles and all that. Obviously if it's a human, manly driven car you would see an emergency vehicle and try to yield to that vehicle and stop or take the appropriate action. You can also try to emulate that using an autonomous vehicle. And in fact, that's what we have done here.

So this is essentially a roadside unit. Here you have two cars in this demonstration. You have the French car, which is an autonomous car and you have another car that is following, which is an emergency vehicle. So the autonomous car either does not have a sensor to actually know that there is an emergency vehicle behind or it's just like anything else that you do. You know, you have sensors but it's just broken. Right? It just doesn't work.

So in this case at least what we have is the information from the emergency vehicle descends from the camera unit and then that information is sent back to the autonomous car using the DSRC communication system in real-time and you do the appropriate response. So that's the -- what we do here that we are going to show. And this is all real-time processing. I can go into more details if anyone is interested, but this is really for two vehicles. We also try to do a platoon of vehicles. In fact, we have two cars -- we have a platoon of three cars here. In this demo, actually, we have the front brakeless autonomous car. The vehicle in the middle is a human driven car. And the last vehicle, which is basically either it's an emergency vehicle or a police van or whatever it is. And here you see that there is no data decline between the autonomous car and the emergency

vehicle. And so these are the kind of applications where the infrastructure of roadside units, the cameras could really help.

So again, the concept is the same, so the information -- this information is identified by the camera units and then sent back to the autonomous car which is what is processed in real-time. And that is the response that you see here where essentially the autonomous car comes to the other lane, and of course, a manually driven car also parks itself and you let the emergency vehicle go. Right? So these are some of the kinds of things you could do.

We have also done that with different test case and here we have, you know, modeling humans is always the most challenging thing to do and you obviously don't want to test these kinds of things using real humans so we have these human-like robots that you can manually control. We can get them onto the lane and off the lane and all that. So the concept again is the same. The information is basically sent from the camera back to the car using the DSRC unit and you can actually post a lot of problems. And I know Dr. Swami is working on different applications on this.

So this is just an introduction to what is possible when infrastructure is not involved. I think the point again I want to emphasize is that I don't think there is one versus another. I think it has to be collaborative. You need maybe some onboard sensing because many of the cars that you already buy already has its own GPS units. It has immunosensors so you can use that information and you can mix it with what you get from the roadside units and do better things and hopefully improve safety and everything.

And that's the point here. Right? So I can complement the onboard perception units. The infrastructure can actually provide real-time information that when you don't have line of sight, direct line of sight and it provides redundancy. And essentially, you know, most of these applications, I'm sure that anyone who works on it knows that things fail and that's the standard. The rule of thumb is that things are going to fail. And how do you, you know, accommodate and react to what is important? So if you have more sensors and

more redundancy all the better.

So anyway, so that's the first part of my talk.

The second part is going to concentrate on lane markings, which is really -- are an integral part of the lane departure warning systems. You know, we have taken huge strides in autonomous vehicles in the past decade and this is going to continue and we are going to see deployments of these autonomous vehicles in some sections or some cities in the United States and things are going to improve probably in some sections of the highways. But we are not, I mean, autonomous vehicles, at least in my lifetime, I don't see that replacing -- completely replacing all the human-driven vehicles.

So at least over the next 40 years, you know, you're going to have human-driven vehicles also and they have to coexist with autonomous vehicles if at all we have any penetration. So which means that at least my assumption is that as long as there are human-driven vehicles on the road, you are going to have lane markings to guide us. Right? So if you look at it, in 2000, there was less than one percent of all the vehicles at least with advanced driver assist systems. Depending on what study you look at, by 2030, 50 percent of the vehicles are going to be equipped with advanced drive assist systems. And when I say these advanced drive assistant systems, they could be adaptive cruise control, automatic braking, lane departure warning systems. It could be tire pressure monitoring systems, things like that.

The lane departure warning system is one of the key features that is proposed. And the main reason why it is proposed is because people think, at least many studies have shown that it can actually improve safety.

Now, this is just a report from one of the projects funded by USDOT where they show that the lane departure warning systems can actually save -- that can potentially reduce hundreds of thousands of crashes every year and can save a lot of lives. And there's around 3,600. And anyway, I don't want to go through all those numbers but the point here is that, yes, there is potential for safety benefits but these systems are not yet

used. And there are a combination of reasons why they are not yet used. It could be because of lack of good lane markings. It could be because we don't have good algorithms yet. Or it could be a lack of common performance standards for evaluating these algorithms.

So if you look at a lane departure warning system, it's actually just, you know, I just want to tell you how complex this problem is because, you know, this is just one feature that I would say it's a new term technology that's going to be there in the cars. And maybe now it's in the high-end cars but in the next 15-20 years I'm sure it's going to be there, more prevalent in most of the cars. And you can see how difficult the problem is when you also have to rely on infrastructure.

Now, if you look at a lane departure warning system or a lane detection systems, it really consists of three parts. You have the software, you have the hardware, and you have the infrastructure. The software is really the algorithms. Hardware, if you use a camera. So cameras, the reason we don't talk so much about cameras is because it's cheap. You know, the lighters, I think someone talked about it $60,000. I mean, you can pray and hope that things -- costs come down but it's going to take time to actually have cars that you put radars on, really good radars. Right? Cameras are cheap and that's the reason why they are an integral part of these lane detection systems.

And of course, you have the lane markings, which is an integral part of the infrastructure. But you can actually get hundreds and thousands of variants based on what kind of algorithm you pick, what camera you pick, and what kind of lane markings on the infrastructure you have.

For example, if you just take off lane markings, you know, they could be made of different types of materials. You can have different striping processes. You could have white followed by black and you could have white and black juxtaposed. You know, you could have different payment types. So you know, it doesn't matter how good your lane marking is. You know, if you don't have contrast between your lane markings and the surrounding parts of the road, your departure warning system is not going to find it. So it's a

contrast that is very important.

And also, your lane geometry. Your thickness and everything. You also have different cameras you can pick, and of course, the algorithms, many people have been working on that and I don't have time. I think I'm only done. I have a couple of minutes.

But the point here is that we are not at the end of the story because the performance does not just dip in on the algorithm you pick or the sensor you pick or what lane marking you have. It also depends on the environmental conditions. You know, the edge cases, which is going to really determine it's not the usual normative cases. The normative cases, you know, you can get 90 percent, 95 percent accuracy, which may not be good but it's still better. But it's the age cases that are really going to determine how good these vehicles are going to be or how good the systems are going to be.

Now, you know, you can have, you know, direction, streetlights that could radiate your performance. You could have -- you know, this is one of the hard cases. You could have sun and reflection from the red surface. Snow you could have all markings, construction sites. Payments.

So really, I don't think the camera is going to solve all these problems. You're going to have multiple sensors and do sensor fusion and really key point here is that we do not know what the optimum performance we could get out of just these cheap cameras at this point in time at least. There's a lack of common standard which could help us in keeping track of the different components -- the evolution of the different components -- the evolution of the different components of the system and how it affects the performance. So that's what really we are working on. We are trying to develop at least an open source platform where we can test the infrastructure side, the algorithms, as well as the hardware and all that. And we are also developing metrics to actually evaluate and rank these systems and do it. Of course, it has benefits to the federal agencies. The USDOTs and the state DOTs because they can actually answer questions like do my lane markings in my state actually -- are they fit for a level two operation or a level three autonomous vehicle

operation. So you can answer questions in a simple but basic questions like that. You know, obviously, it's useful for infrastructure providers because they can actually test new materials and algorithm developers, of course, because you get new sets of data you can work with.

Anyway, I'll just stop with this. I just already running out of time. But the point here is that you need a systems approach. It's not about just developing algorithms or it's not about, you know, the infrastructure companies just doing their lane markings. It's an overall system so you have to look at everything and see how the improvements in each of the parts will affect the entire system.

So with that I'll just stop. Thank you.

(Applause)

MR. DARBHA: Hi. I'm going to depart from the standard howdy.

So anyway, so I have about 10 minutes so I'll try to make it crisp and short and I'll also answer some other questions that were raised earlier, each in connection with what all I've been doing.

So I'll focus on certain aspects of connectivity and infrastructure. So for me, infrastructure comes through communications.

So what I have been doing for 30 years depends primarily, it's mostly based on how information amongst vehicles will help promote safety and mobility. So this is basically what the focus has been on, and I'll talk a little bit about emergency lane change then. But I'll take this time to tell you something about one of the questions that was raised about autonomy and connectivity.

So my interest in this particular area of autonomous vehicles goes back to my doctoral thesis, which is about developing automatic vehicle following control algorithms in the '90s for the for the Automobile (inaudible) Systems Project. So I'm also interested in what all -- not just in developing the technology but also assisting what the impact is on traffic safety and traffic mobility.

So to give an answer to that question, so if you are looking at adaptive cruise control systems, which I think all of you know, so the minimum time gap that you need to maintain, which again goes back to my thesis, is that it should be at least twice the sum of all the reaction dealings, the action lags and dealings that you have in the system. Otherwise, you would have this slinky-type instability, accordion type effect, which will cause pileups.

So recently, so this roughly translates for trucks it's about 0.6 to 0.7 seconds. So you're looking at a minimum time gap of about 1.4 seconds. But for (inaudible) and other kinds of things, people are interested in a sweet spot of about 0.7 seconds if I'm not mistaken. So to cut down that much with the app which controls systems, it's just not possible. And people have been doing experiments, especially in the T&O group, as it was in the California PATT group, they assured that if you had the cooperative adaptive cruise control system, that is like if you had the information of the vehicle and had acylation information of the vehicle, you could cut down the time headway.

So, in fact, my recent paper, this is a paper that I'm quoting, it basically assures that it can carry down by a fact of two if I had the acylation information of the vehicle ahead. But if I had the information for all vehicles, I had like let's say three vehicles ahead, I can cut down this minimum time gap by a factor of four.

So that means that connectivity does help and here is where the infrastructure can actually play a significant role. For example, this is under the assumption that you have perfect communication. Okay? So vehicle to vehicle communication will not help in the imperfect case because it's primarily local because autonomy is biased on onboard sensors. But if you have connectivity, you can get it to the infrastructure what is happening much farther ahead. And that is what is required, and that is the way how we can actually make the benefits quantifiable.

So, and the same thing with safety also. There are a lot of safety studies that one can talk about.

I also work on -- the infrastructure also plays a significant role in commercial vehicle operations. For example, one of the projects that I'm doing, the Safety Center, Universal Transportation Center, is on developing automatic diagnostic systems for autonomous trucks. Essentially, the purpose is to facilitate pre-trip inspections, automate them. You could also use it for automating enforcement inspections and to make sure that trucks comply with the FMVSS 121 standard. So this is the kind of thing that we are doing.

There is some work that infrastructure can also help in traffic harmonization, some work that I've done recently, and then in this particular work for lack of time I'll just basically focus on emergency lane change.

So how does infrastructure help in emergency lane change maneuvers? I think as the previous speakers of both my colleagues here and the Florida speakers have mentioned that you could get real-time information about vehicles, obstacles in a time-efficient manner. But more importantly, it's not just that that you require for safety. It also requires some way to localize your positions very effectively. And here is where infrastructure can actually play a significant role.

So normally in terms of -- I also want to mention here there are two types of queue that you would have for lane change maneuvers. Here in the first one you would have the queue for the emergency lane change maneuver comes from the front of the string of (inaudible) you have. And in the second case, as my colleague has mentioned, if it's like an ambulance or something it actually comes from the back of the string.

So if you had information about these things much earlier, then you could plan and act accordingly. And in the second case it's even more important because it could save lives. So that's the reason why it's fairly important.

So in the emergency lane change maneuver, essentially, it's a maneuver in which you have an obstacle in the road and the vehicles are basically trying to evade this. And here I've shown a two-lane scenario where the obstacle is in the right lane and the vehicles are basically trying to move over to the left lane. Okay? The point of this entire

exercise is to show that if you did not have the information of the obstacle and there's no communication between vehicles, then the following distance that each vehicle should maintain should be much more than otherwise. The reason is, the vehicle behind would be blinded by the vehicle ahead because it will be blocking the obstacle and the thing is you would want the following vehicle to see the obstacle at least at the same location that the previous vehicle, the preceding vehicle would have seen it. Okay? And this cannot be possible unless you had some sort of communication or you keep a huge following distance. And that's basically the point of it.

So the rough calculations will tell you that it should be, at the controverted end, it should be about 1.8 seconds of time they need to maintain. And that's clearly not acceptable from the mobility point of view.

So I think I don't want to talk a whole lot about the experiment and facility at RELLIS because I think you've seen this before. So here what we are doing is we are looking at the emergency lane change maneuver design and control of design. So the difference between regular lane change maneuvers and emergency lane change maneuvers is that the vehicle when it makes a lane change maneuver, you cannot make use of the lane markings of any of those things because the trajectory of the vehicle ahead is designed in real time. And what the following vehicle has is only a limited preview information about how much of it it is. So the question is whether you can actually make the design happen and have a controller which actually tracks the path of the vehicle ahead. This is essentially what the problem is.

So we simulated, because I'm only dealing with one vehicle from the point of view of safety first, and then after that, probably in the next year or two we'll do the two vehicle and three vehicle lane change demonstration in a similar setting.

So in the first run, what you would have is we just had these cones, and then we had the vehicle drive manually to collect, restore the GPS information. And this GPS information will basically define the trajectory for the second run, which is the

autonomous mode if it's the following vehicle, and what we want to do is we want to track this. And the amount of information that is available to the following vehicle is just a few samples of where it is. That's about all that you have.

And you can actually simulate it for multiple vehicles, too, because you can store the second vehicle run and then use the first two vehicles and then you can see what happens to the third vehicle.

So these are technical details. I'll just skip it.

And this is based on the work of my student, which we presented in the ECC in Naples.

So I have only one second left. So I'll just show some demonstrations. So this is at 45 miles per hour. I'll just show two vehicles. This is the aerial view at 45 miles per hour, and the other one would be at 70 miles per hour.

So the cones are the ones which are defining what the lane -- that is the double lane change maneuver.

This is an in-car view at 45 miles per hour.

None of the cones fell over.

Okay. This is at 45 miles per hour. So I'd like to show you the 70 miles per hour videos and then I'll stop after that and I'll take any questions.

So the drone that we have was not able to keep track of it, so that's why you see it blocked because this is going too fast.

And this is the last video. This is the video. This is at 70 miles per hour.

So I think I'll just pass at the moment. So thank you and I'll be glad to take any questions.

(Applause)

SPEAKER: Thank you for the interesting presentations. I like the way you emphasized both the opt-in sort of paradigm as well as thinking in systems. The question I had was in my Chrysler Pacifica I have all the latest advanced safety features you describe

with adaptive cruise control. And I've got Android Auto that's pulling in the data feed from Google with speed limits, congestion, other things. But currently, those two systems don't talk to each other. So I'd like to just take the speed limit feed from Google and tell my adaptive cruise control, just go the speed limit that you know is there. Do you see that kind of like system connection emerging in the coming years or are there different incentives for the OEMs and the data providers that is kind of hindering that or what do you see as how that might play out? Because then you could have adaptive speed limits if the weather is bad and that would feed into the adaptive cruise control. How do you see that evolving in the coming years? Thank you.

MR. DARBHA: This is a problem that is considered -- this is traffic harmonization. So this is a traffic harmonization problem. That's where people usually refer to where it's like variable speed things in different sections of the highway where you advise, that's the kind of the thing that is considered a traffic harmonization problem. I think this can be done. It's not -- the question is, how do you set the speed limits on the highway depending on the weather conditions? And there is research that is going on and there is some preliminary work that I had done last year with some of my colleagues. So it can be done.

MR. GOPALSWAMY: I just wanted to add one thing. One is technologically whether it can be done, and that's of course like what Dr. Darbha is saying. It's definitely feasible. But the bigger question is will the OEM trust the data? And if the data is going to come from a completely different source, then the question of trustworthiness of the data becomes an issue. Whereas, if there's a prior agreement with the infrastructure information provider that this information is trustworthy in some sense, then I think it'll happen. Until then, you cannot, you know, do it and make people delay on that.

MR. WINSTON: So normally in scholarly work we begin with a literature review. Now, in this area this is quite difficult because you've got a lot of players. There are many universities in this country and all over the world that are working on autonomous

vehicle problems. There are many technology companies and auto companies working on this. And even government are working on all these problems. And I think it really would help this presentation if you stepped back and gave us an overview, really, that this is a cooperative and competitive effort. Because what you've got, its' in the weeds. You're one player. Maybe you'll be around in 10 years. Maybe you won't. And I've seen these presentations, and what I've seen is much more sophisticated than what you've got. But then they had a lot more time to present it.

And my point is, it's useful to put this stuff in context. In other words, what is distinctive about what you're doing as compared with the big picture which everybody is doing? As I said, this is a global, cooperative, and competitive effort. But at the same time, those features are what are so important to actually giving us optimism that we're going to get these things sooner rather than later. You may not be part of I but Stanford might be, Ohio State might be, Michigan might be, or no universities at all. That is, it's all driven by the private sector.

So I think broader perspectives on really what's involved here, and not just one small thing and one small problem. You mentioned environmental problems. There are tons of companies who have identified and are working on all these problems as we speak. You know, it's not that you can continue to point to things. I mean, everyone is out there doing this and I think it's important to really get that message across.

MR. GOPALSWAMY: I think that's a fair point but let me explain two points. Two parts to it.

Number one, most of the work that's being done is either looking at autonomy by itself, focusing on the ability for autonomous vehicles. Or using the infrastructure to provide augmented information, such as in traffic intersections and specific places like that. There has not been work that we know of that is focusing on providing real-time information from the infrastructure that will actually be used to drive the vehicle autonomously without using sensors onboard the vehicles. So that's actually -- we have

done the research and we have not seen any work that does that. Number one.

Number two, on the part of the environment, the people recognize that there is an environmental issue. People have been working on the front types of snow weather conditions. But what's not happened is taking a systems view and saying we need to have a standardization that will provide a metric that can be used to say, is this system good? Is this infrastructure that we provide, is the lane marking going to provide adequate support for lane (inaudible)? Is the camera system going to provide adequate support for lane (inaudible)? That's the systems-level standardization that is (inaudible). People have been focused on what is important for them. For example, the people who do vision, they are focused on vision algorithms. The people with the cameras, they are focused on the cameras. But there is not a general purpose here for it and that's understandable. That's kind of what we want to say and trying to say we would like to have lane keep, lane marking, lane detection standardization, a metric system that can be used to promote what it means.

MR. RATHINAM: I'll just add one more point. At least from my point of view, most of the work that has been done in companies is from the point of view of single vehicle autonomy. That is, you have -- try to have all the sensors on board and try to make your vehicle as safe as possible. I think one of the efforts that we are trying -- I mean, we didn't have time to present today but one of the things that we are doing, Texas A&M is trying to look at safety problems and other issues for the collection of autonomous vehicles when they are connected. So if you have a platoon of vehicles that are driving on the road and they're all talking with each other, of course, if you have communication, great communication between the vehicles it's all good and fine, but what if that doesn't happen? What if there are communication failures? You know, let's say if you have a collection of five vehicles, if there is a communication failure between the first vehicle and the third vehicle and fourth, whatever it is, how does it affect safety and performance? And so I think our effort has been focused on that.

Companies try to do that. I don't want to name the companies here. They

have tried to develop safety metrics from a single vehicle's perspective, but it's all great but it would not work in reality. The reason is that if you're just looking at single vehicle and just trying to make that safe, I don't think you will get the efficiency benefits that you desire. So if you want safety and if you want to have the kind of performance that people are talking about, then you need to look at the collection of vehicles and that's something that we are looking at and I don't think the companies are -- I mean, those are long-term problems, research questions, and companies, they may get into it but not right now.

MR. GEDDES: Yeah, I don't want to jump the queue, but thanks.

So Rick Geddes from Cornell Public Policy.

And I want to go to a point Professor Gopalswamy -- do I have it right? -- has touched on, which is super important in the policy aspect of infrastructure. And that, as you mentioned, charging by the mile. One of the biggest challenges seems simply, is how you pay for the infrastructure. And currently we pay on basically a per gallon fossil fuel tax on either gasoline and diesel fuel at both the state and federal level to pay for, you know, the vast majority of the roads. But you mentioned charging by the mile. The State of Oregon is the leader in pilot projects over the past decade to try to make that simple switch from charging per gallon to charging per mile. And it's been a real slog, a real challenge politically to get drivers to accept that, although the State of California is interested in doing that.

So there's my questions for anyone on the panel. Do you see the advent of autonomous vehicles as facilitating the acceptance -- and they call them mileage-based user fees, MBUFs, in a way from a per gallon gas tax so that people will be more accepting of incorporating what we would think of in terms of utility pricing as a facility charge not the price of a trip. Right? So it's been sort of driver resistance. That seemingly simple change which is super important in the economics of this, could we see, you know, the interaction of autonomous vehicles and the way you pay for the infrastructure as facilitating that improvement?

MR. GOPALSWAMY: Yeah, my thinking is yes. And the reason I say that is if I look at toll roads, that's the prime example where the, for example, in Texas, we have all these -- and in fact, in a lot of places we have this auto charging of tolls and it's become so ubiquitous that you start forgetting and then you start not worrying about it too much as long as it seems reasonable and it is actually in some ways based on usage.

So my point is people would be more comfortable paying by mile if the process of doing it is very easy and very convenient. If it's seamless for them, the almost don't have to worry about it. Then I think it would be okay against if you actually have to pay explicitly for a bill.

SPEAKER: Thank you. First of all, I wanted to build off of Cliff Winston's question. And I think first of all, I think it's not true that there are no companies that are working on independent infrastructure dependent autonomy. I am aware of two companies that are building their sensors into the infrastructure because their use cases, they want to serve a limited service area of multiple areas so it turns out to be more effective to build the sensors into the infrastructure than to build the sensors into each vehicle. And so I think, and so I'm aware of two companies who are building out that approach in commercial service. And so I think that gets to a larger question which is, what is the right mechanism for public-private interaction and particularly private academic interaction? And I'd like to turn this into a question, and the question is, what has your mode of interaction with the private sector been over the last five years in which we've seen not just one but two C changes in the direction of investment in autonomous vehicles. About five years ago, we started to see a massive amount of private sector investment in autonomous vehicles. Brookings put out a report that said about $80 billion had been spent on JVs and M&A in the autonomous vehicle space. And then so in the last year or so, we're seeing increasing consolidation and engagement in the academic sector. So I would hope that the approach around how do you divide problems, which ones are best approached by the public sector and which are best approached by an academic sector and which ones are best approached

by the private sector has changed. So I'm curious about what you've seen over the last five years or so.

MR. GOPALSWAMY: It's a pretty complicated question. So let me try to answer that.

My thinking is that first of all, some of the work that's done by private companies, we don't have access to that. All we know is they are a marketing blurb. So from a literature survey perspective, we will not be able to assess what exactly they are doing. And so my answer was more in the context of the universities. So that's number one.

Number two, but on the flip side, there have been companies, you are right. For example, I think Daimler has a parking lot scenario where you actually drive inside a parking where there are a whole bunch of sensors in infrastructures that support that.

What we have been working on is the extreme scenario where we are saying, okay, how much can you push it? Can you be completely independent from sensors to be on the vehicle and use almost 90 percent of the information coming from the infrastructure? That is kind of how we have been trying to position ourselves.

In terms of the public-private partnership, it is actually an ongoing thing. For example, we are discussing with some companies, specific companies which do lighting, for example, who want to get into smart infrastructures, smart cities. They have been willing to support it. In fact, we may even actually have a formal agreement with them to support some of the work.

We have had conversations with many other companies such as 5G companies that want to install 5G because they need a physical infrastructure also and we have the RELLIS campus, and so they have been willing to come down and say, okay, we will install 5G. Can you demonstrate use of that in a very meaningful application? So that's something that we are working on.

We have talked with automotive odium. They have expressed interest but

we have not had actual work yet.

SPEAKER: I just wanted to make an on-the-record comment for basic research and investment in basic research. All of you sitting there, 30 years ago the investment at Berkeley and other places in intelligent control system, PTT planning, computational geometry, the whole PATT program at Berkeley. So I think we have to very much compare (inaudible) the fact that investment in basic ideas, risky ideas, 30-40 years ago that took place, is not paying off and you people are talking about just certain aspects of it, but basic investment was made 30-40 years ago and you should try to keep as a policy matter in perspective that fact because in the present environment you will see that we are only picking up the fruits but we are not looking at the roots of the thing. I think we have to pay attention to that fact.

MR. DARBHA: Yeah, again, I'm one of the early graduates of the PATT program. So that was not my piece the program was on. So thanks for finding that out. People seem to have forgotten the PATT program.

MR. RATHINAM: I also work for PATT. And you know, we -- we work on fundamental problems and that's where my interests are. Today's presentation is just one -- I had 15 minutes to talk so you know, if you give me more time I can talk over the fundamental problems. I'm not sure how much of the odium I can retain but I'd be happy to talk about it.

SPEAKER: I don't know how much time you have.

MR. GOPALSWAMY: We don't. Sorry.

SPEAKER: Thank you.

(Applause)

MR. RAY: Okay, howdy. Great. Welcome back from lunch. I hope everyone had a nice break. I'm going to introduce our keynote speaker for the day.

Derek Kan is here. He is the executive associate director at the Office of Management and Budget. He has a long history of working in the transportation industry

and in policy. He was most recently undersecretary of transportation for policy at the Department of Transportation, which he held almost for two years. He's also been a member of the Board of Directors at Amtrak. He was a general manager at Lyft. And then he had several other private sector experiences before that.

Derek also worked in the Bush White House where I knew him. He got his MBA at Stanford GSB where he was an Arjay Miller scholar. I can tell you I was co-teaching a class when I was getting my Ph.D. at Stanford more than two decades ago, and the Arjay Miller scholars are the top 10 percent of the class. And I can tell you that I wish everybody was in that top 10 percent. Of course, mathematically that's not possible, but they were the best students. You get that award for the highest GPA in the class, and it was really a job a teach them.

He also has a degree in economics from LSE and he graduated from USC.

So, without further ado, here is Derek Kan to talk about autonomous vehicles and the topics of this conference. Thank you. (Applause)

MR. KAN: Thanks, Korok, and thank you all for being here. Nothing like a post-lunch fascinating conversation. (Laughter) So hopefully, the blood is flowing from your brain to your stomach and we'll see who stays awake in 45 minutes.

I wanted to thank you for the kind introduction. It's great to be here at Brookings. There's a lot of familiar faces in the room. You had a great presentation this morning from Ken Leonard, who leads a lot of the work at DOT. And the afternoon is much more exciting. I wish I could stay because the next panel is fascinating with some of the foremost experts around P3.

So you have Rick Geddes, who literally is the nation's top expert in public-private partnerships. Marjory Blumenthal has perhaps the best most comprehensive analysis she wrote at RAND on a safety framework. And Cliff Winston has this really creative, fascinating paper on why traffic deaths drop during recessions. And it's really, in short, a self-selection process is sort of what he predicts. But just a great set of panelists.

And at the end of the day you have Tanya Snyder chairing a panel. And Tanya's great, she's a reporter at Politico. She always asks very insightful and provocative questions. I'm thankful she's not going to be able to ask me any, I hope.

So I want to do a few things this afternoon. I wanted to share some broad observations on mobility and broad trends. Then I wanted to talk about broad observations about autonomous vehicles, what the Federal Government is doing for mobility and AVs. And end with just a lightning round of big questions that folks are asking and my short answers.

In terms of broad observations on mobility and autonomous vehicles, we see a megatrend around mass urbanization. The data shows that about 55 percent of the world currently lives in major metropolitan cities. By 2050, that's expected to grow to 66 percent. Consequently, urban congestion will be the greatest challenge for the next generation.

And you not only see mass urbanization growing, but also the concept of mobility and the concept of a car is changing. One of the megatrends around the car is they expect cars of the future to be three things: shared, connected, and electrified. And I think the jury's still out on some of these, but shared, certainly the case; connected, a lot of the panelists this mornings talked about the importance of connected vehicles and it seems like there are demonstrated safety benefits; and electric, I think that one has some open discussion and sort of open debate if we see that.

We're also seeing with mobility a much greater understanding and insight into travel patterns like we've never seen before. If you look at how people travel, most recent data from the Federal Highway shows that people -- travel patterns follow a Poisson distribution. Seventy percent of the trips you take are 10 miles or less. And once upon a time, you had three modes of transportation: mass transit, car, or train. Well, then the airplane came along and that sort of was the three or four main travel modalities. However, today you have eBikes, you have scooters. And what you're seeing is for these 70 percent

of trips, there's going to be a whole set of options that you've never seen before.

And on top of that, with companies like Uber, Lyft, and DiDi and all of these ride-share companies, we now have an app that can help us make the trade-off between time, distance, and price, which is something we've never had before. And as a result, the way we travel is changing rapidly.

Also, people tend to think that transportation will move slowly and evolve slowly. That's not completely true if you look at history. In 1900, there were about 8,000 cars in the United States. Twenty years later, in 1920, there were 8 million cars in the United States, a thousand-fold increase. And from 8 million cars in 1920, today you have about 270 million cars. And so the first 20 years of a new technology you see radical transformation. And today, we have more cars than we do adults over the age of 18.

Part of this, part of this fascinating expansion in the early 1900s, was the creation of the car dealership. And I'll touch on that briefly. But from 1900 to 1920, tens of thousands of car dealerships grew across the country. And as we started thinking about the autonomous vehicle, there's a core policy question of this important constituency, car dealerships, what will be the future of them?

We're also seeing new business models that didn't exist a year ago, from ride-sharing scooters to eBikes. And as we think about new business models, dealerships are going to play an important role.

Two other sort of macro trends here. There's significant regional variation as you look at automobiles generally. Detroit, when it was first conceived, was the perfect mix of talent and supply chain. It was where a lot of railroads cross and so it was easy to get auto parts into that region. And suddenly, you had automakers, parts suppliers, transportation hubs, what we in Silicon Valley call the ecosystem. You had a perfect ecosystem to distribute this innovative technology at the turn of the 20th century.

However, in the last few years, we've started to see a massive shift away from Detroit to the South in states like Alabama, Kentucky, and Tennessee. And so today,

Alabama is one of the largest manufacturers of autos because of things like tax incentives, a robust ecosystem of talent and suppliers, and close proximity to a supply chain, namely ports and transportation hubs.

And so this raises an important question, I think, for policymakers, for researchers. Where will the first 10,000 autonomous vehicles be produced in this country? Or maybe around the world, in what country will you see the first 10,000 vehicles? And in what state will you see these first vehicles? Will it be in Silicon Valley, where technologists, computer scientists, and sensor experts live? Or will it be in a manufacturing hub where low cost of labor, auto parts manufacturers persist?

Finally, one broad observation, global competitiveness. Right the United States has perhaps the greatest capacity for innovation and I think what we're going to see in the next 10 years is which country will lead around autonomous vehicles. Right now there are really three broad models in terms of national regulation.

You have the Chinese model, which is a very unitary, central plan model, where they have the next 15 years' layout of what milestones they hope to hit in terms of cars produced, tech milestones. They literally have a national product roadmap for the introduction of the electric vehicle and the autonomous vehicle.

You have Europe that has a council. In Germany, they have a council, and I think it's called the Golden Council, that together this council made up of stakeholders of unions, of car manufacturers, together set policy.

And then you have the United States, which is very open. We have federal voluntary policy, some state policy. But for the most part, a very open, let the thousand-fire blooms approach and see what emerges.

The fascinating thing is going to be over the next decade which of these three models will emerge. And I have a point of view that I'll share at the end, but it's an important question that we as policymakers think what does the competitive landscape of this look like?

Some broad observations on autonomous vehicles. Every 5, 10 years people have a look forward of what AVs will look like. And I think people love predicting the future of AVs and have we hit the milestones. In short, we've gotten some things right, some things wrong, and a lot of things we don't know.

What did we get right? We knew that the technology would be very difficult. We knew that partnerships between OEMs and technology would be important. And we had some interesting theoretical observations very early on in the process. For instance, the introduction of automation and AI taught us that autonomous vehicles actually do something very different with the concept of risk. And Korok has a great paper called "Driverless Cars" on the concept of risk.

Autonomous vehicles didn't diffuse risk, it actually centralized risk. They centralized risk with the engineers. And so instead of those of us in this room potentially getting in a car accident, what we did is we resulted in a single computer engineer potentially putting into a line of code a major incident that everybody in the room would suffer if their care was in a similar situation. And so that was an early observation that theorists had and it's helpful in some ways and something we need to be mindful of was we move forward.

I think some other things we got right, two more, one is partnerships are key. The Department of Transportation recently put out autonomous vehicle demonstration grants. And if you look at these grants they are designed to have people apply as partners. And we're realizing that no single entity, no city, no OEM, no technology company can do the entire stack. Rather you need a partnership that manages hardware, software, customer. All of these things together is going to enable the autonomous vehicle to come to market.

And finally, we also got right I think that the city, state, and federal rules will be very different. And I think for the most part these are largely agreed upon. They're not settled matters, but they're largely agreed upon.

The Federal Government's role is to oversee the engineering and the

design of the vehicle. The state's responsibility is around the operation of the vehicle, so speed limits, things like what is considered safe and unsafe behavior, and insurance which has largely been delegated to states throughout our nation's history.

We got a lot of things wrong, though, too, at the same time. We got wrong things like timing. We assumed that products would come to market much faster. Every five years a forecast says, in four years this will happen. We've actually it seen with all the OEMs. And literally every prediction of when cars will be on the road have been missed.

Ten years ago we thought there would be thousands of autonomous vehicles deployed in the country today. That certainly hasn't been the case. Today there are 1,400 vehicles all being tested in the United States, but none that are being sold for commercial purposes.

Number two what we got wrong were metrics to evaluate success. And I hope this afternoon the people in this room can really help us with this question. It's a very complicated policy question. But if you recall, when autonomous vehicles first hit the road there were two main metrics people loved to talk about. Maybe three, but two main ones.

Number one, vehicle miles tested. Whose tests did the most miles? Who's hit a billion miles? Who's hit 2 billion miles? Who's hit the most miles tested? Number two was disengagements. How often did a safety driver have to take over the car? Disengagements, miles tested were the two metrics that some states asked autonomous vehicles to report on.

Now, we've learned over the last few years that both these metrics, while helpful to advance the dialogue, create major principal agent problems. Vehicle miles tested is a very, very blunt test. Think about it. If you drive 50,000 miles across the coasts, in between, that's a very different test scenario than 50,000 miles inside a major metropolitan area. In some parts of the country you could drive a thousand miles without seeing another person, another car. And so this whole concept of vehicle miles tested, we sort of look at it like, yeah, that probably wasn't the best metric to lead off on.

The second also created major challenges and took us a little bit for a curveball. That was disengagement. All cars today have -- or a vast majority of cars today have a safety driver. So if you're driving in a vehicle and there's a problem, the safety driver takes over, takes control of the vehicle. Some states, city of San Francisco, state of California, I believe, wanted people to report on the number of disengagements.

Well, the problem with disengagements is it's a gameable metric. And this is one of the points that Marjory puts out in the RAND paper that you'll probably hear about in the next panel. But if you can game a metric, if you can game a safety metric, it's not a very good metric. And so as policymakers, it's something we spend a lot of time thinking about, what are reasonable metrics, non-gameable metrics?

And we actually see it. It's not simply an autonomous vehicle problem. It's a problem that exists throughout all transportation. For instance, dangerous driving. We know the consequence of dangerous driving has a clear red line, which is a fatal car accident. But precedent to that, what are other examples of dangerous driving we have proxies for? But if it doesn't lead to a fatal accident, was that really dangerous or not?

And so you get into these challenges of what are good proxies for safety knowing the outer bounds of safety are accidents and the outer outer bound are fatal car accidents. So one of the things we got wrong very early on were metrics to evaluate success. And it's not anything wrong, I mean, in the evolution of policy. It's where you'd expect us to be.

I think one other thing that we are moving away from are the SAE five levels framework. We talk about Level 3, 4, and 5. And we've realized that Level 3 is an important -- it's a useful framework for the starting point, but Level 3 is a very broad bucket with a lot of examples. And we're starting to figure out how do we parse Level 3 SAE testing.

What we still don't know. I think there are two big things we still don't know. One, what are the metrics we use to evaluate success? And this is so important. I truly hope that the people in this room can help us think about this question and think through

what should the metrics be that the Federal Government uses, that a state government uses to measure success.

And number two, what is the sensor stat? That's a technology problem, but a very serious one. There really are two big heuristics that exist in this day and age. One is the autonomous vehicle replicates two core human functions, core human cognitive functions: the ability to see and the ability to think. And the theory goes if the ability to see is what the autonomous vehicle has tried to replicate, then all we need are cars. We don't have internal radar. We don't have internal sonar. We just have two eyes with which we can see. And so the concept is let's have only cameras, not LIDAR and not radar and not all these other things, simply a camera.

The other end of the spectrum is all of these things are important. We actually do have depth perception, which is radar. We do have the ability to see how fast things are moving, which is LIDAR. And so to replicate the eye you can't simply use cameras. You need a comprehensive sensor stack of LIDAR, radar, cameras.

This is an important decision because it really gets to who is going to win in the hardware space and starts getting to regulation and policy. To what extent should policymakers say this is what your technology stack needs to look like?

We still don't know what the stack looks like. We don't know how to measure that sensor stack. And we really don't know yet how safe is safe enough.

Our hope is that where we are as a nation, though, is at a good place, and I think it is. We currently have 1,400 vehicles in the United States being tested by I think over 70-some different companies. And I think Ken Leonard in the back has all of the numbers chapter and verse. In California alone, we have 1,200 vehicles being tested.

I want to spend the last few minutes talking about policy broadly, what the administration's doing, and conclude with a lightning round of major open questions. The administration has laid down broad principles on autonomous vehicles and it touches and builds upon the earlier part of my talk.

Number one, prioritize safety. No matter how exciting this is, no matter how many lives we can save, no matter how many people in this room can sleep in the backseat of an autonomous vehicle like they are right now, you know, it could satisfy, safety must come first.

Number two, tech neutral. The Federal Government nor any government in our opinion should be saying that this is the ideal technology stack. So we call that tech neutral. We don't know if one form of LIDAR, a solid-state LIDAR, is better than a non-solid-state LIDAR. We don't know if a LIDAR is better than a radar. Rather what we want to move toward is a performance-based policy, a performance-based regulation versus something on the front end where we lay out specific, detailed approaches in terms of the inputs. So prioritize safety, tech neutral.

We also are not top-down command and control, but rather our approach has been to modernize regulations. If you look at regulations, particularly the Federal Motor Vehicle Safety Standards, there's 400 different -- 4 different chapters. The second chapter of FMVSS is called Crash Worthiness Standards. The 200s are general Crash Worthiness Standards. In the case of an automobile accident, what are the internal components and design standards of a car that reduces the impact and ensures the safety of the people inside the car?

Well, as policymakers an interesting policy question came before us when I was at DOT. What if this car is designed to never have a person? What if it would never, ever transport a human being, not as a driver, not as a passenger? Do we need to put in airbags, windshield wipers, mirrors?

Well, there's one company in this country designing a self-driving package delivery vehicle that says FMVSS, Federal Motor Vehicle Safety Standards, requires these things, so we have a seatbelt in it. We have an airbag in our prototype. (Laughter) And I sit and think like where is your airbag placed? Like who are you protecting? And so this is a perfect example of how we need as a Federal Government to modernize our regulations.

At DOT we've looked at all the activities around autonomous vehicles in three big buckets: regulations, research, and public awareness. On the regulations front, we've streamlined the exemption process, how you can apply to produce more autonomous vehicles for sale. We've begun to update and modernize standards around Federal Motor Vehicle Safety Standards. And what that means is systemically going through every rule we have to better understand is it applicable for an era in the concept of things like package delivery?

And some are easy. Some are very easy and upfront. For instance, does the steering wheel need to be designed a certain way in terms of the radius of the steering wheel if you don't have anybody behind it? And so that's one clear example where we probably don't need things like a steering wheel and brake pads.

But then there are other parts of the Federal Motor Vehicle Safety Standards that raise other questions, such as in case of crash avoidance, how proscriptive should the Federal Government be in laying down specific engineering rules as to how self-driving cars can avoid accidents?

So the streamlining, the exemption process is easy. Modernizing standards in FMVSS is a little hard. Some are easy, some are hard.

Two other fronts we're spending a lot of time on is on research. We've put out -- this administration has put out two autonomous vehicle voluntary guidance. Secretary Chao, when she came into office, was very eager to make sure that the Federal Government would not be an impediment to the adoption of autonomous vehicles, but rather that would be left to the public sector, to the public. And that the only real constraint of adoption should be a willingness of the people in this room to get in back of it. We do not want the Federal Government to be the constraint here.

Also on research we've done things like incorporated new technologies into our discretionary grants. And we've even begun to do things like develop crash dummies for rear-facing seats and researching alternative occupant protection systems. So that's

regulations, that's research.

The final one we spent a lot of time doing is on public awareness. Campaigns like this, conferences like this are great because the policy questions are complicated. And so we've done a number of listening sessions and a number of events around the country highlighting good research, innovation, and also the policy questions that exist.

And so at a high level what DOT has done in the two and a half years under Secretary Chao and President Trump is transformed itself as an organization. For the better part of 50 years we were focused on existing transportation modes. However, we've moved from basic existing transportation sources to new technologies, and it's been a cultural change like you've never seen. As we look at everything from discretionary grants to activities around the country, we'll ask ourselves how do we imbue and embed technology into this? And it's a long road, but the department is well positioned to embrace this.

We also see this shift and this embrace of technology on the Hill. Last year Congress appropriated $100 million for autonomous vehicle demonstration grants. And right now there's talk of should we enact an AV START bill which deals with federal preemption in allocation of liability in this space?

I want to end in our last few minutes with a few big questions and sort of a lightning round and conclude. I see six big questions that folks like asking about.

Number one, where does regulation go from here? I expect regulation to have a lot of stops and starts. I expect the Federal Government to put out more RFIs, maybe even a Proposed Rule, get a lot of comments back, and will stop and analyze it for all. I expect states to do the same. I expect some states to go out very quick, something happens, and they pull back. We see that in Phoenix right now.

Number two, when will AVs launch? The question everybody always has. Hard to say, but my guess is much longer than people think. A lot of people are predicting in the next few years. My personal sense is it's going to be a few years, five years or longer,

before we see autonomous vehicles commercially viable for the broad public.

Number three, what will the role of infrastructure be? And I know that's a key part of today's conversation. My sense is infrastructure is one of many variables in determining what region wins, what country wins. And what I mean by that is infrastructure V2V, V2I technology is potentially important, but not all car companies believe it's a prerequisite to success. Rather it's going to be one of many variables, such as state and local laws, such as the ecosystem I talked about earlier, customer acceptance and public perception, and how you will have fixed and zoned routes. So infrastructure will be important, but I don't think it will be the driving exogenous factor.

Number four, how will liability be sorted out? And I think it's an important question. We're starting to see the development of insurance products for ride-sharing companies. I expect the same to happen with autonomous vehicles. And so how will liability be sorted out? I think through the market and through the creation of new products and then finally through the courts.

There's no clear federal rule for insurance as its generally regulated at the state level. So I see states starting to think about how they assign liability. And right now the model people frequently point to is the aviation model.

How will locals respond and what will it look like around the country? I think there will be a patchwork for a long period of time with local governments learning from each other. And you're starting to see that now with ride-sharing and right now you're seeing it with scooters. Some cities are very, very much embracing scooters. Others are setting quotas on scooters. Others are setting licenses. And so we see cities having a very different approach and then evolving into cities teaching each other what they've learned.

And we're seeing it now with airports. For anybody that travels to an airport in a ride-sharing car, you're now taxed, often at the airport, and that airport revenue is used to make up for parking loss revenue. And this was not sort of a centrally planned thing. Just a few airports had this creative insight in elastic demand of going to an airport in a ride-

share. Two dollars isn't going to make or break it. And so you're starting to see cities across -- municipal airports across the country embrace this.

I expect the same with autonomous vehicles, that there's also a major, massive business opportunity here. Helping cities develop the platform and tools to manage new mobility options is going to be something major and something significant that you will see one day there will be the Google platform of all mobility options in cities.

And finally, who will win globally? My sense is Asia will likely win in the near term. There the next three, four, five years we're going to see China just start producing more and more autonomous vehicles. But I believe in the long term the United States will win just because there are parts of the technology stack that are probably incorrect that we're not even thinking about today. Just like the cellphone. When the cellphone first came out, which was about 11-1/2 years ago, the camera being a part of it was strange. Why do we need a camera in our pocket all the time? But now as we go out, I'm going to be taking a selfie with all of you, so clearly, it's just such a critical element of our life.

I want to just conclude by saying this is an exciting time and this is just a time in which there is so much hope and excitement around autonomous vehicles and there are so many eyeballs on this new technology. And the excitement and the hype in AVs is shared by the administration, by the department.

But underneath all of this excitement there's a huge body of work being done. There's coding done by computer scientists. There's the muscle of automotive engineers putting components into cars. There's hardware engineers thinking of what the next graphics processing unit should look like, the grit of infrastructure builders, and the insight of policymakers. And I think half this room is made up of policymakers, and this is where a lot of the hard work will be done.

Believe it or not, the papers you put together, the paper that RAND put together was such an important piece of work. The driverless cars piece that Korok wrote in December, so helpful in shaping the views of policymakers.

So for those of you in this room that are sitting here listening and thinking about how AVs play out, I welcome and encourage you to keep being part of the dialogue because it's through the notice and comment, through the Request for Information that you inform policymakers about what AV 4.0 should look like, what the next set of AV rules should look like. And so that help is so important to all that we do.

I spent a lot of time today predicting and sort of sharing a forecast of what the future's like. In the words of Yogi Berra, prediction is hard, especially about the future. (Laughter) So take it for what it's worth.

And with that, I want to thank you all for being here, for being part of this great conversation. And I'll open up for Q&A. (Applause)

SPEAKER: Thank you for your comments. It's very helpful. I know you had said earlier that you felt that infrastructure is not going to be the driver for AVs. But I think it's safe to assume that most AVs are going to be EVs. And so with that, given that there is money in the public space, particularly through states, to spend money on EV infrastructure, and I know that there has been some hesitation on spending some of that money because states are very concerned about I want to spend this money smart, I don't want to spend it for something that's good for three years. I want to think about the next 5, 10, or 20 years with respect to how to spend this money. And on top of that we know that Senator Carper has proposed a highway corridor bill which could introduce additional monies, particularly along the highway corridor to support this.

So with that in mind, a highway corridor bill, the VW settlement, a lot of this money is in state hands, what should they be thinking about today to spend that money wisely and be able to enable technology that we want to see in the near future?

MR. KAN: The question was how should cities and states think about all of this money that we're seeing in infrastructure from the Surface Transportation Reauthorization bill. Earlier this week, Senator Carper and Senator Barrasso, chairman and ranking member of the Environmental Public Works, released a bill. The bill was about $297

billion over 5 years in increased infrastructure spending.

I don't think infrastructure's going to be an enabler, but I do think infrastructure has the potential to be a blocker. If you look online you'll find a lot of pictures of situations where self-driving cars are unable to drive in because the infrastructure just doesn't make sense. So while the right infrastructure will not bring AVs to your cities or states, the wrong infrastructure will deter you.

So I do think that you're going to see from the Department of Transportation and from Congress an expansion of how surface transportation programs operate. And just in general, the way surface transportation programs operate is they are federally funded, state administered. And so the Federal Government takes the money from the gas tax, gives it to states, and there is a broad set of eligibilities that state can use this money on.

States are seeing increased eligibility for things like technology and electric vehicles. That was passed in the last Surface Transportation Reauthorization bill called the FAST Act. Also, there's a number of discretionary grants that the Federal Government has and we've incorporated technology into it.

So the way I would think about it as cities and states is this Department of Transportation, this administration is very eager and open to new technologies and innovation. And so if you look at the discretionary grants that the DOT put out, technology was an important element.

So what I would encourage cities and states to do is to think how can you infuse AVs, new technologies, innovation, EVs into the thinking of applying for state and federal funds? Because it's definition something that the Federal Government looks at and it's something that has increased eligibility.

What will be interesting over the next six months is not only did we expand eligibility, but are you going to see a shift in criteria where there's actually emphasis placed upon EV infrastructure or AVs? My general sense is part of our tech neutrality is while industry seems to be pursuing electric vehicles and autonomous vehicles, this administration

does not take that as a given. And so if there's going to be an AV with a combustion engine, we're not going to say that doesn't make sense. Rather we are tech neutral, particularly as it pertains to EVs and combustion engines.

SPEAKER: Thank you very much. My question is what are the real costs -- vehicle's cost for everyday life, for everyday citizens? I'm not sure that anybody mentioned about that subject. Particularly I'm concerned like automated streets, you have to pay (inaudible) how much. Probably it won't happen too soon, but if it happened everywhere I wonder that maybe somebody has to think about something like the food stamp, something like a road stamp for low-income people.

MR. KAN: The question was how do we think about AVs to specific populations, like low-income and populations that have greater needs? Well, I can share with you the Department of Transportation was given $100 million. And it's actually presented a very complicated policy question. In a space where there's billions of dollars, the Federal Government gave us $100 million to allocate, well, there literally is billions of dollars from venture capitalists to OEMs. So the way we look at this pot of money is where is there a lack of investment? Where is there a market failure in the sense of not enough research going to a particular area?

The specific area in which we invested it were in populations with the elderly and the disabled. And we thought that most AV companies are not going to go out and think how do we serve low-income populations or populations with people with disabilities? Rather we as the Federal Government, as the administration said this is probably going to be an area where you don't see a ton of fruitful research. And so we designed a lot of our research agenda around this particular question. How will AVs serve this population?

And on this front, and this is sort of going back to my experience before government, the amazing thing about ride-sharing companies and autonomous vehicle technology is it is a great tool for certain populations, such as the elderly, such as those that are in need as the questioner asked. Because we could deliver transportation to your phone

and tell you please go outside right now to catch a self-driving car that's going to come and find you.

And so what you see is this technology has so much potential to really transform the lives of people. It's just are we going to have enough investment and focus on it? We as a government, as an administration are trying to answer this exact question and make sure there is enough research done to what everything from the human design of the car should look like to how will we ensure that populations, all populations will have access to these vehicles?

SPEAKER: So one of the things you brought up was the importance of states and localities. And following on the prior question, if you are blind or unable to drive, you literally can't sit in the driver's seat, even in a self-driving car. The Uniform Laws Commission did just complete after two years a model four states to overcome these types of legacy problems. To what extent do you see the administration's ability to help normalize state laws across the country with respect to enabling access and mobility?

MR. KAN: Great question. What is the Federal Government doing to help mobilize state patchwork of laws around mobility, particularly for specific populations? We try to find -- this administration's philosophy is we want to find that right balance from identifying good practices without being heavy-handed and tell all states to do something, particularly when it's not entirely clear to us that there is a federal role as set in the Constitution.

And so if you look at AV 3.0, the guidance Secretary Chao put out last September, September of 2018, we actually lay out model or best practices at the state level. And in that section we talk about specific populations. And I expect at some point in time over the next two years we'll update that and say here are what we're seeing among states. And here are the best practices, some of the best legislation we're seeing in states, and we recommend that other states start thinking about these things.

And so what we've done is we've tried to pull up at the federal level all the

things states are doing and put together resources that we can then distribute to other state legislators. Our view is not to be command and control, in large part because populations in every city and state are different, so it's somewhat presumptuous for us to believe that there's a one-size-fits-all approach, particularly when it comes to particular populations. Because that's not just population, but it's also what does the city look like? How is the city designed? And these are things we clearly recognize as delegated -- authorities delegated to the states.

However, we believe there's an important federal role in identifying the best practices, the model legislation, the best practices legislation, and then circulating that and sharing that with state DOT heads and state governors.

SPEAKER: So there's no legislative framework for autonomous vehicles. There are no federal regulatory requirements. It's all voluntary. And Tesla is saying that they're going to have -- release kind of a software update within this year to have fully self-driving cars.

Already they have autopilot on the highways. They're saying that they're going to have the capability to do the same in urban areas. That's making a lot of people very anxious. But is there -- what is the Federal Government's ability or interest in setting some guardrails around that?

MR. KAN: Great question. The question was there are no federal laws or regulations around this. What is the Federal Government's role going to be when companies claim or pronounce they're going to put cars on the road?

So that first part of your question is actually somewhat of a misconception. The Federal Government does have tremendous authorities. We have something called defect authority and we have the ability to direct automakers to cease and desist. So defect authority is a very powerful authority that NTSA has. If there is a component of a car that is defective, we can pull cars of the road. And our interpretation of our defect authority is that this applies to the algorithm, the AI, the brains of an autonomous vehicle.

And we describe this in AV 3.0 and our voluntary guidance that we have all of the authority that we need. That if we see bad actors, if we see cars not doing what they're programmed or what they're marketed to do, we will take those cars off the road. And, in fact, we have. In Florida, there was one AV shuttle provider that had claimed they were testing this AV shuttle. Well, it came to the department's attention that they were transporting children to and from school or around the city. And so in our mind that is clearly not testing. That's actually deployment of technology. And so we ordered them to stop all testing.

And so the concept that we aren't doing anything is a bit of a misnomer, but we actually are monitoring vigorously what is happening across the country. And NTSA's defect authority is an extremely powerful authority where we can take any set of cars off the road.

The hard part of this as policymakers is when there are cases in which it's a combination of poor user error and poor design, and it's not entirely clear where the problem is. And that's oftentimes where the gray area becomes should we more aggressively use defect authority or not? And so Tesla's going to be one example where we are going to be tracking the deployment of Teslas very closely and seeing how that plays out.

But there are federal laws. There's a federal law that has been on the books for decades that empowers NTSA to identify any defects and take cars of the road.

I saw one last question and then maybe we'll turn it over to the next panel.

SPEAKER: Thank you. You said that autonomous vehicles replicate our ability to see and think. And I would argue that they also will hear and remember. So --

MR. KAN: They what?

SPEAKER: Hear and remember. And so I think that in the priorities that you listed I didn't hear data privacy and security issues as one of them. And I understand that there are a lot of people currently claiming jurisdiction over those issues and it is not necessarily a place where DOT has had to tread. But at what point do you see DOT

needing to engage with data privacy and security issues when you're engaging with this new technology? I realize I'm asking for another prediction, but.

MR. KAN: The question was how does DOT think about data privacy? Because one of the components of what cars do is not only see and think, but also hear and remember. And that's absolutely true. The reason self-driving cars are getting better is because they have an algorithm that learns from the past, similar to how we drive.

The role of data privacy is a very open question which has tons of different views. I have a personal view and sense of where things are going, but it's very unformed because there are two major issues here.

One is there is not a clear legal authority for DOT to acquire, regulate, track, mandate any type of data standard, and that presents a complexity here. There are pieces of law we can interpret, such as different types of authorities we can interpret broadly. But there's not been any clear direction from Congress what the desire is for DOT to do or any federal agency to do around data privacy.

However, there's a very good model out there. It's called the ASIS model, A-S-I-S. It's a great model; people should look. After I forget if it was '93 or '94, there was a summer in which there were a number of significant passenger plane accidents in this country. ValuJet was one of them in the Everglades, New York had a second one. And what air carriers did is they came together and said, you know what, we should figure out a way to share information in a way that we don't trip any anti-competitive laws, we protect our trade secrets, and we don't get into trouble with these things. And so they created a system called ASIS where twice a year for I think two days the top operators from air carriers share data.

I was landing at JFK and my warning indicator started beeping, I don't know why. Another person in the room says the same thing happened to me. And suddenly, through pattern recognition different air carriers with different pilots started pattern recognizing and understanding some of the problems they ran into.

This is not -- there's no congressional mandate, there's no legal requirement to do this. But what Congress did do is it passed an indemnity provision that said if you share data for public good or public safety for this specific program, you're indemnified from prosecution provided it wasn't intentional and provided you report within 24 hours. So there's basically a voluntary data-sharing organization that came about.

And I think this is going to be one of the important ways that this is addressed, that as AV automakers start coming together and sharing data, that it'll address some of it. But it doesn't address the other side of that coin, which is personal data. And that's one that there are tons of different views. My personal prediction for this, again channeling Yogi Berra, take it for what it's worth, is I think you will see Europe much more aggressively thinking about this than the United States. With GDPR you're already seeing question around data, around what tech firms are tracking.

And so what tells me is you're going to see other countries move faster on this data privacy piece I think than we are simply because that's an issue that they think a lot about. Whereas here, it's unclear, is this a state issue? Is it a federal issue? Where will we derive our legal authority from? And what are the mandates that we put on them?

So what I see in this country at least there have been two modern attempts to create a voluntary data exchange. The problem with that is when you have companies that are at very different life stages, pure startup to companies that have invested $50 billion, there is no desire to share data. And so what we're seeing with some of the resources, as some of the panelists are going to talk to next, is what should they even be tracking? And my hope is before we get into even privacy, we begin to just align on what is the specific safety standards we want data to report on? And let's start sharing those things before we start getting into the very sticky wicket of insurance, of data privacy, and data sharing.

So with that, I very much appreciate Korok and Brookings for hosting this fascinating discussion. I hope you all stick around for the next two panels and really appreciate your engagement on this issue. It's really active citizens, engineers,

policymakers that together are going to help shape this technology that our kids will look back at and say it transformed the world.

So thank you very much. I really appreciate the time. (Applause)

MR. RAY: Okay. Thank you. So we are going to move forward with our next panel on *Policy*.

This will be a little different from our morning sessions -- so that timer is something I should get. The next time I get into an argument with my wife I'm going to bring that.

So, we are going to have more of an open-ended kind of broader conversation about policy. I would like to try to connect our conversation to everything we've done so far this morning, the technical topics as well as the keynote. So, basically what we're going to try to have as much of an open conversation as we can, and to address many of the issues that have come up.

So again, just to level set, I think this is -- I think we're all on the same page. We want to understand how this technology can eventually develop. And I think it is a big challenge that will require the coordination, or at least the cooperation of multiple different parties.

To me this area is wide open, there's still -- you know, we're in the very early innings of the game, and as a community I think we need to think through how exactly this will work out with both private sector, public sector, and everyone in between.

So let me introduce our panelists who will speak about these issues. What I'll do is, I'll do a quick intro, they'll kind of do a longer intro on themselves, it's always optimal that way. And then they will give a little bit of an opening statement to talk for a few minutes about their thoughts broadly on this topic, and then beyond that I'll go into some leading questions, and if the discussion is not conversational enough I'll try to be more provocative.

Okay. So first I'd like to introduce Cliff Winston. Cliff has been at Brookings since 1984, he was the -- at one point the Editor of the Brookings Papers on Economic

Activity. Also in a prior life he was Associate Professor at MIT in Civil Engineering. He has a lot of writing on autonomous vehicles, and also on privatization and deregulation. He's had many books and essays with colorful titles like, *Let's Deregulate All the Lawyers*. He has a PhD from UC Berkeley just like everyone on the A&M infrastructure panel.

Okay. I'd also like to introduce Cliff -- I'm sorry, I just did Cliff -- Rick. Rick is a Professor of Policy Analysis and Management at Cornell. He's the Founding Director of the Cornell Program in Infrastructure Policy, CPIP. So, he is a real expert on infrastructure policy. He was at the Council of Economic Advisors three years before I was, so 2004 to 2005, and he has a PhD from my favorite university, University of Chicago; second-favorite, A&M is my favorite now.

Marjorie is a Senior Policy Researcher at RAND, she has worked at the Office of Science and Technology Policy, and she was also an Associate Provost at Georgetown. She has written extensively on autonomous vehicle safety and policy and has an MPP from Harvard.

So sorry to repeat the credentials, it must be my Indian American upbringing to constantly think about my credentials, that's how I was raised. (Laughter)

So that's all I'm going to say up front, and then I'm going to sit down, and then why don't we just go sequentially from my -- from left to right on my side, just to talk a little bit about -- say a few more remarks about yourself and about your views on autonomous vehicles, and then we'll get more specific. Does that work?

MR. RAY: Yes. Five minutes timing.

(Recess)

MR. WINSTON: It's been a while. Two articles were -- Sunday on autonomous vehicles, in the paper, I'll go through those briefly to frame my comments. It's not to point out it was fake news, to point out it was incomplete news which I'll fill in from the perspective of transportation economics.

The first one was in *The Times*, and it was one of these ones it says: We're

not going to get autonomous vehicles tomorrow, they'll be long off. What we're really missing in that piece was some historical perspective. It really would have been helpful to mention the airline industry. The 1920s even though the industry was growing there were many people who did not think we would ever have a commercially viable airline industry, even in the '30s when the industry was moving along people said, aircraft technology has peaked, we're not going to see better planes than what we've got now.

Obviously they were wrong. The same kinds of problems are going to exist with autonomous vehicles.

What would have also been helpful was to point out the development of the airline industry was not hampered by its own progress but by the government. We learned that very quickly when we had regulation and deregulation in the '70s, and we saw what that did, constraining pricing, entry/exit, and so on and so forth.

And remarkably it exists today. We still don't have open skies on all our routes and most importantly we don't have cabotage, foreign carriers cannot serve our routes. That would be handy now given that Boeing has grounded its 737 Max, all that could have been filled in with foreign carriers.

The other problem is infrastructure, we've still got public airports, still got public air traffic control, you can't get any more efficient than either of -- inefficient than either of those and those have hurt the industry.

The second article was in *The Post*, also on Sunday. That was one: What are the failures we've learned about autos that we can learn to try to improve autonomous vehicles? Maybe you saw that article. I didn't get any of the failures out of there, I couldn't figure out what they were talking about.

The New Yorker has a similar one, equally bad. It's very obvious what the failures were, again all from highway policy. All the inefficiencies that have compromised automobile travel are going to make autonomous vehicle travel even worse, all right.

It hurts the transportation sector, but importantly, which wasn't mentioned

earlier, it helps the -- it hurts the growth of the economy.

Okay. So my views on the industry are positive and optimistic when it comes to the private sector for an obvious reason, it's incredibly competitive. We've got U.S. automakers, foreign automakers, technology companies, and most importantly there are huge stakes.

This is not the case of GM making Chevy Volt, and if it doesn't work out, you know, they'll make money with SUVs. If it doesn't work out, they are through, all right, and they cannot count on 20 years: President Ivanka Trump or President Alexandria Ocasio-Cortez bailing them out, it isn't going to happen. So all of them know this, this kind of competition is exactly what we want, all right.

So, where are the problems in the industry? It's from public policy, all right, from the get-go. First and foremost, why didn't we have testing passed? What was the problem? Why couldn't Congress pass AV START? Why didn't NHTSA step up? They could have done it and got a national framework for testing, all right. It really would be nice if policymakers would get behind this industry and recognize what it could do.

The second, infrastructure: this is the public, automakers don't own the infrastructure, the public sector has really got to handle all of this, the city and state, and ultimately the national level, if they don't do anything that's going to ground these vehicles in their place.

Finally, most importantly, what inefficient highway policy has done, all the way down the line, inefficient pricing, inefficient investment, inflated production costs, regulatory delays, misallocation of funding from states, and cities, and so on and so forth, and most importantly, constraints on technological advance and innovation.

All of that, huge welfare losses for non-autonomous vehicles, and will do exactly the same to autonomous vehicles. That is what you've got to improve, all right.

And if you don't think this is important for the economy. Suppose Trump says, you know, I've really had it with the West Coast and Washington State, let's ground all

of Boeing's planes, let's really see what's up with them. They'll never vote for me anyway. What do you think that's going to do the economy?

It won't just be delays in the travel sector, the whole economy will be affected, labor markets, production, trade, so on and so forth, so when you get improvements in delays, which is what autonomous vehicles can do, it affects the whole economy.

We estimate about a 1 percentage point increase in GDP growth from autonomous vehicles, that's what's at stake.

I will conclude with a positive note. The good thing about all of this is that everybody knows it. That is: the public sector is going to be competing, cities, states and government, the national governments, and they already are. Right?

Bloomberg has a website that says: here are the cities where autonomous vehicles are being tested. They're going to have another one, to say: here is where autonomous vehicles are operating. As word gets out, and some cities and states are readying up for doing this, there will be a political cost to this.

So I'm hoping, in the same way that competition is really going to help this industry develop, no question in my mind about that, it will also put pressure on governments, expose the political costs, and hopefully billion dollar bills, or even trillion dollar bills won't be lying on the sidewalk.

MS. BLUMENTHAL: So many ideas, so little time, so, much to respond to. I wanted to frame some starting comments based on a handful of questions, but I think I should also address Korok's zeroth order question, which is to observe that I have a long background, a career in science and technology policy, I've come relatively recently to autonomous vehicle safety, but that is the area in which I have been focusing when it comes to AVs.

That said, I can draw from looking at the rise and the varied applications of information technologies across the board, including how policy has and hasn't worked in

those areas.

So, my first question is: What is safety? And one of the things that surprised me in my recent work is there is no consensus definition, there's no consensus definition in general, and I found that out in talking to people at the National Safety Council, as well as elsewhere, and there's no consensus definition within transportation.

So, at some level we don't really know what we're talking about. In our work we define safety as avoiding harm to people, whether they're in the vehicle, or on the roadway ecosystem.

You heard about crash worthiness from Derek Kan, that's one angle, and of course -- it was interesting he didn't mention there's also occupant protection, and that's another major strand of the Federal Safety Standards.

But if we look at the last decades of the previous century, you know, we've gone from 1950s and seatbelts being very rare, but beginning to appear, to debating about different passive restraints in the 1970s, then the '80s the fuel economy drove us to reduce vehicle weight, which of course added to the safety problems,

And steadily through the end of the last century we started to see more electronics in vehicles which is what brings us to where we are today.

Where and how can AV be measured: is my second question, and that is one that that we looked at in depth, I'm not going to go into depth at the moment, but it is important and again Derek Kan touched on this, to recognize that many things affect AV safety, beginning with the components.

And so it makes a difference if you're AV has cameras, radars, LIDARs or everything since, as we just heard, that that sensor stack can be quite varied among vendors. Testing and measurement are immature, and I would say to my panel member on the left that that's one reason why we've seen some Federal policy slowness, let's say, because we don't yet know enough how to do those things very well.

You heard earlier that people talk about how many miles the vehicle

traveled. I have colleagues who estimated that a vehicle would have to drive hundreds of millions if not billions of miles for statistical confidence of their safety. That's not happening. It's certainly not consistent with what we're seeing with the 1,400 vehicles you just heard were being tested.

We are doing a lot of simulation, and simulation is very helpful, but as anybody who really understands simulation knows, you can only simulate what you know to be able to simulate. And so there are going to be situations that are rare but important and sometimes fatal that will not be captured in simulations.

Finally, AV developers are not telling us what they know, and that makes it hard for policy makers to plan for safety, part of that is because of the competition you just heard about. This is a great race, and people who are in that race don't want to share.

Third question: Can we compare AV safety to safety of conventional cars? Well, that's what everybody wants to do. We all know conventional cars, we want to make the comparison, that's obvious, but a computer system on wheels does work differently from the combination of a human being operating something on wheels that has computers and other stuff in it.

The other comment I would make on the challenge of comparing is that it may be easier to avoid being a cause of an incident as opposed to being a victim of one, and that's probably true for both AVs and conventional vehicles. If you imagine a three-lane highway, and if you are the vehicle in the middle with three vehicles to your left, three vehicles your right, one behind you, one in front of you, if one of those vehicles screws up there's not much that you can do about it.

Fourth question: How much safety is good enough? And that relates to the question: Is it reasonable to expect that AV's be at least as safe as human-driven vehicles?

Safety advocates either want them to be at least as safe, some of them actually want them to be better. I have colleagues who did and analysis that showed that once you get to that, at-least-as-safe point, then there are benefits in terms of lives saved

and other problems avoided by getting those as safe vehicles out on the road. So you should beware having the perfect be the enemy of the good.

And then my fifth is a grab bag of: What are some other important considerations in the context for AV safety? First, AVs are not consistent in their design or operation, they operate within specified sets of circumstances.

And you heard that, again, from Derek Kan talking about a thousand miles across the country and whether you do or do not encounter other vehicles or pedestrians along that way.

We do expect the fleet to be mixed for a long time, and that's consistent with the slowness to getting meaningful deployment. There is a big difference in terms of safety between whether you have a minority of vehicles in the total fleet that are automated, and then the majority are conventional cars driven by people, as opposed to some anticipated future where most, if not all cars are automated. The whole world works differently in that second scenario than in the first.

We do expect -- again you just heard a little bit about that -- there to be more communications between vehicles, between vehicles and infrastructure, between vehicles and people, and so on, but that all isn't going to happen for a long time. When it happens it will help with safety.

So, finally, I would say that it's important to think about safety from a systems perspective, and I learned that when I looked at some of the work involved with what's called vision zero, the quest to eliminate all traffic fatalities ideally by the middle of the century.

If you're going to do that you're going to change your vehicles, you're going to change your infrastructure, you're going to change your policy, you're going to change your incentives, everything will change; and so as we think about what it takes to make safety we can't focus on the AV alone, we have to think about all these factors interacting together.

MR. GEDDES: Thank you. So, I'm not going to spend any more time on -- I'll just get my clock going here -- on bio, because I'm going to try to solve the world's most pressing policy problem, and offer a suggestion related to autonomous vehicles, and do it in about five minutes. So that's all I've got.

So you heard Derek Kan talk about the megatrend, and the megatrend was mass urbanization, and along with it increasing traffic congestion. So, as the world middleclass grows people, first they want to get a car, they want to move into the cities, and they of course, you know, drive those cars in increasingly dense environments creating traffic congestion around the world.

There's a whole slew of social problems associated with that, there's wasted fuel, there's wasted time, there's fine particulates produced from diesel fumes that have shown that babies who grow up near increased diesel fumes have worse health outcomes. I could go on. But that is going to be, and is, a huge and increasing social problem.

Now to the economist, the economist who looks at traffic congestion, Econ-101 says: every bit of traffic congestion is due to the mispricing of the use of the road at that time. It's due to the mispricing of the use of the road at that time. That is, the price of the road is too low. If you could get the price of the road correct you could regulate the market both on the supply side, and on the demand side in order to make the flow of traffic through that facility smooth, so basically going at free flow.

So, imagine we could do that. Imagine we could, and the panel of engineers I think agreed, that driverless cars are a way of getting people to accept road usage charges per mile a little bit better than they have in the past, they're a tool.

So imagine we could do that, we could price per mile, but that price per mile is not fixed, that price per mile is variable, okay. Like, like the price of bread, the price of beer, the price of ties, I don't know, those prices vary but they vary in real time, and the price per use of the road at that particular time varies.

And it varies in a way to clear the market, so when an economist says clear

the market that means that the demand for road space exactly equates to the supply, and the cars flow through at maximum cars per hour.

Now, you could imagine that market for road space clearing centrally so that there's some -- what we call an independent system operator -- an ISO perhaps that serves as the central clearing mechanism for that market, okay.

If that seems, I don't know, pie in the sky as we sit here, the market for wholesale electricity, probably the electricity we're using in this room right now, the wholesale market not the retail market, clears down to the second in a way to equate the supply and demand for electricity on the grid.

The same is true for radio spectrum. If you went to Chicago the market for number 10 wheat would be clearing that way right now. The market for pork bellies, the market for coffee, the market for orange juice, all these commodities are clearing in this, you know, sort of constant way.

So, imagine now that we had that data, so we knew we were pricing not only according to per mile but in a variable way, in a way that clears the market, and then that price data were plugged into your app, okay, and that that price was the key thing that say your Google Maps, or your Waze, whatever app you want to do, was telling you how to get to work, okay.

So you say, I'm going to use an autonomous vehicle, I've got to go to work, I hit the button: how much is my trip to work in the cost right now? Well, according to current road prices it's going to cost 6,075 cents.

However, there's a there's a little arrow, and the little arrow tells you whether the price is going down or whether the prices going up. So, if the price is going down you wait 15 minutes, you answer some emails at home, you have a cheaper road price to get to work.

If the road price is going up you say, I've got to get in the car right now, give me that driverless car, I'm going to work right now, okay. So, that is, imagine both, not just

the market currently, which is what we call a spot market, but also a forward market which is what you have in almost all commodities.

But the market is a new market, it's the market for the use of road space, and that forward market if you're worried about price risk, allows you to hedge if you're a big user, say like United Parcel Service, DHL, FedEx, you want to lock in those prices, you might hedge in the forward market for road space.

So that is the basic. I think the key thing, we've talked about safety, critical issue, we've talked about potential time savings, less aggravation associated with driverless cars, but my hypothesis, my strong hypothesis first is that we could eliminate all -- I'm using that word carefully -- all traffic congestion through accurate prices of roads that would clear down to the second or every few seconds, and we would have a spot and a forward market.

And second, with leading to that, okay, to eliminate one of humanity's most pressing problems, in my view as an economist, would be the single greatest benefit of autonomous vehicles. If we could get people to think about the trip differently, and the way they pay for roads differently that would be a huge advantage.

So, if you want to read about this some more, I'm honored to have a paper in the journal *Nature*, the British journal *Nature* with two esteemed economists Peter Cramton and Axel Ockenfels. If you want to read it give me your card that says: send me the *Nature* paper, and we have a longer -- that's a comment almost -- we have a longer paper in the academic journal called *Journal of Institutional and Theoretical Economics* that works all this out in gory detail about how the Independent System Operator would work.

Peter Cramton has set up electricity -- wholesale electricity markets around the world, he's also set up spectrum markets and, you know, we explained how this would apply to the market for road space.

So as I think about this as an economist, I love safety, I think it's important, I think there's a lot of challenges, but I would hope you think about autonomous vehicles as leading to this new economic world where we accurately price the use of roads in real time.

And I'll stop there.

MR. RAY: Okay. Thank you, panelists. So, let me just begin with sort of a broad question. This morning we saw that there are some -- there are a lot of opportunities and challenges with -- on the technical side of autonomous driving, and then Derek Kan said that we're a little bit slower on the timeline than he expected.

Can you, all three of you maybe, just speculate on how do we get to a path towards adoption both on the private side, in industry, as well as on the public side? In a sort of a thoughtful and proactive way, how would we -- how would that happen? Go ahead.

(Off-the-record discussion)

MR. WINSTON: They're not independent, right?

MR. RAY: Right.

MR. WINSTON: I mean, the private sector -- and that was my point, the private sector is constrained of what the public sector is doing, right. They can't just -- there's sort of this Tesla fantasy. They can't just make cars and just dump them out there and say, go adopt them. I mean this is not how non-autonomous cars worked, right. You realize that.

The way we have cars out here is they still have to go through a Federal regulatory inspection, right, for safety -- you know, for safety reasons, and of course and there's obviously licensing, you know, and all that.

So, you know, this is not going to be something they can do by themselves, they're going to try to work obviously as quickly as they can subject to competition, but the government really has to take the lead, first getting the testing framework nationally.

I mean, you know, this notion, Marjory, that Mitch McConnell and Elaine Chao held up the legislation because of their concerns about AVs doesn't make any sense. If they were so concerned, why are they allowing the cities to do it? We have testing going on all the time now, so they haven't stopped it.

I mean they could have taken the lead and they didn't. It wasn't one of

McConnell's priorities, and I really do not know what Elaine Chao cares about. But the truth is, that's what happened, and it's a fantasy to think otherwise.

So that's where that has to happen. They need to take the lead to get that going, then once that happens then, as we know, this is going to be a cooperative activity, there's going to be a lot of learning back on that RAND Study that says we need to go X-trillion miles, which is ridiculous, and it's a terrible study, there's learning by doing, right.

You're not just going to have to go a trillion miles, each time you drive you're going to learn a lot. So that obviously is going to cut down the amount of time you need before these things will get you get well.

So the point being is that then we have that secondary time when they're testing and they're learning, there's obviously going to be some cooperation there. I'm not quite sure how long that will take, you know, it depends who emerges as a leader, right, and how much politics will go in.

You know there are going to be low-end people that are going to try to slow things up, so that they're not going to lose, and then there's the final stage, so then the transition to broader adoption, and then the policies that facilitate efficient usage.

Again, all of this involves heavy involvement of the public sector, and you know the history, it's not great about what they do in terms of constraining efficiency, innovation and technological change.

MR. RAY: Marjory, do you want to answer that? (Laughter)

MS. BLUMENTHAL: So, I actually was going to go in a different direction, which I will get to. But I think what we just heard is that a reason we don't have a national framework is that we do have a situation where people are learning by doing, not quite let a thousand flowers bloom, but we do actually benefit by having multiple experiments, in multiple tart parts of the country, by multiple government entities, multiple companies, and so on.

And because they are all leading us in different ways nationally and

internationally, we are learning by doing, and although I haven't dwelled on the subject, I think that that actually provides a basis for not jumping in with a Federal intervention that might be poorly informed and poorly formed. That's my response to my colleague to my left.

But I think in terms of how might we move forward? It is interesting, you know, that there were some references by Derek Kan to liability, and liability is driving many people to assume that when these vehicles come on the road they're likely to be deployed as parts of fleets.

You know, we can talk about Tesla all we want, which is making an individual consumer retail play, but we're talking about vehicles where, if that sensor stack is not well maintained then there is a risk that the vehicle will not perform as it is supposed to do, and if there is no human driver then the only people who are going to be blamed are the owners, operators, developers of the fleet.

They have a lot of incentive to get it right, and I think that is how we're going to see some of the initial rollout.

MR. GEDDES: So, great. So to review, the question is how do we get adoption?

MR. RAY: Yes.

MR. GEDDES: And now we go back to Cliff's point that all the infrastructure assets that are discussed here are publicly owned, the states are owned entirely -- the interstate highway system is entirely owned by states. I don't think there's a foot of it anymore that's owned by the Federal Government.

There're city streets, there're county roads, all these assets are owned by some public owner. If there's -- not owned by anybody let's get some free infrastructure, but of course they are. So you have to deal with public owners, so one thing that concerns me about these discussions is it was alluded to on the last engineering panel a little bit, is about the public ownership of the infrastructure assets.

So to get any of this stuff deployed in a serious way you have to take their

interests, and their incentives, their budget constraints, et cetera, into account.

So, you know, running the Infrastructure Policy Center for the past 10 years at Cornell, you know, I love these people. They're all wonderful, they are risk averse. If you're the state highway official the worst thing for you, is to see that something about the highway system on the front page in the newspaper tomorrow, you bear all the downside but you don't bear the upside.

They're budget constrained, so if you go with them to a proposal to spend money it's probably going to, you know, go in one ear and out the other.

So what, I'm going to launch a term that I would like everybody to keep in mind, it's called "value capture", okay, I don't know how many people have heard of value capture -- but you've heard of it. It's a great -- I know Baruch has heard of it. It's a great term that is gaining traction in infrastructure policy.

So the idea is that there's enormous value in everything we're talking about, that the value is latent in autonomous vehicles, there's safety value, maybe congestion reduction, et cetera. The question is: how do you share that value with public sector officials in a way that they benefit from the adoption?

If I have time for a quick example, from my own town of Ithaca, New York, in Upstate, we had a hundred-year -- and I love sewage treatment plants that's what I do -- we have a-hundred-year-old sewage treatment plant, you know, the same thing with the big settling pools, and skimmers, et cetera, tremendous methane dispersion into the atmosphere, methane is a bad greenhouse gas.

Johnson Controls comes in and says, hey, folks we will install a methane digester, which is a giant white sphere larger than this room, that will capture the methane as it's processed, we will use that methane to turn three or four, it's called micro turbines that turn at 120,000 RPMs.

Those micro turbines will produce electricity for this plant, enough to cover the whole cost of the electricity for operating this plant, and we will install that technology to

you, the city of Ithaca, at absolutely no cost.

The way we pay for it, is allow us to capture some of your reduced electricity bill. Allow us to capture some of your reduced electricity bill, we'll bond against that and raise the money to install the technology.

I got a tour of the plant, it's so successful the city of Ithaca Sewage Treatment Plant is selling electricity outside the plant onto the grid. Johnson Controls, or somebody's going to install another methane digester.

Its neighboring counties are actually bringing waste to be processed, paying the City of Ithaca to do that processing, and I believe the water discharged in the Cayuga Lake is actually cleaner than it was before.

So, I urge us to think about applying that model to driverless cars. One super valuable thing are the streetlight poles, right, the poles themselves you can put up cameras, 5G, et cetera, you install LED lights instead of pressurized sodium that will give you more lumens at a lower electricity cost, just share some of that with the public sector owner so that they gain and say, by the way, we want to, you know, help us with the autonomous vehicle thing.

So think about those win-win situations that don't require the public sectors to spend money, and are low risk, and I think that's -- that it's part of the solution.

MR. RAY: Thank you, Rick. So, I will actually want to follow up on that point. We've heard a lot about infrastructure today, and you're an expert on infrastructure financing and -- tell us a little bit more about how smart infrastructure in particular could develop in the future under new and novel financing arrangements that were possibly not possible under the kind of -- the older model? What new opportunities does this, all of this new technology bring on the infrastructure side?

MR. GEDDES: Yes. So, great question. I mean I think that a lot of old structures should be relied upon first and that's -- one of the things I've learned as a, you know, sort of observer and commentator on this area is that everything in this sector is risky.

Any time -- just think about building a bridge okay, kind of a common thing, that everything about that is risky.

There's design risk in the bridge, there's construction risk, there's geotechnical risk, there's strike risk, there's operating risk, there's acts of God, force majeure risk, you know, I could go on down the line.

And so the companies involved in this, you know, risk is like a hot potato, they want to get rid of it, right, and so they're trying to distance themselves or control the risk as much as they can so a disaster with the infrastructure doesn't bring down the parent company.

So what they do -- this is lawyer intensive -- is they form SPV, special-purpose vehicles, which are these legally created entities that manage the risks, they issue debt and equity themselves, they are the actual legally contracting entity. So, to deploy this new -- trust me this is all risky -- what we've talked -- everything we talked about today is risky, to deploy this and that's -- the key thing is that the debt issued by the special purpose vehicle is issued by revenues coming into the SPV only, so that's called project financing.

So we would use project financing structures particularly. One of the interesting things I'll just -- just a footnote -- is bond life. In other words the bond market usually has 5, 10, 15, 20, you know, very fixed-term bonds, and I think that matching the bond life to the payback is getting more flexibility in that bond market, whether it's taxes on municipal bonds, or taxable corporate bonds, is something we could do to help facilitate this.

But what I would do is go back look at -- you know, there's a whole world of finance of this, infrastructure financed on Wall Street and elsewhere, take that expertise and think about how to modify existing project financing models to adapt to the new technology.

MR. RAY: Yes. Cliff, go ahead.

MR. WINSTON: So, so an interesting thing historically, in this country and probably everywhere else, its modes, virtually all of them lead infrastructure. We first had cars before we had roads, we first had planes before we had airports, and air traffic control,

and so on. And that is how I think it's important to think about how autonomous vehicle infrastructure will evolve.

We're going to first have the vehicles. They're going to continue to get better before we get the technology and infrastructure to accommodate them. Now, what's going to be interesting though is that effectively the pressure that autonomous vehicles are going to put on infrastructure providers.

Normally people tend to think about financing which is not unreasonable, however, there's to be something else they're going to have to think about, and that is the performance of their infrastructure, because if it performs badly it'll significantly compromise autonomous vehicles' performance. If it performs well it'll enhance autonomous vehicles' technology performance.

Now, there'll be a number of ways, both economic and technological, that this infrastructure can succeed. As I noted, just messing up on pricing and investment in things that should have been done with non-autonomous vehicles but were never done cost us quite a bit, but that's masked over the fact that we spend so much money to cover it up and have trillions of dollars invested. That really will show up with autonomous vehicles.

We will have induced demand, so if they're concerned about congestion and you don't introduce congestion pricing that's obviously going to compromise to a significant extent what autonomous vehicles can do.

If you do not get build the roads properly and you have a lot of potholes autonomous vehicles aren't going to like that, and that's going to really hurt their performance as they try to figure out what to do.

If you're going to blow the chance to optimize on capacity, and now making lanes thinner or narrower which you now can do instead of making them wider, anticipating there'll be free flow traffic that never materialize, that's going to waste a lot of capacity. That's just on the economic side.

On the technological side that's going to be harder because you're then

going to have to start interacting with the vehicle and say, okay, at various levels, at the street level, optimizing stoplights, things like that.

The question I asked earlier in the day was, basically getting at the point, we have not changed traffic like technology for decades, they are based on the assumed traffic flows that exist. So when you show up at 2:00 a.m. and see a red light there's no one around, and you're wondering: why isn't this thing turning green or blinking red, you can thank the decades-old policy that is still used to do that.

Obviously that's the kind of thing we want to be changing with autonomous vehicles. Then more broadly trying to coordinate then massive movement of autonomous vehicles on highways, and so on and so forth, that now is open for a lot of different explorations.

Utah is partnering with the private sector entity, Colorado is partnering with a private sector entity, all trying to look at best ways to do this kind of thing. But I think ultimately of the autonomous vehicles getting out there, they're going to put the push on the infrastructure to develop and then the competition will exist, and we will see what best practices are and we'll see the costs and benefits of who succeeds.

MS. BLUMENTHAL: I would just add that picking up on the point I ended on about safety being a system, a lot of what's going to happen with AVs is going to fit into a larger system of activities. So, land-use planning is going to change. You know, some of that pressure on road use that Rick had talked about may change with AVs because they can go in sort of bizarre routes and park themselves, and do things that we don't expect to see with people, and cities are going to plan for that.

Cities are in fact, as you've just heard, working on their traffic management systems and between them and the interactions with AVs we now have new cybersecurity concerns. That's another risk that is going to drive investment, because if you don't attend to that you're going to have huge problems. So I think systemically we'll see a number of motivators for investment and for creative responses.

MR. RAY: So let's talk more about safety, and it's given that Derek and Ken both said it's kind of the number one priority, and you mentioned this before. So, we're now in a world where say 40,000 fatalities a year on U.S. highways, and there's one crash in Arizona and Uber shuts down their program.

If there is such an emphasis on safety how are we going to get there if all technology is very preliminary, and there's going to be some growing pains, how do we -- how do we overcome that when -- even if there's -- and there's a long-term benefit, but there's going to be short-term costs. And how do we -- how do we as a society get there?

MS. BLUMENTHAL: Well, you heard Derek Kan that projections have changed for when we're going to see significant deployment, real commercial deployment. And I think that that is a reflection of industry recognizing that the problem is harder than they thought it was. And so having this internalized adaptation is going to be critical.

I think because of the competition that I mentioned before among developers, we have yet to see a true sense of shared fate that is it wasn't: oh, Uber had the problem therefore I'm clean.

Everybody suffers, public trust, and confidence suffers when there's any incident, so one of the things that my report had recommended is that when there is an incident, because it is so uncommon. that people share information.

And again you heard Derek Kan talking about an aviation example, but the more people in the business share information at least among themselves, arguably also with the government, the more we will learn from these scarce incidents, and be able to progress together. But the most important phenomenon that we see now is that people have lowered the temperature of their enthusiasm and the hype, and I think people are self-moderating.

MR. GEDDES: Can I just add?

MR. RAY: Yes, go for it.

MR. GEDDES: So, to me -- this is a great, great question, Korok. So, to

me it's analogous to what I tell my policy students at Cornell about type one versus type two error at the FDA. Where type one error is you release a drug that actually harms people, type two error is where you don't release a drug that actually helps people.

MR. RAY: Right.

MR. GEDDES: And you see the type one error, but the type two errors like an opportunity cost that you don't see. So, I think part of the role of policy people is to emphasize the cost of not having a safer autonomous vehicle.

So, you know, the weird things that I calculate everybody -- many people up here probably have been to the Vietnam War Memorial, and I look at all the names on that wall, the terrible loss, it takes us about 18.23 months to kill that number of people on U.S. roads and highways, okay.

So that visualizes it, they're disproportionately young people, just horrible carnage on the roads today. So every week, every day we don't have this new technology deployed, all these young people, those crosses you see on the highways we're being lost because of human -- the majority is human error.

So I think the jobs of economists is to hammer on opportunity cost, use the type one versus type two error, you know, analogy and just say, look, yes we know someone was killed in Arizona, it's terrible, it's horrible, but we have to -- this is better than the massive, you know, people drinking, and people texting, and everything else that's causing this carnage on the roads. And I'll just keep stressing that.

MR. WINSTON: So, when Derek was mentioning his example, I don't know if any of you market-oriented people were thinking the same way I was, but he's talking about airlines landing and one of them having a problem and saying, you know, why can't I share that with all my fellow pilots, where was the FAA? When did the FAA take note of that?

What if the FAA says, hey, we'll keep track of all of this when you have a problem, and we are in charge of promoting safety in this industry, and we will make it aware

to all of you, you know, when a pilot has a problem at one of our airports, and then hopefully that will help induce cooperation? Where were they?

Why do we have to have the private sector say, hey, why don't we organize and have a cooperative effort where we solve this problem? I'll give you my answer in a second, but this is how things work when you're dealing with the government. I mean these are things that are occurring even now, already there have been coalitions of various automakers and technology companies, now, in autonomous vehicles to promote safety, okay.

Whereas, again, and I don't know why this hasn't gotten across, the Federal Government has to actually authorize the standards for autonomous vehicles for them to be sold, they can't unless that happens.

Congress authorizes NHTSA to do it, that's what we need the legislation for, then they can sell cars. They can't do it before that, all right. They have to take the lead that's just the law, okay.

And that's really what we should be looking for but we're not getting that kind of leadership, all right. Ultimately it's going to come in pushing from the private sector to do it, and they're frustrated, because they really would like the public sector to engage, but they don't.

Why? Status quo bias, if you look repeatedly, decade after decade, policies that should have changed long ago they don't, and then when you have technology being such a challenge as it is, these guys don't know what to do, and that's what -- this is not new, this has been going on forever, and it's probably going to continue to go on forever.

It's going to be an uphill fight, but hopefully through these demonstrations, and again this is a global effort, so it will get attention in this country too, we'll get somewhere, but it's going to be a lot harder than it has to be. Defend the government. (Laughter)

MS. BLUMENTHAL: I think -- if I recall correctly, Brookings has published a

lot of work talking about regulatory capture, and the fact is in a lot of industries where there is regulation the government can never understand the world as well as the people that it is trying to regulate.

SPEAKER: True.

MS. BLUMENTHAL: I cannot forecast well enough what will happen in this space but I have seen and read enough about what happens when regulatory policy goes wrong to understand that if the whole system, the industry, the governments at different levels, if everybody goes a little slower maybe we have more of a chance of getting it right.

MR. RAY: So I have one more question for the panel, and then we'll open it up. And the question is about sort of long-term cost and benefits from autonomous transportation, in particular for, say, the labor market and the capital market.

And so what are some things maybe we haven't discussed yet of benefits or costs of autonomous technology, say for all of the truck drivers in the U.S. today, or for the price of land across the country. Can you either speculate on that or offer any opinions?

MR. WINSTON: Okay. So I actually will answer that, but let me fill that in. You know, I may -- I told you that there's an estimate of GDP growth. Okay. The intuition, I'll give you one intuition, Boeing -- let me go back further. Let's go back to the Stone Age when we did not have a transportation system, okay, so all your production was, you know, where you lived in your cave. You know, you worked where you lived in your cave, you know, and so on and so forth. Okay.

What did transportation do? What it did is enable you to get all the benefits of modern economy, economies of scale, you can produce and sell to many places, product diversity, you didn't have to eat the same -- I know what you ate then -- bison or something.

You know, competition, diversity in labor, you know, all these markets opened up, so you can think of infinite congestion in the limit, that's the Stone Age, you can't move, all right. So as you get incremental improvements in congestion basically what you're doing is opening up all the things in an economy that we get from a transportation system,

and that's what autonomous vehicles will do.

Not just the transportation system, but it's going to open up all these sectors. Now, admittedly we're not where we were in the Stone Age, but we obviously suffer from pretty extreme congestion that affects everything, labor, trade, competition, and so on and so forth.

So the hope with autonomous vehicles operating efficiently with the right technology and the right economic policy is we will get these congestion improvements that'll make the whole economy come alive even more.

Now, it's disruptive. Again, governments don't like it, labor markets some do -- some parts do some parts don't. Obviously labor gets hurt when there's capital labor substitution, okay. So the truck drivers obviously in this -- in the seat, they're out of work, all right, and that's the offsetting part, or the negative part that people get nervous about, it's disruptive.

Okay. But there are two other parts that offset that, that are very important. One, productivity increases, output goes up more. So even taking the technology as constant, you are at least going to do more, and you need at least some labor, you're not completely substituting away from all labor to produce that output.

But here's the big-ticket item. New occupations, all kinds of things will open up with new technologies, jobs that we didn't have before, new things we didn't have before, and what's important is with the growth of the tech companies in the tech economy most of the new jobs or a large fraction of the new jobs are in new classifications of occupation.

So you put that all together and you're saying: yes, there will be some loss in employment from capital labor substitution, but productivity increases and the creation of new jobs are quite likely to offset that, and obviously there are going to have to be the adjustments, as there always are with a new technology.

MR. RAY: Okay.

MR. GEDDES: So, I want to address that. I agree with everything Cliff

said, Cliff has done more analysis on this, but just kind of a broader -- a broader view. If you think about transportation in general, you know, it's been treated almost like a utility, and the thinking about it. So nobody should go without clean water, nobody should go without electricity, once we have that nobody, you know, should go without a number of other -- maybe communications, nowadays nobody should go without heat and, you know, that's just I think a great part of American society as we sort of believe these basic needs should be met.

And that's been true for transportation for a long time. So, in the early part of the 1900s there was something called the Farmers to Markets Movement, and this was the idea that farmers had all these crops that they were growing more than they could ever eat themselves, and they wanted to get it to market.

But a lot of the roads were dirt roads so when it rained they couldn't move their crops to market, so there was this rural road movement to try to get the farmers to allow them, you know, to get their crops to market.

And then the very name of the interstate highway system is to connect the nation together, sort of the old postal service notion of binding the nation together, except it was done through a -- you know, a system of interstate highways.

So as we, you know, move to this new technology; I guess I'll just tell another quick story. Everybody here who is in D.C. in January should go to the Transportation Research Board Meetings, the TRB, and I love that meeting, right. And they have an exhibit hall there, they have all cool -- they had the autonomous car last January. So early January they had a car moving back and forth, you know, I think you could ride in it.

But one time I went there, and it was a couple years ago, and there were these guys, kind of interesting looking guys, standing next to a vehicle that was on one of the earlier slides which was an autonomous bus maybe or six- or eight-seater, right. And, you know, he said this is interesting, but (inaudible). I said, oh. They said that we're running this around Boston, right, and we're running it -- I said, you know, really that's really cool.

And I said, but doesn't that -- there's an MTA in Boston, don't they have exclusive rights to operate buses in Boston -- yeah I'm a policy guy right -- so how do you how do you overcome this? And they said, oh, we're running our autonomous bus where the MTA in Boston doesn't serve. I'm not indicted them, it just doesn't serve these underserved areas.

And he explained to me the way the app work. You have an app and they say this autonomous bus -- you are two blocks from this autonomous bus stop, five other people want to ride this bus from A to B, come to this corner in six minutes, and this autonomous bus will take you from A to B, okay, at a very low cost.

And so that's how they were doing it. So there are these gaps, we don't think any neighborhood should be cut off from some form of transportation. There are these gaps in our system that I think autonomous transportation is filling, right.

So I see that. Now, how does that get back to your jobs question? A key thing is access to jobs. It's that, can people get to jobs? In New York City where I spend a lot of time, it's really expensive to own a car, right, so you have to have some form of public transportation to get to a job, and I think that if we, you know, creatively use autonomous vehicles, they can help solve that age-old transportation problem of really providing universal service. And that's just one example.

MR. RAY: Okay. Marjory did you want to say (inaudible).

MS. BLUMENTHAL: I would just add that when it comes to -- when it comes to trucks we benefit again from the fact that technology is not changing as fast as people think. So if you talk to people who are in the trucking industry they talk about various assists, and they talk about first assistance in the long haul portions, as opposed to the, you know, getting on and off of a highway, and so on.

There are also people who will talk about how the age structure of the commercial driving population is relatively high because those jobs are not attractive to younger people. So there can be problems getting enough people to do today's trucking

jobs.

If you add that together with slower than some people would like to see deployment, you may have a self-correcting problem, which is not to say that some people will not lose work and certainly opportunities will be foreclosed, but as the new kinds of opportunities that Cliff mentioned come online, again the system may regulate itself and I end up being a little bit less worried about trucking than I do about other kinds of jobs.

MR. RAY: Okay. Let's open it up to questions. I know people might be nervous about asking the first question, so let's go straight to the second question. (Laughter)

SPEAKER: Thank you. Actually I would like to ask three questions in one minute if it's possible. Marjory Blumenthal talked about the AV timing. Aren't we asking too much of AVs without providing a lot of support from all of us? Because the assumption is AVs are super intelligent machines looking for zombies on the unorganized asphalt, when we have urban planning that could organize the urban mobility by speed and by modality. And we have psychologists, and educators that could educate the population in terms of behavior.

The second question for Rick, if I may: land value capture, and public goods, and public value. My overarching principle is if you have an agency that provides a public good it should have an endowment such as land-grant universities, in this country's long tradition, such as foundations, such as metro that is land, public transit is one of those. So you can use land value capture like Tokyo and Hong Kong, in order to provide that additional support.

The third question to Clifford Winston. Mayor Bowser wants to spend a ton of money to buy nine electrical buses. They would be -- no, no, I have a lot of respect for the Mayor, this is my personal -- but that would be expensive to buy, it would be expensive to operate, and logistically difficult. Wouldn't it be better to use a pilot on those grid corridors and have something like Navya, you know, pilot the shuttles, electrical NAVs. Thank you

very much.

MR. RAY: Yeah, just to give everyone a chance. Maybe just answer one of those questions, so just one of you, to pick. Yeah.

MS. BLUMENTHAL: I think in response to your question, when I was talking about a systems approach, or referring in response to something that Rick had said to land-use planning. I agree that there are many kinds of planning, many kinds of personnel that have to complement the vehicles themselves. It's never just the vehicles themselves.

And, you know, we heard earlier about public awareness, even some of that work perhaps, it's the psychologist you were referring to, to advise the public on what it is they can expect. You know, there was a case in Boston where a consulting group got together with the city government, I think it was, and had an AV petting zoo.

I mean that's just a way to, you know, get people exposed because you have to pay money to get into TRB, and that we need to help the rest of us.

MR. RAY: We have to be maximizing?

MS. BLUMENTHAL: Yes. Yes.

MR. RAY: Yeah, let's just keep it quick so we've got the --

MR. WINSTON: Pretty quick.

MR. RAY: Yes.

MR. WINSTON: I'll alienate the rest of you. Public transit was an experiment in this country, okay. Initially we had private transit that was before public, all right. It's been a mistake economically as it turned out, it's an experiment that failed. From an economic perspective if you look at the user benefits and even account for any savings and externalities, and congestion reductions, and compare that with the cost and now the huge and ever-growing subsidies they get, they are not socially desirable; all right.

And the advent of network transportation companies like Uber and Lyft is just putting the final nail in the coffin. Transit was just a mistake, it will be one of the benefits

of autonomous vehicles is it will make it increasingly clear that those systems should be eliminated, and that we will have effectively personal transit companies.

So I am not supportive of any spending on transit, if anything I think we need to realize that subsidizing people like myself, you know, from coming in from the suburbs really just has not worked out, and that the mobility that autonomous vehicles will get us will give us the final push to get rid of those systems.

MR. RAY: Okay. Let's take the next question -- let's see -- how about right there? Yeah, you can stand up so we can -- yeah.

SPEAKER: Hi. I'm Eta Nahapetian from Fairfax County Virginia, and we are working on trying to get an autonomous shuttle happening over the next few months in Fairfax, and we're looking -- and we're focusing on making it a transit solution, because we think the opposite, and that we're hoping that these AVs become -- help us get to a transit solution so we don't have this crazy increase in traffic. As you might know Fairfax has a lot of traffic.

So we're really struggling with some of the regulatory issues. And going through figuring out how we're going to work through the NHTSA waiver process. We're partnering with Dominion to -- they're going to help purchase our vehicle but we're -- as we're trying to jockey to figure out what kind of vehicle we're going to get, we are struggling with the NHTSA waiver process.

And I guess maybe this was a question for Daniel -- for Derek Kan, but do you know if there's any kind of movement to not make it such a black box? You know, it is a black box to local government to whether -- what the regulatory requirements will be.

MS. BLUMENTHAL: The simple answer is. I don't know. But that sounds like a question for the Conference of Mayors or League of Cities who I know are looking at some of these issues.

MR. RAY: Okay, great. Now, our next question up here in the front; yeah, great --

SPEAKER: Thank you I had a question about the safety elements of autonomous vehicles. If you look at sort of everything the USDOT is saying, and what a lot of the OEMs are saying: safety first, safety is our top priority, presumably from the OEMs that's because they see a consumer desire to hear that the vehicles are safe. But then like Rick was saying earlier, is we already accept the vast amount of fatality on the road as consumers.

And so there's something about our personal utility choice that we decide to make these trips when we know the statistics and we know how dangerous it is. So how do you reconcile that moving forward? What's the barrier there from an -- I guess economics perspective, which I don't know anything about? And how do we push past that?

MR. GEDDES: I mean I guess, to go back to the FDA, I'm old enough to remember the AIDS crisis and, you know, there was the AIDS Cocktail and the -- you know, it wasn't 100 percent solution, but the FDA was holding up the deployment of those drugs. And the gay community got together, and they lobbied, and they demonstrated, and they said, look, you know, some of us have AIDS and this drug is available, you know, let us have it, right.

So I would take -- I mean it's a heroic analogy, but I would take that -- and again I think economists are not vocal enough in pointing out opportunity costs. This is something we cover in the first week of Econ-101, right, it's the things you do see, you know, which are the people who die from the AV in Arizona, and the things you don't see.

The things you don't see are the people who would be alive today if they had had an AV, instead of the human error that's killing, you know, 30,000 people every year. And so I think the role of the policy people, and the economists in particular, is to be much more vocal about the opportunity costs.

And to say, yes, fatalities are terrible but, you know, in the deployment of any -- I mean aviation was like that early on, it wasn't long after the Wright brothers flew, that the first person was killed in an airplane crash.

So, you know, I'm not minimizing that harm, but I'm saying we have to stress the harm to society of not having the technology deployed, and these regulatory holdups are killing people. Yeah, I could give you other analogies, but you get the point.

MR. WINSTON: What you're getting at though that's important, is the notion what we call heterogeneity. You see there isn't this "we", we're all different. In other words, when you look at the breakdown of auto fatalities what do you see? You know, drunk driving, right, not wearing a seatbelt, texting, it's what we call heterogeneity.

All right, I'm going thrash the engineers for a second. There was a question about what major one should have to do this stuff? A little econometrics wouldn't hurt.

This is what the Engineering Safety works, it's just awful. They go out and they get police accident reports, right, and they fit models to what we call severity, all right, and they use the data on the police accidents reports: Were they drinking? Were they speeding? Was there a hairpin curve? You know, all that kind of stuff, right, and they draw results from that.

Well, the obviously dumb thing about that is this self-selection, right, you only -- you're in that sample if you got into an accident, right. It's not a random sample, what you'd want is a sample that has everybody, and most of those people don't get in accidents, because they take actions, right, to prevent that.

That's what autonomous vehicles are doing, they're eliminating the heterogeneity, all the dumb decisions that people have made to self-select, and put themselves out in a snowstorm, you know, when they run into somebody. You know, or after they've been drinking they run into somebody, or run off the road, autonomous vehicles are going to say, sorry, you can be that way but once you get in us you're all the same, all right.

And that's really how we're going to get the improvements, it is we're cutting the heterogeneity making everyone the same.

MR. RAY: Okay. Let's -- yeah, go ahead.

MR. GOLOVIN: Karl Golovin. I'm wondering if a defining moment will come when apparently Tesla is working to set up its own insurance company for Tesla owners as well as its own collision repair because, you know, their cars are unique enough you don't want to take him to a -- you know, a traditional repair shop.

So once the owners of Teslas; and Tesla itself, through its insurance company, is willing to accept the liability that the assurance that they believe their self-driving vehicles are sufficiently safe, they're willing to incur the liability; won't that be a moment when all -- many Teslas are already on the road will become autonomous?

MR. WINSTON: They really need Federal approval for all this (inaudible), they can put anything they want in them; they cannot sell them and operate them.

MS. BLUMENTHAL: I also don't think that a model of complete vertical integration, where a company does everything and self-insures is scalable. So, it would be interesting to see what happens, but we've heard a lot of announcements and pronouncements coming out of that company; and then reality, you know, looks a little bit different.

SPEAKER: Yeah, exactly.

MS. BLUMENTHAL: So I'm not going to worry about that one.

MR. RAY: Okay let's take one in the front, yeah?

SPEAKER: It seems like this -- I call this NEAT system, Network Electric Automated Transport. It seems like these this whole NEAT System is based on having -- you know, a $700 mobile smartphone with a 40 to $80 a month data plan in order to be able to use it.

Is there a way -- you know, do you know -- you see the future being able to use a Hale System -- or a transport like this, without such a device in your pocket? Or it's assuming that you have to pay this expensive data plan and have this, you know, $400 iPhone thing in your pocket in order to use, you know, this network transport? That's my question. Thanks.

MS. BLUMENTHAL: Right now there are a number of models that people are experimenting with for different kinds of platforms, supporting mobility as a service. Some of them draw on public information as well as private information. This is an evolving space, and AVs are a part of it. My guess is that just as all of that kind of matching, and planning, and payment services, as that's evolving will also end up with different approaches to accessing it.

So if there is a digital divide issue, which is what I think you're getting at, then we'll also be looking at some alternative public kiosks, or other options. They may not be as flexible as having a device in your pocket, but ideally, for reasons that have been covered by others in government, local government will make that kind of thing happen. And we may end up with different kinds of technology innovation that will lower the cost of the communications and information aspects.

MR. RAY: Let's take the last question. Yeah, go ahead.

SPEAKER: All right. Thank.

SPEAKER: I'm sorry. A comment to Cliff, and a question for Rick; and I usually agree with Cliff but I think that -- I think the FAA was very involved in the ASIAS Program. I know they were very involved in developing a sister program which encouraged pilots to share information on near-miss accidents. There were so few accidents beginning -- around that time that you needed to start to extract information from near misses. And so the FAA encouraged pilots to do that, and gave them the same sort of indemnification that the ASIAS Program. So I would give FA credit for that one.

My question for Rick; Derek Kan said the Federal Government was neutral between internal combustion engines and EVs, this was in response to a question, internal combustion engines create carbon emissions that's another unpriced externality. Do you agree that the Federal Government should be neutral in the AV debate between electric vehicles and -- or hydrogen fuel cell and internal combustion?

MR. GEDDES: Do you mean, so you're asking my own personal view on --

SPEAKER: Yes. Well, your policy view as an economist. Yeah.

MR. GEDDES: Well, so I'm sort of in favor of electrification. I mean I think there's -- a lot of reasons to reduce fossil fuel usage, carbon dioxide is one of those, there's others. One thing -- and I think there's this sense that autonomous vehicles and electric vehicles are kind of converging, so just you know --

SPEAKER: Yes.

MR. GEDDES: Again, to underscore my earlier point, I hope that the takeaway from my earlier comments is that everybody thinking about this will think about real-time road pricing as the third piece, right. So autonomous vehicles, electric and road pricing is kind of -- kind of converging, right, so I am not fuel agnostic and, you know, it would take a little bit longer to talk through that, I can think of a number of reasons.

One thing though that I'll just say, that is a cautionary note and, you know, one of the great things about me as an economist studying infrastructures, I get to talk to engineers, a lot more different part of campus, and they're very concerned about infrastructure resilience, particularly in the State of New York after Hurricane Sandy. That was a big thing for our state.

And one of the things you do and, I'll just toss it out there. When you rely more on electric vehicles you integrate the transportation system with the electric system more profoundly. So if you were to -- if somebody were to take down the grid and you can't get a charge on your vehicle, that's a real problem, right.

And what we study hurricane after hurricanes, one of the biggest problems is actually -- the impact of the hurricane on infrastructure itself is big, but people can't get fuel after the hurricane. The pumps themselves at gas stations run on electricity, right. So, one of the problems, biggest problems, biggest impacts, is the days after the Hurricanes where people can't get fuel.

So, I guess I'm just cautioning to think about the impact of integrating your transportation system more deeply with your power grid, because your power grid then

should be much more -- stronger, resilient to either, natural disasters, terrorist attacks, cyber events, et cetera. So, I'll just toss it out there. But I personally am not fuel agnostic, I think there's reasons to favor electrification.

MR. RAY: Okay. We are out of time. So let's respect everyone's time. Thank you to the panelists. If you have further questions you can come up. (Applause)

MS. SNYDER: All right, we are going to get started now. Thank you all, first of all, for being here for this really exciting conversation about how autonomous vehicles are going to change the world and the ways that we need to change the world to accommodate them; and what role we want them to play in our world.

We're going to be talking about public policy. Policymakers have struggled to develop a framework for brining autonomous vehicles onto our roads. To catch you up quickly, the House of Representatives overwhelmingly passed a bill in 2017 which got bogged down in the Senate last year and died there.

The Department of Transportation, as you heard from Derek Kan, has published three versions of voluntary guidance, but no binding regulations. So, that's kind of the environment that we find ourselves in right now.

I'm Tanya Snyder, I'm a transportation reporter for Politico Pro. Hopefully you all subscribe to Politico Pro Transportation, or at least read morning transportation, and if you don't, come talk to me afterwards (laughter).

I want to introduce the panel, too. To my left is Tom Madrecki, Vice President of Supply Chain and Logistics for the Grocery Manufacturers' Association; Beth Kigel, Vice President at HNTB, and Director of their Smart and Connected Solutions program; Baruch Feigenbaum, Assistant Director of Transportation Policy at the Reason Foundation; and Jyot Chadha from the New Urban Mobility Alliance at the World Resources Institutes Ross Center for Sustainable Cities. She leads NUMO's work to develop partnerships on tech and mobility.

So, thank you all for being here, and thank you all for being here. I want to

start with this question of not just the ways that we need to transform our cities and places for autonomous vehicles, but the way that we can put them to work to make our cities and places the best cities that they can be.

We hear a lot of potential benefits that seem to solve a lot of the most vexing issues that cities have about congestion, emissions, safety, access, mobility; how can cities best put these to work so that, you know, we're not just, sort of, making space to accommodate what industry wants to throw at us, but that we are using them for our own purposes. And we can start with Beth on that, actually.

MS. KIGEL: Can you hear me now? Okay, great, so it helps to be flexible. Well, one of the things that I'll share with you about my background is, prior to coming to HNTB, I was a Florida Transportation Commissioner for seven and a half years, and I led a chamber of commerce at the same time for about seven years.

So I come at this from a little bit of a different perspective; kind of, a combination of policy, technology, and then understanding community engagement, and economic development, and quality of life issues.

So, first and foremost, I would say heard a lot about -- we all here today, we've been educated quite a bit, I think, on the things that we've heard. Think about some of the localities out there and how much they do not know and understand. In terms of what cities can do, cities first and foremost, can start to really become educated on the benefits and the risks of what is happening with autonomous and connected technology.

The other thing I would say, is to be open to actually bring pilots into your city. I think that's critically important because not only is it something that might help the AV entities, but it also helps you learn more about your city; where the pitfalls are, and things of that nature. Where do you need to improve?

Miami and Ford had a really great relationship when Ford came in with their AV testing down in Miami, as you might expect a very congested environment, just an interesting place to test. So, great information for all to get.

I would also say that collaboration is very, very important as a city, and even as a county, between private and public sector entities of all kinds.

I led a chamber in Palm Beach County. We actually were able to immerse all of our entities in an education about autonomous connected vehicles, as well as smart-city technologies. When you start bringing together not only elected officials and administrators from cities, not only private sector participants, including hospitals and others; you start bringing all of them together, along with the Urban League and what have you, you really start to get an education about how these advancements can really advance a locality and be better for a quality of like, and, I heard earlier, competitiveness, because we are in a global market and how our quality of life stacks up, and what kind of efficiencies we have within our regions and our localities, the more competitive we're going to be as well.

MS. SNYDER: Great, whoever wants, take it next.

MR. MADRECKI: I think, just building on what you said, I think that one of the really important things to also consider as a city, you need to proactively consider the future deployment of AV technology is that this isn't occurring, or isn't going to occur in a vacuum.

And so, there are many different things happening all at the same, right. So, if you have just the tremendous, sort of, growth and demand for ecommerce delivery, for example. Prior to my role at GMA, I was the Director of Urban Innovation and Mobility at UPS, and so I would talk to cities all the time about the tremendous influx of demand that curb space, and the strain of that physical real estate asset in a city, and how that demand shift is happening.

You have the emergence of micromobility, you have the emergence of TNC, all of these things are happening, and so you can't just say, let's take the AV bucket, or let's just take the TNC development; all of this is happening at once. And so, as a city, I think you need to adopt this very integrated, proactive view.

MR. FEIGENBAUM: I would say, I think one of the questions is what about

cars? Because, obviously, cities have got concerns about congestion and about mobility, and as was mentioned, about the curb space because there's going to be a lot of competition.

And so, our approach at Reason, not surprisingly as a free-market approach, has been pricing. And I know it was mentioned a little bit on the past panel, but I think there's a lot you can do with pricing.

If you're worried about zero-occupant vehicles, sort of, the zombie cars, as they are sometimes called, roaming around, then you can price those vehicles higher. If you want to encourage carpooling, you can price those vehicles lower or not at all.

Now, we don't have a great history for carpooling in this country. There's a lot of hope, and Alain Kornhauser at Princeton has spoken on this, for those of you that familiar with him, that with some of the automated vehicles, and the improvements with ridesharing, and what we see even today with smartphones, there's going to be a lot more of that.

We also have to talk about the 800-lb gorilla, which is transit. And obviously, in some metro areas, New York, D.C., others, transit as we have it now works okay. I'm not going to go quite as far as Cliff went and say it's a total disaster (laughter), but it needs a lot of improvement in a lot of places and it's not great.

And I think automated vehicles can do a lot of that in terms of maybe getting rid of the labor costs down the road, looking at smaller vehicles, right-sizing. I think partnerships with the private sector is going to be important as well, working with Uber and Lyft for some of the low-density routes. We see that already with first mile and last mile.

So, I think that pricing for cars and figuring out how we can make transit better are two important things.

MS. CHADHA: I think I'll focus a little bit on what Tom brought up, which is on micromobility, and I'll just take a quick poll: how many of us have been on a shared scooter or a shared cycle? Okay, that's a lot.

The point of view that I think I'm coming from is that today we have that opportunity to start flexing our muscle, and start to have discussions and pilot an experiment on the topics that will be important when AVs are eventually on our roads, today itself with micromobility.

So some of the topics that are hot with micromobility right now is the use of space, and the allocation of space, is pricing, as you were saying, and thinking about what are the different models behind that; around regulations, around permits, thinking about market entry, and I think we really do have that opportunity today to start linking some of that groundwork for when AVs are actually on our streets.

Where micromobility and AVs differ, though, I think, is that in the current ecosystem that we have today, AVs could very well fit into the space that we have for personal cars. And I think that we do have the opportunity today; cities and other stakeholders, do need to come together and thing about how do we use this moment in time to really think about the goals for our cities, and what sort of cities we are trying to live in.

So, we would really push for cities that are active and are shared in terms of mobility; so, thinking about a 20-minute neighborhood. We think that, clearly, land use and planning play a really big part of making that happen, but a lot of these new mobility entrants are starting to add to the possibilities in that space.

So I really think that engaging on the topics that are at hand today gives us that platform to be able to get our cities into a position that we have the right sort of infrastructure, we have the right public/private partnerships, we have the right mode choices that we would want for different types of purposes and different types of populations.

MS. SNYDER: Picking up there a little bit, how as we think about remaking our infrastructure for a new autonomous era, how do we avoid some of the mistakes of the highway, where highways were built through low-income neighborhoods, where they accelerated sprawl; how to we make sure that we are working sustainability and social equity into that infrastructure?

MS. KIGEL: Going back to the point that I said, you have to start looking at that data, and the statistics, and putting them at the forefront, to really bring that to reality.

One of the things that I would talk about, since I am from Florida and I served on the commission, Florida actually is embarking on its Florida Transportation Plan, and they're putting some of those statistics right front and center, with all of the stakeholders that are looking at it.

So, looking at how many people live within a half a mile of a healthy food source, looking at how many live below the poverty line? How many households do not have a bank account? Actually, 8.4 million households in our country do not have a bank account.

Transportation in Florida is the third highest household cost for a family. 56.5% of our residents live within a half a mile of fixed-route transit. So that means the rest of them don't. So, we're actually putting those issues at the forefront and having those discussions so that is part of our overall transportation and smart-city planning.

Social equity is becoming more and more of a hot topic. I mean, it's a national discussion relative to this and others. So, the more leadership that's taken within our communities and our states, and etc. on this, the more we'll include those in our solutions.

MR. FEIGENBAUM: I guess I will just say, to be a little contrary in here, after the first answer, we have to realize, obviously the highway building era had some real problems in terms of building through neighborhoods. I mean, there's a situation in Atlanta where there's a highway that actually takes a curve when going straight would have been the cheaper and more direct route, because they were trying to separate the low-income minority from the central business district.

That's a pretty awful policy, and we certainly want to find ways that we don't do that in anything, really, again. And I think looking at the overall costs, you know, in some ways, the Federal government can actually be a problem here, because to the extent that it

is incentivizing certain policies.

When it was incentivizing highway construction with a large Federal share, cities and states were sort of doing what the policy designed them to do, which was build roadways even if it wasn't necessarily to logical places, or it wasn't the cheapest place, because there was that incentive there. And so, we have to make sure we're tapping the right Federal incentives.

But I will say, we don't want to forget that highways and roads in general move the mast majority of folks. Certainly, lower in cities, and certainly lower in D.C. and New York than at other places around the country, but even if the automated vehicles are shared, they are still going to be on roadways, and we have to make sure we have sufficient capacity for that.

MS. CHADHA: I think to add to these points, I'd also say that -- and I'm sure that this has been covered in depth through the day, I'm sorry I couldn't be here earlier -- but that we have the opportunity today to rethink what a vehicle looks like as well, and many of you in the room are engaged with that.

And so, we have that choice to think about wheelchair accessible, service animals, how are we going to build vehicles to allow for that level of access for all. But I think the point also goes back towards, is there political will, is there general will, what is our mindset around these topics.

MR. MADRECKI: And on the subject of political will, I think that -- and I'm going to go a little philosophical in this, but I think that part of demonstrating political will is also the ability to step back and to say that you don't make infrastructure equitable; you start with equity, and then you would sort of underline, or sort of think through, well what is it that you even want to achieve in the first place, or do you need that infrastructure to make that connection.

You start with that equity goal, and then your finding ways of moving people around, rather than just be, "Well, we need to build a bunch of roads because we need AVs.

Oh, by the way, we need to incorporate equity as a part of that." I think it's just like a philosophical reorientation.

MS. SNYDER: I think that's what I was trying to get at with that first question, also, of, what are the problems that we're trying to solve and we figure that out first, and then figure out how AVs can help solve those problems; rather than say, they're coming! What do we do!

I wanted to ask, maybe at the risk of fixating too much on Tesla, you know, Tesla has had several high-profile fatalities. Uber, obviously, their self-driving car that hit a pedestrian last March; how have these very high-profile -- and understanding that we have 37,000 deaths on our roadways every year, but these get a lot of attention -- how do these incidents change or impact the approach that cities or states are taking to regulating or embracing driverless technology? Start with you, Beth.

MS. KIGEL: I want to look at this first from a little bit of a different angle because we heard earlier today about how the OEMs are responding to this as well. I think what this is doing is, this is raising significant awareness that this is not as basic and as simple as many thought.

I mean, when you're trying to replicate the human mind and the decisions that are being made that way, it's very complicated. And so, actually, in talking to some of these OEMs, they have pulled back and they have really intensified their testing processes. Some of them have their own tracks, in fact, and they are putting them through much more rigorous testing.

And, one of the things that I think is recognized, we actually did a national survey that dealt with a number of items, including public acceptance. We found out that 52% of the people that we surveyed with the national sample poll actually believed that the greatest benefit from all of this is increased mobility for non-drivers. That's the number one benefit, and then safety is second.

But how the public actually responds, whatever their first experience is with

an autonomous vehicle, or any of these other modes that we're talking about, is going to really shape things. So, just like we heard earlier, if there is a fatality with an AV that's being tested on a road, that's going to affect the whole industry. There's pullback on that side.

I think we're seeing a little bit more patience within our communities, and on the public sector side, an appreciation of that.

MR. FEIGENBAUM: I would say, to directly answer your question, I hope they don't because I know it's easy to look at something like the Uber crash, and say, "Boy, this is a dangerous technology and we shouldn't do it." But as was pointed out in the last panel, 37,000 lives a year is a lot of people that die and even if automated vehicles are able to reduce that by 50%, that is still a tremendous improvement.

Now, we all hear the statistic, I guess it's 94% of crashes are caused by humans, and the reality is that while a lot of those will be gotten rid of, probably not all of them, and AVs may introduce some new crashes. So, I don't want to be too Pollyannic here on the options, but I do think a 50% improvement is better.

And I do think it would be helpful if there was some Federal -- the legislation, the Self-Drive Act, I happen to think it was a good bill; it wasn't perfect.

Now, I can say there were folks on both sides of the spectrum; folks who thought it went too far, and also someone who's worked on AVs for a while, who's name I will withhold, that said it thought it was an abomination. That being said, passing legislation is very challenging, and I think it will be a good start because the Federal government is the one that has traditionally done with safety, whereas the states do with licensing. And I think if we introduce new dynamics where states and local governments are specifically looking at the safety of vehicles, I think that's problematic for a lot of reasons, including the number of different modifications that the OEMs would need to make to vehicles.

MS. CHADHA: I think that just adding to that good point that you were making, you look at the number of deaths and accidents that have taken place with AVs -- you can count them on one hand -- you look at the number that are caused when you're on

a cycle or on a scooter, and then you sort of, like, in scooters you're probably getting to around the tens, and then cycles and cars and pedestrians goes up a lot higher; and it's always interesting to see the uproar that's caused by the one or the two, versus just the complacency with the every day.

But aside from that, I think that it's also interesting -- I can't speak for Tesla, but I think it's interesting with some of these other new mobility companies like Uber and Lyft, about how they're becoming, not a right-hailing company, but a platform company, right. Aside just from the new modes that they're bringing into their platform, and the new modes that they're trying to invent. It's also the one-stop shop for you to get your information and make your travel decisions, to make your purchases for transport as well.

And I think that when companies start thinking in that sort of holistic way about the entire transport ecosystem, that starts to position them -- or I'm hoping that starts to position them -- differently in the minds of people, rather than honing in on the, like that one accident that took place. Not to minimize any death, but I think that sort of thing is taken out of context, out of proportion.

MS. SNYDER: I want to ask also, and Baruch, we'll start with you because I want to ask about Federal regulation, obviously a lot of people think that the bad PR that goes along with a fatality is enough incentive for OEMs, for AV developers, to wait until the technology is ready. And like you said, when is it ready? It's an open question because even if they're going to improve things, but it's not, you know, they haven't worked out all the kinks if they are going to make it 50% safer, maybe it's ready?

Putting that aside, a lot of people also look at it and say, when we're looking at corporate accountability, we also have Takata airbags, we also have VW emissions cheating, can we rely solely on corporate self-policing? Is there a role for the Federal government to sign off on these vehicles before -- and I realize that this is something that no one in the Federal government seems to have much appetite for, but I think that when we see the kind of reservations that the public has about this, maybe it's a conversation worth

having.

MR. FEIGENBAUM: Sure, yeah, I think that's a very good question. Couple of thoughts, there are some -- obviously the state of California requires certain things that the auto makers have to do, and many of them are in fact testing there. And there is the self-certification platform where the auto makers do have to show that their vehicles are testing, and the Federal government does have to approve that. So, there's a little bit of that, and should there be more?

I guess I would say not at this time, and there are a couple of reasons for that. First of all, the Uber crash was awful, and I think nobody was more upset with it than me. And the reason I was upset with it is because I really believe that these companies have a responsibility to put safe products on the road, and clearly, that's not what was going on. This Uber vehicle was clearly not ready for primetime.

The good news is I think the market, and also the state of Arizona, punished them for that action, that I think was honestly far more punishment than they would have gotten from the Federal government if that was the only thing they could have gotten.

And the other challenge goes back to the part of your question, which is, does the Federal government know when these vehicles are safe enough, how do you prove that, how do you weight the cost benefit of potentially a loss of life here versus getting the car on the road sooner and doing the loss of life there; I don't know. It's hard to say.

I don't have confidence that the government would have enough information to actually weigh that correctly.

MS. SNYDER: No one wants to argue with Baruch on this (laughter)? All right, the Senate is about to markup their five-year reauthorization bill and getting back to infrastructure, Derek Kan said infrastructure is not an enabler, but potentially a blocker; that it is something that can get in the way of the deployment of autonomous vehicles -- though it can't necessarily, kind of, conjure them.

If we're about to set policy for the next five years of highway policy in the

United States, what should the Senate, what should Congress be looking at now that in the next five years will need to happen?

MS. KIGEL: Well, they might be able to look at what the state of Florida is doing, in fact (laughter). I know I keep going back to that, and I promised I would (laughter).

MS. SNYDER: It's okay, I keep going back to Tesla.

MS. KIGEL: But, actually, if you take a look at what Florida is doing now; legislation has been enacted and projects are being sought to actually embed the technology in new infrastructure. So, when we're looking at long-range planning, this is something that should be a part of that.

We've talked a lot about the life-saving elements of this. Well, if we're going to be serious about it, we're going to start including these things in our long-range planning, including things that have to do with the electrification of vehicles, and expecting those on our roadways, for example.

So, in looking at long-range transportation plans, how do you address that, and if that's the way the automobiles are going for various reasons, then you have to ensure that the infrastructure can support that, you have to find ways to start being forward-thinking about how do you handle things such as hurricanes, that we heard before under those circumstances. So, these are some things that can be looked at in transportation planning.

Also, we had a discussion about 5.9 Gig that happened earlier, what kind of leadership role can the Senate play in that to ensure safety over the long-term, and what have you.

MR. FEIGENBAUM: I would say there are currently grant programs right now for a lot of the smart infrastructure that I know Beth has been talking about, and I think those are important, and I think those should continue, that's obviously separate from the five-year authorization bill, but I still think that's important.

I also think there's value in the so-called dumb infrastructure, which is maintaining your roadways, making sure your lines are painted. And Kirk Steudle, who was

former Michigan DOT Secretary, brought up a good point, which is that, well, if you're in a cold weather place, your lines and your roadway pavement can get chipped pretty badly in the winter.

So, I think we need to look at some sort of partnership, possibly a public/private partnership, where state DOTs are going out and making sure that the maintenance for the self-driving vehicles is actually there. And that's not necessarily just the pavement, but it could also be if there's vehicle-to-vehicle; I'm personally more of a fan of cellular v-to-x, than I am of DSRC, I think that's kind of, well, we'll see where that goes, but I think that is really important and that has the advantage of, not only helping automated vehicles, but also helping today's vehicles and transit vehicles, and so shouldn't be challenging from a political perspective.

MR. MADRECKI: Just to add a little bit about targeting dumb infrastructure, and taking more of a nuts-and-bolts approach, but I do think that there's a degree to which that you can sort of write in some degree of prioritization about specific -- it could be a freight pinch point, it could be particular areas where spending money matters.

And so, a lot of states have done this in terms of right-sizing infrastructure projects, and thinking about, well what is currently in the pipeline and do you actually need the 90 million dollar project, or could you accomplish 98% of it with a 9 million dollar project.

So, I think there's ways of sort building in that philosophy of prioritization and then right-sizing into how the actual reauthorization is structured.

MS. CHADHA: I'll just pick up on the point that Beth was making about hurricanes. And I am wondering what the opportunity is to look at funding resilient infrastructure in cities and marrying that with the recreation of transport infrastructure that's needed as well.

And I think that there is common cause with a lot of these new mobility platform companies that are looking at streets that are slower, that are looking at re-thinking street allocation and I think that bringing some of these moving parts together can actually

spread that forward.

MS. SNYDER: I've been sitting here trying to think whether I want to go down the rabbit hole of 5.9 gigahertz that you brought up Baruch, let's go there for a minute.

The FCC is still kind of in this decision-making process about whether to reserve this kind of safety band for vehicle-to-vehicle or vehicle-to-infrastructure transportation communications. it's very underused right now.

There's also this kind of raging debate about what is the right -- maybe it's not even raging anymore, maybe it's settled -- that the original DSRC technology that the Federal government had, sort of, chosen, is not the right one. DOT now wants to be tech-neutral and aside from that, most of industry has embrace the new technology.

So, right now DOT has just chosen to stay out of it. They have kind of frozen rulemaking on that. Is that the most helpful thing for them to do, to just stop. Or, do they need to, at some point, just say, this is the policy, and move forward. Because it does seem like this limbo is more harmful than having new policy.

MR. FEIGENBAUM: The answer to your question is, yes. For the time being I would say -- because I don't think it's settled -- that they should stay out of it; but yes, at a certain point in time -- and, of course, I wish I could tell you when that time is, and I don't know -- we do need to choose a technology because we can't just go on this forever.

I think the rationale for staying out of it right now is that as it stands currently, DSRC, would be more effective, because 5G v-to-x is not ready for primetime. But many people expect that within a few years, 5G with v-to-x is going to be the better technology, but because, of course, we can't predict the future and we don't know, I think we shouldn't be making a decision just yet.

And there are -- I don't want to trash DSRC because there are advantages of DSRC, Europe is doing a lot with it -- it's just that when I look at the 5G versus DSRC, DSRC is going to require a lot of government funding and spending. And, at a time when, honestly, we don't really do a good job of maintaining our roads, sort of the classic, I just

don't see the political support there. I really don't.

It could be a great technology in a laboratory, but in the real world I have some concerns, and I think with 5G in v-to-x, you can get the private sector to pick up a lot of those costs and it's a benefit. I would say I am generally supportive of keeping the wireless spectrum in the DOT.

Now, I do think at a certain point in time, we need to show in the transportation sector that we're really going to make good use of it because, obviously, there's competing demands right now; but I'm not just willing to seed it to the FCC because it hasn't been used yet. But I do think we need to make some progress there.

MS. SNYDER: Anyone else want to weigh in on this? Okay, that was long enough for that (laughter).

I'm curious, also, about the role of the private sector and partly in some of the infrastructure upgrades, perhaps electrification upgrades, that need to happen to prepare for the autonomous era.

You know, is that something that the Federal government should be doing, or is that something that the private sector, that these companies need to do themselves if they want to roll out, for example, electric vehicles, that they should be in charge of figuring out of how to also roll out electric vehicle charging stations. Whose job is that?

MS. KIGEL: Well, I don't know that it's limiting, that it has to be the private sector or the public sector. I think it can also be partnerships between the private sector and public sector. It's just like what we were talking about before; there are certain conditions and situations for electric vehicles and electric charging stations.

If those were going to be installed and you have a significant amount of your population dependent on that, then you have to make sure that you have a resilient infrastructure that can accommodate that.

So, when it comes to the overall resiliency and safety, that's usually something that is a public sector responsibility. But I think you can work very closely in

partnership with the private sector because there are definitely some benefits. Even benefits from the standpoint of if you're implementing infrastructure that includes sensing technology and data collection technology and what not, that data that's collected can be very valuable, also, to the private sector.

And that goes to a whole other discussion about data generation, data sharing, who owns it, that sort of thing, but I'm not so sure that that is a singular answer. I think there can be a tremendous amount of partnership in that.

MR. MADRECKI: And I think inherently, it almost has to be a partnership. Fast charging a Class 8 tractor trailer essentially requires the same amount of energy that's used in a single data power at Walmart.

So, even if you were going to have a fleet of Class A trucks, you sort of need exponential demand that you're putting on the power grid which would seem to apply that if like, let say my former employer UPS wanted to roll out a bunch of trucks, we might need to coordinate with the utility and the city and others to sort of create an environment that's actually conducive to us doing that.

So I think there's a lot of interplay and potential to work hand in hand to bring different technologies on line and structure rates appropriately and provide that infrastructure where necessary.

MR. FEIGENBAUM: Yeah, in theory, the private sector should do it, but I see nothing wrong with public/private partnerships along the lines of those just mentioned. I think those are a win-win, and I think those are a great way to get it done.

MS. CHADHA: That's an interesting question and I was thinking back to two examples. One was Bird's announcement to allocate a billion dollars last year. They made that announcement towards the creation of bicycle lane infrastructure in cities. I'm sure a lot of you remember that and then how, I think, six months later, if I remember correctly, that program was closed. Not to point out Bird in particular, but I think that there is skepticism, and maybe healthy skepticism, when private sector is pushing for some of these

infrastructure changes.

But then, on the other hand, you read cases about how some of these new mobility companies are working with local communities that have been historically neglected in terms of transit investment, and how they're working at quite a grassroots level to help bring infrastructure, whether it's the docked bicycles, or other types of infrastructures into those communities.

So, I think that you're right. It's probably not a straightforward or an easy answer. It does have to come through coordination and through partnerships.

MS. SNYDER: Talking about public/private partnerships. Ford has a partnership with D.C. right now to introduce some autonomous vehicles. These are happening all over the country. What will it take for some of these pilot programs to become continuous, permanent introductions for autonomous vehicles in cities?

MR. FEIGENBAUM: I think it's important that folks get out and experience the technology. One of the things we've seen is if you ask a survey of people and what they think of autonomous technology, most folks are usually negative; and they're negative because what gets the coverage is what happened in Arizona as opposed to the number of successful rides that another one does, because that's really not very interesting or newsworthy.

But we find that when folks actually ride in these vehicles and find that they're not altogether different from today's vehicles and they're not taking them around corners at 50 miles an hour and crashing them into other vehicles, they become much more supportive. So, I think the pilots can sort of build on themselves, and I think it's important that the pilots go to different places in the city, not just one select.

I know oftentimes it can be easier just to geofence it and put it one place to start, and I think that makes sense. And, obviously, many of these vehicles are what they call Level 4 on the society of automotive engineer's scale, they're not going to be everywhere. But moving them around to different neighborhoods to increase support, I

think, is really important.

MS. KIGEL: And I'll just add to what Baruch said. I completely agree with that, and also to have those sustainable -- when I say sustainable, I'm not necessarily talking about environmental. I mean sustainable from a longevity standpoint. Those sustainable pilots are really important for information sharing. Just as I said before, there's a lot for both parties to learn when you do that, and then the public engagement is very, very important.

Even if you look at some of our communities, those that are 65 and older, and as you get to a point where maybe you lose your ability to be independent, and you rely on others for mobility. When you can start to expose those members of our cities and our states in the technology, and they can experience it, it definitely helps with public acceptance and trust.

And that is probably one of the biggest factors that will either enhance or impede rolling this out. So, I completely agree with what Baruch said.

MS. CHADHA: I'd add and say that in addition to these pilots, or in conjunction with these pilots, that I'm hoping that there is robust discussion around what are the goals that those cities are trying to achieve. So, not just simply procuring a widget, but rather thinking about, what is the challenge, and what is the solution that they're hoping to experiment around.

I'd also say that it's important to sort of think about the current mix of modes in that city and not only where the goals of that city are, but what does this look like in a city like D.C. where 40% of the population versus other cities in the U.S. where 10% of the population don't have cars.

MR. MADRECKI: Just really quickly from a pilot perspective in making it actually last well into the future. I think we also sometimes have a tendency to want the idealized version of autonomous vehicles to be what's piloted, rather than what is, perhaps, very practical in the short-term and very executable on a repeating basis.

And so, if you look at things, like some of the -- and it's not true like full AV,

of course -- but like, automation at ports; very implementable, achievable, repeatable, and can be scaled to different places. I think that doing things like that also builds slow acceptance over time of increasing automation. That it doesn't just have to be like immediately you will be able to go everywhere in an autonomous Uber.

MS. SNYDER: Jyot, I also want to open some space; NUMO works at a global level, you just moved back from India, I would just love to hear what you're seeing around the world.

We've been focusing a lot on the United States, and kind of, what you're seeing around the places as places are beginning to wrestle with this new emerging technology?

MS. CHADHA: Thanks, I think in the global south the rise that we are seeing of ride-hailing has been very interesting, especially where the entire population doesn't have access to formalized banking products, or even sometimes internet access on their phones. I think mobile phone penetration is quite good entities in the global south at this point. And so, it's interesting to see these new products that are coming out, and I'd love to see some of those being tested over here as well for unbanked populations.

So, that's one piece. There's, I think, a very big question around how to regulate those models, but I think maybe the entry point of this discussion is fundamentally different from the entry point of this discussion in the U.S., which is that the majority of trips, for example, in a city like Bombay, are done by walking; 50% of trips is walking. Then of the motorized, another 50% is public transport. And so, you get down to about like 8, maybe, or 10% of trips that are being made by car.

And so, in an ecosystem like that where these cities are undergoing massive changes, new populations coming into the city, a lot of growth potential, many aspirations for people to enter the middle class, where a vehicle has been that traditional way to show that you have entered the middle class, I think there are very big questions about, well, are these new models sort of substituting for people wanting to own their own

vehicle, or is it actually shifting how people think about moving around?

But also, fundamentally, the capacity of cities in the global south is a lot lower to be able to deal with a lot of these changes. So, the hand-off of what should be done by the public sector and the private sector, I think, is a bit more stark over there.

Aside from that slightly depressing story, I think that there also just really exciting things happening around how we think about informal transit and power transit in African cities, in Indian cities. Data standards that are being developed off of those. How we're thinking about utilizing motorcycles as taxis, as well; very large operations of those emerging. So, there's a lot of innovation that's taking place, but I would say just fundamentally, it looks a bit different than what's happening in the U.S. because of that mix, which is very different, and the affordability, which is very different.

MS. SNYDER: I'm kind of reeling from the mode-share that you just described in India, I mean, 50% walking, 8% single-occupancy vehicle, if those even were single-occupancy, is just so opposite from where we are. And, Baruch, you also mentioned how autonomous technology can be helpful in transit.

I think that there's a lot of concern that autonomous technology, like TNCs, can increase congestion because when, if taking your own door-to-door vehicle is the cheapest, most efficient, most accessible way, then what are the incentives not to do that. So I would love to hear more about how autonomous technology is going to get us closer to 50% closer and 8% single-occupancy vehicle, and is going to actually help the transit sector, instead of rendering it obsolete.

MR. FEIGENBAUM: Sure, well, I don't think we're ever going to get to 50% walking in those modes --

MS. SNYDER: That's sort of a joke but --

MR. FEIGENBAUM: Maybe in New York City -- right, okay, I just didn't want to get anyone's hopes up for that (laughter). So, first of all, as I think I mentioned, I really believe pricing is the key.

There's been a lot looked at urban growth boundaries, changing land use, and all of that can work in certain situations, but what we found is that that what folks are most sensitive to is cost. That's what makes them change their mind. They're not, at least by and large, sensitive to nice societal goals, as much as we might want them to. Folks generally tend to be kind of selfish. Sorry for that downer, that's just kind of the reality. So, I think that's important.

I would also say we may need to change our mind on what we consider transit. Certainly, in core D.C., in core New York, the heavy rail lines are never going away. But, in a lot of places where we have bus -- I'm a big fan of BRT; sometimes I even look at BRT. That may not be the future.

The future may be smaller vehicles. The future may be, in fact, cars where we actually have four people in them, as opposed to 1.1 people in them, which is basically what we have now. And I think transit agencies, and everyone, really have to look at how they can work together.

One of the challenges is, we've been doing transit basically the same way for the last 50 years, and ridership is going down, and we're not real good at change because it's hard. And, I'm hopeful that automated vehicles and some of these new technologies will be the impetus for folks to actually step out of their box and we are seeing it.

In Jacksonville, transit agencies are actually doing some interesting things, they're testing some AVs instead of -- I think they had a people-mover system. So, some transit agencies are looking at new technologies, which is encouraging.

MR. MADRECKI: I will add a little to that and just say that there's still only -- especially as you go into a city -- there's only so much physical real estate. And so, at some point, you're just talking about if you can fit X number of people on a bus, X number of people in a transit line, X number of people in an automated car, you're still stuck with some of those limitations.

And so, I think that **that** interplay of available real estate, how that real estate is actually used and thought about as a city; how are you building this infrastructure to facilitate cars? Are you aiming to facilitate more walking? And the leverage that your pulling as a city plays a role in, ultimately, whether AVs cause a decline in transit use, or actually somehow play a role in encouraging it.

MS. SNYDER: I'm going to talk about curb space too. Tom you have a unique take on this as both an urban bicyclist and a UPS driver, and curb space is becoming very crowded with Ubers and Lyfts, with bike lanes; there's just increasing competition and it's becoming more of an issue.

There are pilot programs trying to deal with this. I just kind of wanted to hear what we've learned about how to manage curb space in a place where people are less driving their own car and parking it, and more being picked up and let off.

MR. MADRECKI: In case this hasn't come through yet, I tend to often take 10 steps back from questions, think about it philosophically and then go from there. So my take on this -- and I had the luxury, and continue to have the luxury, of talking with a lot of DOT officials all across the country, thinking about, what do you actually want to achieve, what are your goals, how do you want your city to work and function?

And so, I straight up ask them, what are your transportation priorities if you just listed them out. By and large, and rarely has this ever deviated, the answers I get back are that they care most about safety, they care about equity, they care about shared mobility, they care about basically making sure that their businesses stay in business and they continue to have economic development, and then mention single-occupancy personal vehicles.

And then I ask them, well then why does every street in America look the exact opposite, right? That there's personal vehicle parking, there's probably one loading zone; there's no bus lane, or there's some other impediment to that, I'm going to die crossing the street, and nothing is equitable.

So like, this comes -- the orientation of the curb, and when I think about curb, it's a political decision ultimately; and it's demonstrating political -- well, they'll say like, you're curb doesn't have to look that way, it doesn't have to be five metered spaces that collect a dollar an hour or something like that. You could blow up the curb entirely.

Actually, I think that D.C.'s DOT is actually very progressive in this. One of the pilots that UPS, in conjunction with a start-up called Curb Flow, just launched actually in D.C., is to really think about if you could take the 8 or 9 different spaces in a city that were particularly congested, contributing to a lot of double truck parking, places like The Wharf, if anybody's been down there, where it's really just not easy to get around, partially also because of Uber and Lyft drop off, and just say, do we actually need that parking space, or do we just turn that entire curb into a giant flex zone, essentially.

Eventually, I think the idea -- and the connection back to autonomous vehicles here -- is that as you start to think about available curb space at designated times, you can integrate that with whatever -- from an autonomous vehicle perspective -- so that you know when vehicles are going to arrive, you have available curb space for them, they're able to use that and then get on their way, and move and sort of better manage that curb use accordingly. But I think the ultimate thing is that you don't need to do things the way that you do things today.

MR. FEIGENBAUM: I will say that like a lot of these issues, this is not necessarily new, it's just being maybe exacerbated, my automated vehicles. I mean, we have problems today with truck loading, and bicycling, and walking and all the rest of it. I will say -- a little plug here -- that I think 25 years ago, my boss, Adrian Moore, wrote a book actually for Brookings that was called, *Managing Curb Space*, and it's kind of cycling back around again.

And not surprising pricing has a big part to do with it, and who you're going to price, and how you're going to do it. And, to Tom's point, making sure that you're having all of the various users come in there.

I think very often cities don't necessarily consider the freight in the private delivery. I mean, we see this a lot with designing streets. You want narrow streets because you want to encourage certain uses, which is great; but if you're freight trucks can't get in there and make deliveries, that's kind of a problem.

So, making sure you have the cyclists, the walker, the freight delivery, the people who are going to drive their cars, the Uber, Lyft, taxis, all those folks involved I think is important.

MS. SNYDER: I want to go to the audience for questions. Does anybody -- oh, good. Yes.

SPEAKER: I wanted to take the advantage of Tom here to talk about freight (laughter), and since you're from the Grocery Manufacturers' Association especially, because one of the things I learned about freight is that the actually deliver driver oftentimes stocks the shelves. So, there's this connection that we don't -- there's this sort of first mile, last mile between the wholesale and the retailing freight.

So from your perspective of logistics in groceries, and that's what you're -- what are they excited about, what are they skeptical about, what are they rolling their eyes at, what do they think are the big problems, what can you give us as sort of insight into your industry and this automated vehicle space?

MR. MADRECKI: Just to sort of provide some background or context, GMA predominantly represents America's, sort of, favorite brands that make consumer packaged goods. It could be anybody from PepsiCo to Coca Cola, to Proctor and Gamble. So, there's a diversity of products, not just food items, but also razor blades and soap.

That accounts for 1/5th of U.S. freight. Most of the companies in that space rely on external service providers or are paying for transportation. They are not ultimately the ones that have their own fleet. PepsiCo is sort of its own beast entirely and they have own.

But, because of that there's a great deal of beholden-ness, I think, to an

industry that also -- ATA came out with their annual report yesterday talking about a truck driver shortage that there are 60,000 fewer truck drivers today than are needed and that that number will more than double over the next decade.

And so, I think that from our industry's perspective, as you look to automated vehicles, there's, I think, a hope and a promise, just from a purely efficiency perspective from a, how do you rethink supply chains, and you're talking about a technology that can sort of fundamentally, you know, you take something that today takes five days in a truck because of hours of service, and things like that, and it condenses a five-day trip across the country to two days, or even less.

So you open up this Pandora's box of questions of like, well can you just completely change your network configurations for supply chains, could you dramatically change how you do business? From a driver's side, I also don't think that -- we talk about autonomous vehicles -- what sometimes gets lost in that, and especially around truck driving and the commercial side of things, is that there's this assumption that the truck driver just goes away.

Frankly, I think that that's missing the boat somewhat because oftentimes that driver, and this is especially the case when I was at UPS, that driver is either the face of your company, or they have many other roles to play. To your point about, are they stocking shelves, or interacting in a receiving capacity, a customer service capacity; and so I think that there's a real interest in figuring out, how do you couple that technology that can improve safety and efficiency, within somehow enabling that driver to do more and to provide them with additional skills and training as they go about their work.

MS. SNYDER: Other questions, yes.

SPEAKER: This is about regulation. I know FDA, for example, regulates all the pharma companies, right. They don't want the pharma companies to put a drug in the market before they go through the proper trials.

I think that it was mentioned that you don't need (inaudible) to regulate

autonomous cars. But, suppose I open a 20-person company and say, okay, I'm going to go ahead with autonomous cars because I just buy cars from Honda, or Toyota, and add my own lidar technology and put it in the market. Should the government allow me to do that?

MR. FEIGENBAUM: Let me just make sure I understand. Basically, what you're saying is, should the government allow after market technologies to be placed on the car?

SPEAKER: Or, for that matter, allow anybody to put a car out in the market just because they can self-regulate themselves.

MR. FEIGENBAUM: I guess I would say there are certain standards that vehicles have to submit to today in order to be certified. There is a self-certification process. I wouldn't say it's true that right now you can put any technology out on the market, and I don't think we'd want to introduce that.

Part of me likes the entrepreneurial aspect of that, but part of me also realizes there's a safety component as well. I think the process we have today works well. It's a little different than how they do it in Europe because it's generally not super onerous for the company, and so that allows smaller startups to do it. But there is a little -- well, there's more than a little bit -- there's a safety component of it to make sure what's put out there isn't going to kill people.

MS. SNYDER: Other questions? Yes, I knew if I waited long enough somebody would have one.

SPEAKER: I'm still not sure how the technology is affecting an entire population. They can already owe it coming with the cost. So just I'm thinking about that kind of case; there is somebody who is making $15 per hour, and have two children, and have to commute to somewhere, and also have to pick up child on the way the back, and also have to go grocery shopping. For that kind of person, for that person, would benefit or not benefit, how much she or he has to pay more or pay less?

MS. SNYDER: Are you assuming that autonomous vehicles will be

introduced as shared fleets like Uber as opposed to private car ownership?

SPEAKER: Uber or ownership or whatever. What kind of option is available for that person? How much is that going to cost (inaudible) expenditure?

MS. SNYDER: Mm hmm. I feel that question. Busy people making multiple trips, what's the best way to do that?

SPEAKER: [Off mic].

MS. SNYDER: I'm sorry?

SPEAKER: $15 per hour case.

MS. SNYDER: Right.

MR. FEIGENBAUM: Yeah, so that's a tough question. But, okay, when we're looking at technology, at least my approach, is I'm looking if there's overall societal gain. Are some people going to lose and some people going to win? Probably in just about everything in life. Like, trying to make everything better for everybody is pretty challenging.

But, I do think, if you look at the shared model, which seems to be how most people think AVs are going to roll out, at least early; and I do think, I personally do think, there's going to be individuals owning AVs, and probably more than we think, but that certainly does not need to be the model for everybody.

I think if you look at the shared model, because the cost of vehicle ownership is so much less -- and the vehicles might not even be owned by folks using them; there might actually be some sort of lease, there may be companies that are actually using them -- I think that that is going to have a significantly lower economic cost at least over the long run.

Now, the challenge you bring up is, how about folks that need to make trips during the day? Are the vehicles going to be available to them, and that's challenging. That's one of the questions folks are looking at with these shared vehicles; if everyone leaves work at 5 o'clock, are there going to be enough vehicles and how do you guarantee that. And, I honestly think that's a little bit tricky. I think that one of the reasons individually

owned vehicles will be available.

But I do think there is a lot more potential, and there's also -- we have programs right now that are used if folks, for example, take transit one way but the transit doesn't operate back; or they're in van pools, which are where 7 to 14 people share a ride; things called Guaranteed Ride Home, where there's a way to get home or get some place if they need to.

So I think we can expand those types of things. I think we can make it work. I'm not saying we've got it solved right now, but I think it's a very promising technology. And I do think it can make driving more affordable for folks.

MS. SNYDER: People are --

MS. CHADHA: Can I quickly add something to that?

MS. SNYDER: Sure, of course.

MS. CHADHA: I think your question is prompting me to think about an inclusive design process. And I think the private sector is much better at this sometimes. But when you look at how a lot of transit options, or how cities are planned, I think the trips that you're mentioning are not at the forefront for planning those systems.

And so, I very much agree with you that that design process needs to be much more inclusive if we're really going to push for transport that is accessible and useful for all.

MS. SNYDER: I think that that gets to the point also of, what if we put equity first, and framed all of this as we're trying to solve a problem of equity. We can on top of that, also, congestion. We can add on top of it, mobility. And then, what is the best way for that parent working a $15 an hour job to get around.

I also wanted to get back to Baruch's point about everyone leaving at 5 o'clock, will there be enough vehicles? I mean, that's a nightmare now. That is a failure of our transportation system, and a failure of our ability to work around it. If people just had more staggered work times, so many of our transportation problems could be solved.

MR. FEIGENBAUM: I would just say -- and we've tried things. Obviously, we've tried to incentivize carpooling, to get folks to carpool. And it's a little better in the D.C. region because the congestion is so bad, but by and large, we've not been super successful.

I, as someone who gets to work from home a lot, don't understand why folks aren't willing to go in an hour earlier or stay an hour later to avoid the peak congestion. And I know it's sometimes not that easy, you've got to pick a child up from daycare, whatever.

But, again, not to be a broken record, but I think looking at pricing -- taking the I66 lanes -- for those of you who are a little unfamiliar with that. Now, the ones in the morning are a bit of a challenge and it has to do with some geometric design issues. We've got to merge from four lanes to two lanes and also getting into D.C., so okay, but the ones in the afternoon -- I still support them by the way, I'll be happy to talk to you about why -- the ones in the afternoon, though, are really wonderful.

If you look at it, a relatively minor price of maybe 50 to 75 cents per mile, has basically gotten rid of all of the congestion on I66 westbound, going from D.C. out to Fairfax County where I live, and it's actually kind of amazing because it's really not that much in the context of D.C. And, honestly, a lot of the incomes here are fairly high, not all of them, but some of them.

And the biggest problem is what happens when the pricing ends and you have congestion before and after because everyone is trying to avoid paying the price, which I totally get, but if you priced it 24/7 you would not have this problem (laughter).

So, there's a lot we can do with policy. I realize the political acceptance is very, very challenging, but to your point, we can solve these problems if we really want to, I think.

MS. SNYDER: Any other questions from the audience? Yes.

SPEAKER: Thank you, hi, I'm an urban planning student interning at the Federal Highway Administration, who comes from a really rural part of the country, and while we have talked today a lot about these issues in urban places, it has also been alluded to

that this, too, may change the form in rural areas. And so, I'm just curious, from your broad range of expertise and perspectives here, how you guys see this playing out in more rural areas in the U.S.?

MR. FEIGENBAUM: It's going to be different. And I guess, one of the questions in my mind is, will there be enough folks going to similar locations where the ridesharing is going to work? Or is it going to be more individually owned vehicles?

I mean, it's definitely going to be more individually owned, that's just reality. And, obviously, there's been some talk of electrification, and I do think Tesla says a lot of stuff, but they're success with the model 3, in terms of the demand and also producing it, makes me fairly optimistic for electrification. So, I think that's positive there, assuming the power source, of course.

We don't know is the question. We think for the exurban areas there's going to be quite a bit of ridesharing. I think for the rural areas, I don't know. Maybe some of the new models can work to improve the transit service in the rural areas, which is, you know, basically nonexistent, or could actually do a lot with Dial-a-Ride sort of type, but it's going to be very different.

I think you bring up a good point and I think it's going to come to the urban areas first before it gets to the rural areas, but that's obviously a politically sensitive topic.

MS. SNYDER: With the few seconds that we have left, I just want to ask what your biggest worries are?

I don't know if this is a few-second answer. But, you know, as we approach right now, with very little regulation, as we approach the advent of the driverless era, what keeps you up at night?

MS. CHADHA: That after all of this, that we still end up with a transportation system that is the second highest household expense, that results in many deaths, that is a big contributor to emissions.

MR. FEIGENBAUM: I have a two-part answer. Not surprisingly, I'm worried

more about over regulation, certainly not right now, but in the future. And, I also worry that we will not take this opportunity to do things such as congestion pricing that could be a big benefit.

MS. KIGEL: One of the things that I do think about has to do with funding. Funding overall transportation infrastructure, especially when we're going with the electrification of vehicles. And I think we have a great opportunity here because we're talking about a lot of innovation. And as we're talking about innovation, and also as we might be moving towards shared mobility and whatnot, we should really look innovatively as to how we actually fund infrastructure.

It's been challenging, particularly, because we have states that do their own level of funding, and then we have the Federal government that's also responsible for funding. So, as states are experimenting in different strategies to be innovative, we also have the Federal government who covers this fear of the entire country, and we could have the ability of different methods being used in different places, and that could create challenges for us.

MR. MADRECKI: I wish I could tell you that political decisions were made just on the basis of fact (laughter), and like complete logic. So, I think that my fear is political realities, and sort of, the desire of people to appease other people gets in the way of some of the decisions that are crucially needed.

It could be to Baruch's point about congestion pricing, or some other mechanism of changing transportation. But it can also be about just the way that things are rolled out.

And so, if it's more politically viable in the short-term to have a personal vehicle regulatory approach for autonomous vehicles rather than commercial applications -- which I actually, and this may be -- Yes, I represent GMA, but I think that there's more viable short-term options for commercial autonomy than there are for personal autonomy. But that's not a politically viable thing, necessarily, to say. And so, I think the sensitivity there

would have to be just that you don't let politics get in the way of actual progress.

MS. SNYDER: Well that does it for us. Please join me in thanking the panel for this wonderful conversation (Applause).

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CERTIFICATE OF NOTARY PUBLIC

I, Carleton J. Anderson, III do hereby certify that the forgoing electronic file when originally transmitted was reduced to text at my direction; that said transcript is a true record of the proceedings therein referenced; that I am neither counsel for, related to, nor employed by any of the parties to the action in which these proceedings were taken; and, furthermore, that I am neither a relative or employee of any attorney or counsel employed by the parties hereto, nor financially or otherwise interested in the outcome of this action.

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Expires: November 30, 2020