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Future of Transportation Technology

Expert Testimony by

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Good morning. Thank you Chairman Buchon, Ranking Member Lipinski, and all of the members of this subcommittee for the chance to speak with you today. I am John Maddox, Director of Collaborative Program Strategy at the Texas A&M Transportation Institute (TTI), and the University of Michigan Transportation Institute (UMTRI). I am honored to speak with you on behalf of TTI about the future of surface transportation technology, and key steps for creating a much safer and more efficient transport system.

My perspective includes research, development and deployment, with a focus on how to maximize the benefits of new transportation technologies for the people and economy of the United States. I will cover near-term and long-term future vehicle and infrastructure technologies, including the role of government and industry research and development, as well as related policy issues.

The Texas A&M Transportation Institute, established in 1950, has a long, successful history of performing groundbreaking research on a wide range of significant transportation issues. Recognized as one of the premier higher education-affiliated transportation research agencies in the nation, TTI's research and development program has made significant breakthroughs across all facets of the transportation system—from safety, mobility and planning, to intelligent transportation systems, infrastructure, and the environment—and other critical areas vital to an efficient transportation system and quality of life.

TTI's headquarters is located on the campus of Texas A&M University in College Station. The Institute maintains a full-service safety proving grounds facility; environmental and emissions facility; and a sediment and erosion control laboratory, as well as numerous other facilities and laboratories. TTI has 10 locations in Texas and an office in Mexico City, and is home to 10 state and national research centers, including one focusing on railway safety research and another focusing on connected transportation.

TTI is well-positioned to offer objective and credible guidance on a wide range of transportation topics and emerging issues, such as connected vehicles and connected infrastructure. The Institute annually works on more than 600 transportation research projects totaling more than $54 million dollars with over 200 sponsors at all levels of government and the private sector. At any one time, TTI has research sponsors in about 30 states and has conducted research for sponsors in all 50 states and more than 20 foreign countries. TTI has about 400 professional researchers with significant expertise in all disciplines impacting transportation, such as technology, engineering, planning, economics, policy, landscape architecture, environmental sciences and the social sciences.

Transportation is the lifeblood of our economy and society. The ability to efficiently and effectively move people and goods is critical to the social and economic well-being of the United States, and will help us remain competitive with other international economies. It is clear we need a significant change.

Our current transportation system has served us well for the last one hundred years, however our current roadway transportation is showing signs of strain. We experience significant congestion, especially in our largest cities. The cost of this congestion exceeds $121B in direct operating costs, wasted fuel, and lost opportunity costs, including $27B worth of wasted time and fuel for trucks moving goods $_{(1)}$. And this is a growing number. Many people experience the frustration of a congested commute to work or home, including byproduct effects of unpredictable arrival times. Yet our society and economy depend directly on the ability to transport people and goods in an efficient manner. While this is also true of other international economic regions, it may be particularly important for the competitiveness of the US and the NAFTA Region given the vast size of the geographic trading area. Additionally, the basic funding mechanism whereby we maintain our roadway infrastructure is uncertain.

Even more tragic is the fact that approximately 33,000 Americans lose their lives on US roads every year, and another 3.9M are injured. The National Highway Traffic Safety Administration (NHTSA) estimates the societal cost of these crashes at $871B, or the equivalent of 1.9% of the national GDP. $_{(2).}$ And while the numbers of fatal crashes have decreased steadily over the last 10 years, largely due to NHTSA's efforts, , the Automotive Industry, and State DOTs, the numbers of fatalities of vulnerable road users (VRUs: motorcyclists, pedestrians, bicyclists) have not declined, but have even slightly increased. These VRUs are an increasingly important part of road safety, perhaps as urbanism, congestion, and energy costs entice more people to find alternative means of transport. All of these fatalities should be viewed as unacceptable.

Largely we have accepted these undesirable outcomes, including crashes and congestion and wasted energy, as the status quo. We have of course attempted to address these problems, primarily with separate "siloed" approaches for vehicles, roads, and human behavior. But those separate approaches are only producing incremental results, instead of the significant breakthrough improvements that we need.

New technologies such as Connected Vehicles and Infrastructure are creating a significant opportunity to vastly improve our transportation system, especially the way

we move people and goods. This will have great social and economic benefit to the United States, and will help us remain competitive with other international economies.

Vehicles, and the way they are operated, are undergoing a fundamental change. Currently, vehicles are increasingly being equipped with two significant technologies, namely advanced telecommunications systems, and Advanced Driver Assistance Systems (ADAS). These technologies provide convenience and safety, respectively, for today's drivers. Both are the result of significant and successful research and development programs that have been transferred to deployment. Both will be building blocks for future transportation systems.

The telecommunications systems are largely the result of collaborations between the automobile and telecommunications industries, primarily to satisfy the customer's desire to be connected and entertained at all times. These systems have been somewhat helpful for mobility in deployment of navigation and real-time traffic information to drivers. But, while people enjoy ubiquitous connection, operation of handheld devices, such as smart phones, has led to significant additional driver workload, and in some cases, distraction. Integration of these devices or functions with the vehicle itself allows for maintaining that connection but with possibly lessened workload and distraction. So far, issues of privacy and security have not come to the forefront, probably largely due to the fact that they are primarily linked to personal cellular-based accounts which consumers "opt-in" to use.

At the same time, on-board ADAS systems have been developed as a result of collaboration between the automobile industry and governmental agencies in the US, Europe and Asia. These were initially deployed to provide added warning and aid to drivers, while the driver kept complete control of the vehicle, including systems such as Forward Collision Warning (FCW), Lane Departure Warning (LDW), and Blind Spot Warning (BSW). But now increasingly more complex systems are being deployed that actually intervene and take partial control to help the driver avoid or mitigate specific crash-imminent situations. These include Electronic Stability Control (ESC), Forward Collision Avoidance (FCA) or Crash Imminent Braking (CIB), Lane Keeping Systems (LKS), Pedestrian Crash Avoidance, and combinations of these. Even though these are already being deployed, research on these systems continues in efforts to improve their capability, reduce costs, and to identify methods to test and evaluate their effectiveness in a wider range of roadway scenarios. However, these systems are relatively costly, may not operate effectively under all weather and roadway conditions, and even with full deployment, can only directly affect individual equipped vehicles.

The next wave of vehicle innovation will be Connected Vehicles, first connected to each other (Vehicle-to-Vehicle; V2V), then to roadway and infrastructure devices, (Vehicle-to-Infrastructure; V2I), then finally to other road users such as pedestrians (V2P), motorcyclists (V2M) and bicyclists (V2B). Connection will likely prove to be an invaluable asset, as it allows for a "systems approach" instead of "siloed" solutions, creates the possibility for "big-data" solutions for transportation, and is an enabler of automated vehicle technology. Collectively, these technologies represent the future of transportation, and have the possibility to provide significant improvements in safety, mobility, and energy use in transportation.

The USDOT, in collaboration with the Auto Industry primarily through the Crash Avoidance Metrics Partnership (CAMP), and Academic partners, has spearheaded the successful effort to research and develop Connected Vehicle technology. Federal involvement has been critical from the beginning, and continues to be, because the Federal government is in a unique position to bring together companies who would otherwise be unable or unwilling to develop the technology in a very competitive environment with otherwise unclear deployment strategies. NHTSA's regulatory authority provides a pathway to create a deployment strategy for V2V that can ensure a level playing field amongst competitors as well as a known trajectory towards a critical mass of vehicles. Auto Industry involvement, with its in-depth expertise, ensures an outcome that is deployable in a real-world environment. And Academic involvement brings critical expertise and bandwidth to conduct research at many levels, and serves as a neutral third party between the government and industry. And of course Academia can also educate and train the engineers of the future who will take this technology to even further levels. This collaboration is a very successful example of how public private research partnerships can achieve significant results that could not be achieved otherwise, or that would take a much longer timeframe to achieve.

The first of these technologies, V2V, has a foreseeable path to deployment, though focused applied research remains needed to bring key remaining aspects of related technology to a point where it is ready to be deployed at scale.

USDOT and NHTSA announced in February 2014 that they will move forward with V2V technology, stating that *"V2V crash avoidance technology has game-changing potential to significantly reduce the number of crashes, injuries and deaths on our nation's roads."* *(3)* Indeed, that statement generally represents the collective opinion of the research community who have been involved in this program for the last 5-6 years. At this time we are still awaiting NHTSA's report to understand specific outcomes, but the previous estimates from USDOT have been that V2V is potentially capable of addressing 79% of vehicle crash scenarios. (4) Currently, V2V using 5.9GHz Dedicated Short Range Communication (DSRC) is the only proven technology that can reliably communicate between vehicles within the millisecond timescale that is required in a broad range of critical crash-imminent scenarios.

It is that broadcast communication that allows vehicle-based algorithms to generate information and warnings to drivers, as well as provides a building block to enable further levels of automated control in greater numbers of roadway scenarios. Additionally, the broadcast communication from vehicles will also enable the deployment of V2I, V2P, V2M, and V2B, which will themselves allow significant improvements in our roadway transportation system.

The USDOT and the auto industry have invested significant resources to research and develop these V2V technologies, culminating in NHTSA's February 2014 decision to move forward. This extensive collaborative research and testing effort, including the Safety Pilot Model Deployment in Ann Arbor, MI being conducted by UMTRI, has successfully demonstrated the functionality and efficacy of the V2V system. At this time, we are still awaiting NHTSA's full report to understand the specific outcomes.

However, it is clear that there still remains detailed technical follow-on work to be completed to allow full V2V deployment through a potential NHTSA mandate or consumer information program.

Firstly, as NHTSA transitions from a research program into a rulemaking program, the primary technical challenge will be to identify appropriately rigorous performance requirements, test procedures, and potentially new test equipment that can be used in the development of practicable FMVSS standards or NCAP requirements. This is a necessary step for any and every rule or requirement that NHTSA codifies, and in this case it is more complex because it is the first time NHTSA, or any automotive regulatory body, would require equipment for over-the-air safety-related communications between vehicles. The collaboration with the Auto Industry and Academia will continue to be critical to identify new methods that are practicable in the real world, and it is very likely that these requirements can and will be developed.

Additionally, there are concerns about the potential effects of congestion on the 5.9GHz spectrum. Since V2V relies on this spectrum, any other broadcasts or messages other than safety related messages have the potential to degrade the efficacy of V2V safety benefits for connected vehicles. There are discussions regarding the potential sharing of this spectrum for non-safety and even non-transportation use. We must fully investigate and understand the feasibility of any potential sharing regime, and ensure that this does not degrade or inhibit V2V's ability to provide the safety benefit for road users. If there is potential for degradation, then we must investigate effective countermeasures to ensure that broadcast communications get through to the vehicles that need to receive them. And we must ensure that any spectrum-sharing regime does not preclude other critical safety or mobility applications, such as V2I, V2P, V2M, and V2B.

The operation of a Security Credential Management System (SCMS) is critical to the performance of a V2V system to ensure that messages transmitted and received can be trusted and therefore acted upon. While the Safety Pilot Model Deployment successfully included an early version of a security system, continued USDOT, Auto Industry, and Academic research has already eclipsed this level and design of a full-scale capable system is now being finalized. Further research and testing will be required to demonstrate that system's practicability in the real world at significant scale. This must be a continuation of the collaborative effort between government, industry, and academia, as it will be the first of its kind and must be capable of growing to a very large scale. Again, it is anticipated that practicability of this system will successfully be demonstrated.

Lastly, while not absolutely critical to the operation of V2V, the introduction of aftermarket or retrofit devices can help accelerate the trajectory towards a "critical mass" of connected vehicles and devices. Because V2V is a communicative system, it is reasonable to expect that effectiveness of the system will increase with the distribution of equipped vehicles. Since it is expected that aftermarket devices can be introduced faster than the vehicle fleet turns over, it is also reasonable to expect that they will help achieve greater benefit in an earlier timeframe. Research is needed on the design, reliability, and Human-Machine Interface (HMI) of these aftermarket and retrofit devices to ensure they perform at an acceptable level of precision and reliability and don't generate unwarranted workload or additional distraction for drivers. These devices must be field-tested at a level of scrutiny similar to the OEM-developed in-vehicle systems. These devices are also important from a consumer-adoption point of view, in that they can potentially bring additional mobility and energy-saving applications which can help ensure there is recognizable consumer value from "day-one" of deployment. And lastly, but importantly, these devices may pave the way for development of smart-phone based applications that can also act to protect pedestrians from vehicle collisions.

In addition to the technical research work over the last 5-6 years, USDOT and the Auto Industry have engaged in research and discussion on policy aspects of Connected Vehicle technology. Significant progress has been made, and some research questions remain.

USDOT formed an internal multi-modal Policy Task Force that identified, examined, and made decisions and recommendations on those key policy aspects, such as authority, privacy, deployment models, etc. Similarly, the Auto Industry formed a collaborative group, the Vehicle Infrastructure Integration Consortium (VIIC) that identified and addressed policy issues from an industry perspective. While USDOT and NHTSA have not published their research report yet, it is expected that it will address many of these policy issues.

Privacy has been one of the key policy aspects identified since the inception of the program. The V2V system has been designed from the beginning to be very protective of privacy of individual drivers or vehicle owners or operators. And the result is that the Basic Safety Message (BSM) that is broadcast from the vehicles is anonymous and contains no information that identifies the vehicle or driver. As standardized by the Society of Automotive Engineers (SAE) it only contains information about a generic vehicle's instantaneous location, heading, acceleration, speed, and vehicle status such as brake application and steering wheel angle. By design, the V2V system does not track or record vehicle movements, and security credentials are updated on a very short-term basis. Because of this specific design it is practically impossible to track the location or meaningful path history of a vehicle or person through the V2V system, as contrasted to the relative ease of doing so with cell phones.

Additionally, similar protections are designed into the Security Credential Management System that is being finalized by the Automotive OEMs with help from Academia and the Security industry. This system is based on the principle of maximizing individual privacy while maintaining highest levels of security. While the full details of this system have not been released, it is understood that it will incorporate multiple layers of security credentialing and a separation of organizations and databases that will not allow any one organization, or individuals inside or outside of those organizations, to ascertain both the vehicle identification and location at the same time.

Of course no electronic data system is completely impervious to cyber attacks and hacking attempts, and vehicles and vehicle systems are potential targets of such attacks. While no known attacks have been mounted in the real world environment, there have been a small number of demonstrations of hacking into embedded (built into the individual vehicle) systems by academic and research organizations. And V2V/V2I systems, along with infotainment and communications systems, may offer an additional "attack surface" into the vehicle due to their nature of enabling data exchange. Therefore it is prudent to conduct continued research on cybersecurity for vehicles, including these V2V/V2I messaging and security systems, to understand any vulnerabilities and potential countermeasures. This also should be organized as a collaborative research effort between government, industry and academia to leverage the best outcomes for transportation safety and security of mobility.

Liability concerns, though not a strict impediment to V2V deployment, may slow deployment of fully cooperative systems and the resultant benefits therefrom. By definition, the effectiveness of V2V relies on the shared use of data between vehicles, infrastructure, and devices. But inherently there is risk for any one manufacturer when the safety of their product's passengers is partially dependent on another manufacturer's product. There will be a wariness to introduce the full functionality of these technologies in the United States due to our litigious climate. Other countries may very well benefit first from the technologies developed here, resulting in delayed benefits for US consumers and a potential loss of economic competitiveness. Because of this, it is advised to consider research into shared-liability regimes, including limiting (but not eliminating) the liability of automakers and other device makers, as well as the operators of connected infrastructure including the security system and traffic operations, so that we can realize the greater societal benefit of these technologies.

Perhaps the key non-technical issue that remains, and that must be addressed, is that of identifying an entity to operate the Security Credential Management System, along with a viable business model that allows for self-sustaining indefinite operation of the system. The current assumption is that the operator of this system should be a non-government agency to minimize any public concerns regarding invasion of privacy, but that does not preclude the possibility of federal funding that would contribute or fully fund this operation. As the design of this system is finalized, and then communicated and tested, it is expected that a number of potential business models and operating entities will emerge. This could be aided by focused research by government, academic institutions, non-profit organizations (such as the Intelligent Transportation Society of America; ITSA) and stakeholders from various industries including automotive, telecommunications, transportation operators, data companies, and others.

While V2V has a clear path for deployment, much research work remains to be done on a deployment strategy for V2I and I2V to ensure we meet our mobility and energy goals for transportation.

V2V will form the backbone upon which other Connected Vehicle technologies will be built. Data from vehicles will enable many V2I applications that can address key transportation performance needs, especially mobility and energy improvements. For example, V2I connection holds unique promise for addressing congestion. Key applications include adaptive traffic signal control, which uses the real-time data coming from vehicles to alter signal phase and timing (SPAT) to maximize vehicular throughput in a given intersection or corridor. And "probe" vehicle data enables real time traveler information that can guide drivers of passenger vehicles and freight vehicles to take alternate routes to minimize their delay in congested areas. Additionally, vehicle data will enable the operators of the transportation system to understand dynamic traffic conditions, as well as the physical condition of the roadway including the presence and severity of potholes, or the need to deploy snowplows and salt trucks. The list of these potential applications is quite extensive, limited only by the imagination and lack of direct experience of understanding the data availability.

Additionally, I2V (Infrastructure-to-Vehicle) communications will enable yet another group of beneficial applications. For example, if the vehicle knows the intersection's signal phase and timing it can advise the driver to adjust its coast-down approach to minimize fuel usage, and can advise the vehicle of exactly when to restart its engine after sitting at a red light that is about to turn green. Additionally, the infrastructure can alert the vehicle to the presence of a pedestrian in a crosswalk, or the presence of road workers in a construction zone. Again the list is extensive and currently limited by experience with the data.

The USDOT, especially FHWA and OSTR, has undertaken a great deal of research in identifying and defining these and many other V2I applications, and has started on the work of writing initial specifications for communications and application performance. FHWA has announced their intention to publish guidance in the FY2015 timeframe to states and local governments on deployment (5) . But they have stopped short of *requiring* any deployment, as their authority may not allow a mandate. They have signaled a willingness to allow V2I/I2V technology deployment as part of their grant and state funding programs, and that is an encouraging step. Additionally, AASHTO has published their "Footprint Analysis" which elucidates potential key-application deployment installations and operations possibilities, and estimates total build-out costs for the US, but does not describe a clear deployment or financing strategy to accomplish that in the near timeframe.

As of yet, a clear deployment strategy for V2I has not emerged in the US. Contrarily, the Europe Commission and some Asian countries have established and begun to implement an infrastructure deployment strategy. These strategies are based on results of research and Field Operational Tests (FOTs) that have quantified the cost and benefit of critical V2I applications, similar to what Safety Pilot Model Deployment has done for V2V safety applications.

The US needs a V2I deployment strategy that clearly supports and funds the voluntary installation of key applications by the State and Local governments, and is directly supported by research and FOTs that quantitatively demonstrate the installation, operation, and maintenance costs, and the resulting benefit to mobility, energy, and safety. These results will allow state and local governments to make informed decisions to invest resources into deploying applications that are beneficial to their individual transportation needs.

USDOT has signaled that it intends to sponsor such V2I FOTs in the FY2015 – 2018 timeframe, focused on mobility, energy, and safety. (6) This is a critical step towards deployment of V2I, and this research effort should be fully funded. It is anticipated that these FOTs can also form the backbone of regional initial deployments. Additionally, research should continue on developing and defining V2I applications for transportation operations, including passenger and freight mobility, smart parking, data acquisition and manipulation, and other areas.

Building on the success of the V2V collaboration between government, industry, and academia, the V2I research and demonstration efforts need to call upon significant engagement from the manufacturers and users of infrastructure-based equipment, such as traffic signal controllers, data systems, roadside sensing hardware, etc. A consortium of those manufactures and users could be formed to help provide that engagement in a manageable way.

There have been incidents of cybersecurity attacks on our transportation infrastructure such as traffic signals, networks, and variable message road signs. Some portion of our existing roadway infrastructure is already connected through wireless and cellular networks. As with vehicles, additional and more ubiquitous connection of our infrastructure can create additional attack surfaces. Research is needed on cybersecurity of our infrastructure to ensure the integrity of our transportation system.

Importantly, early research must be started on establishing connected applications for safety and mobility of vulnerable road users (VRUs), including V2P, V2B, and V2M.

Pedestrians, Motorcyclists, and Bicyclists collectively make up 30% of all of the traffic fatalities in the US. These road users are very hard to protect in the event of a collision, and the key to improving their safety is to avoid the collision in the first place. While onboard vehicle technologies are beginning to help address this, the effectiveness of collision avoidance technologies can likely be enhanced greatly by providing a channel of communication between the VRU and nearby vehicles. Such V2P technologies have been developed at the concept and demonstration level using smart phones. But significant research questions still exist around positioning accuracy and connected device options and tradeoffs. The smart phone approach can also theoretically be applied to bicyclists, and again additional research is needed to address unique questions around localized travel patterns of bicyclists, and positioning requirements.

Additionally, while motorcycles are technically another vehicle, the current V2V research has not directly focused on their unique requirements for communication systems. They have significantly different usage patterns, such as variable lane position, higher speeds and increased maneuverability, and reduced conspicuity when compared to passenger vehicles, light trucks, and large vehicles. Again, the key to improving safety for motorcyclists is to avoid the collision in the first place by making the driver of the other vehicle completely aware of the presence of the motorcycle, especially under critical crash scenarios. M2V /V2M has great potential to communicate that presence and create that awareness. Additionally, I2M may be helpful in certain crash scenarios by transmitting slippery or otherwise hazardous conditions that can be tailored to motorcycle riders. Both of these technologies require careful thought on the best way to communicate these messages to the rider, and will require unique HMI considerations. This research must also be started and fully funded.

Alongside the development of Connected Vehicle technologies, research on Automated Vehicles will occur simultaneously. These technologies are not competing against each other, but are very complementary.

Currently, there are a great deal of media stories and reports on the development of Automated Vehicles (AVs), or Self-Driving Vehicles. AV research is indeed proceeding at a rapid pace, primarily by certain auto companies, suppliers, academic institutions, and Google. These efforts are primarily aimed at consumer convenience. AVs will result from a convergence of current ADAS driver assistance technology, the connected vehicle and infrastructure platform that can act as an additional and very powerful "sensor", and self-driving vehicle technology, including further advanced vehicle-based sensors and decision making algorithms.

Development will occur along a continuum of increased levels of automated control. But it is clear that operation of these vehicles will still rely on having a human in the driver's seat for some time to come. This is due partially to technical reasons, including limitations of current-level sensing systems and algorithms, but it is also due to yet-unanswered policy questions. Driver responsibility forms the basic assumption of our transportation systems, including responsibility for maintaining safe control of a vehicle, and also for ensuing licensing, insurance, enforcement, liability, and even criminal penalty systems. Therefore policy research is needed to begin to answer questions about these basics when control responsibility is directed away from the driver and towards the vehicle itself.

However, AV technology may also hold great promise for improving the safety, mobility and energy use of our transportation system. Since approximately 93% of fatal crashes involve human error, (7) aiding the driver and providing direct control in normal driving situations to avoid crash-imminent situations altogether through automation should help reduce crashes. Automation has the potential to help smoothing of traffic to reduce congestion in certain limited scenarios, and to aid fuel economy in others. However, it is important to recognize that none of this has been proven as of yet.

The USDOT, especially OSTR, can help the industry develop these AV technologies with studies of how connection complements automation, and how improved or enabled infrastructure can aid automation. Policy research would be very helpful, as USDOT is in a unique position along with State DOTs to begin to address some of the key questions. As stated before, cybersecurity is a growing concern for embedded and connected systems, but is absolutely critical for automated systems that have the ability to autonomously control a vehicle or infrastructure element. NHTSA must continue its basic research on cybersecurity and safe-reliability of these vehicle control systems, and FHWA could begin significant work on cybersecurity of infrastructure systems. Additionally, since higher-level automation can spur new usage patterns and new business models, even potential changes in roadway and urban design and payment systems should be researched, as well as how these vehicles integrate to a full multi-modal system including transit and shared-use models.

In closing, I wish to reiterate that we are entering a new era for a greatly-improved transportation system built on key technologies. True collaborative research partnerships, such as the public-private partnership between USDOT and the Auto Industry and Academia, will be required to develop and realize the best results from these technologies. Other industries should be brought into this effort. USDOT should continue its very successful public/private research program on Connected Transportation as a whole, and be funded to finish the work we have started by:

- **Completing the deployment strategy for V2V.**
- **Establishing a deployment strategy for V2I / I2V and conducting field tests.**
- **Establishing a comprehensive research plan on Connected Vulnerable Road Users (V2P, V2B, V2M).**
- **Conducting public/private research on transportation cybersecurity.**
- **Spurring innovation and deployment of AVs.**

I appreciate this opportunity very much and welcome your questions. Thank you for your attention.

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