TRB AV/SM FORUM
AUTOMATED VEHICLES + SHARED MOBILITY

Agenda

Monday and Tuesday, February 24 and 25, 2020

The Keck Center, Room 100
500 Fifth Street NW, Washington, DC

Monday, February 24, 2020

8:30am **Welcome from co-chairs**
Meeting Logistics
Self-introductions *(committee roster on pages 3-5 of meeting materials)*
Agenda overview

9:00 **Top Ten Research Issues**
Stantec team *(white paper memo is pages 6-7 of meeting materials)*
- Lightning panels to track research topics or presentations
- Breakout groups to discuss certain paper topics further

12:00 Lunch available

1:00 **Future Outlooks for AV and Connected Systems**
Dick Mudge and Alain Kornhauser
Outlook for Automated Vehicle Systems (report is pages 8-28 of meeting materials)

FHWA's *Scenario Planning for Connected Automated Vehicles* (*report executive summary is pages 29-50 of meeting materials)*

2:00 **Interactive Scenario Development Workshop**
Rich Davey, Alan Iny, and Augustin Wegscheider, BCG (*pages 51-73 of meeting materials*)

5:30 Adjourn

Tuesday, February 25, 2020

8:30am Comments from Neil Pedersen, TRB Executive Director

8:45 **Review of research white papers discussion and next steps**
Stantec

10:00 **Review of scenario planning discussion and next steps**
BCG

11:00 **Forum reports**
Review of 2019 activities and products

- E-circular 247: Mini-Workshop on the Importance and Role of Connectivity *(pages 74-91 of meeting materials)*
- E-circular 252: Mini-Workshop on the Transition Toward Shared Automated Vehicles *(pages 92-106 of meeting materials)*
- E-circular 253: Impacts on Traditional Research Processes and Programs *(pages 107-125 of meeting materials)*
- E-circular 258: Mini-Workshop on the Roles of Government and the Private Sector *(pages 126-142 of meeting materials)*
- E-circular 251: Mini-Workshop on the Economic Implications of Automated Vehicles and Shared Mobility *(pages 143-156 of meeting materials)*

Forum directory of information resources, e-community, and website *(pages 157-163 of meeting materials)*
CRP update *(pages 164-169 of meeting materials)*
Upcoming meetings
Other business/comments from Forum participants

12:00pm Adjourn

Next meeting
Sunday and Monday, July 26 and 27, 2020, at the Hilton San Diego Bayfront

Automated Vehicle Symposium 2020: Monday, July 27 to Thursday, July 30

National Academies/TRB Forum
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Stantec

Memo

File: Topical Paper Survey Results Date: February 14, 2020

The members of the NCHRP forum responded to a survey on the proposed topical papers and the upcoming forum. Below please find a summary of the responses that will be shared in more detail during the Forum meetings Feb. 24-25.

ARE THERE ANY SPECIFIC ISSUES YOU WOULD LIKE TO SEE ADDRESSED IN A PARTICULAR PAPER?

Data

Respondents were interested in best practices for data sharing. Another respondent noted that a detailed overview of the most pressing issues would be helpful, although they were not sure what questions even need to be asked. Cybersecurity was raised as an issue, as was whether OEM's and others could share crash and near miss data to accelerate safety attainment. Other issues raised included data ownership, data sharing, quality evaluation and just general data generation and analytics.

Freight/Travel Behavior

These responses noted how freight and travel by highway and surface streets raises far more interjurisdictional questions then a purely local Automated Vehicle (AV) operation. Questions were raised about how AV's operate on arterials vs freeways, how states and localities should prepare depending on the road networks in their jurisdiction, how this will impact the movement of goods, and how to permit new vehicles/tech across states, which will likely come up sooner then for passenger vehicles in localities. Another comment focused on whether changes in travel behavior be used to help decarbonize the transportation sector.

Equity, Accessibility, and Inclusion

Answers to this question focused on aspects of equity, accessibility, inclusion, and positive social impacts that may be overlooked. For example, one respondent noted that these issues have to be considered in reference to shared mobility, not just AVs. Another respondent noted that we need to ensure bikes and pedestrians are prioritized in an automated world. Others wanted a literature survey to answer key questions about how to define "new mobility." For example, it was asked in a comment, what is the current state of the art for assistive technology, especially in regard to new mobility (self-securing wheelchairs for example); how will these technologies impact citizens and reach underserved populations and are there new evaluation frameworks that should be used such as KOMPIS (project in Sweden focused on mobility-as-a service).

Safety

Responses for this topic focused on how do we achieve a consensus on how safe is safe enough? Further, how can we create mechanisms for transparency, and credibility that maintain the public's trust? What sort of safety scenarios exist, and how will AVs respond to severe weather, or protect personal safety? Finally, who is liable for safety failures?

Infrastructure

This question revealed the significant level of concern over making sizable, immediate investments that are intended to last 30+ years and prepare for a rapidly changing field. The sheer scale and complexity of unknowns was noted repeatedly.

Forecast/Modeling Impacts/Scenarios

Questions and comments here included how to develop meaningful scenarios for AVs and shared mobility that are sufficient for inclusion in state and metropolitan plans. How can wise investments be made and losses avoided? What is the private sector's role and how can public-private-partnerships be utilized and encouraged? Will AI/machine learning have an impact? When will different levels of AV's be launched and rolled out? What key factors increase the likelihood of different scenarios?

Land Use

Here, comments focused on: What will the effects be on curbside use, and will changes in travel behavior cause changes in land use as well, for instance by increasing sprawl?

State/Local Laws

For this topic, questions focused on how will differences in state/local laws impact the industry, especially as it matures? Will these vehicles even be able to operate across jurisdictions?

ARE THERE ASPECTS OF THE PROPOSED TOPICS WHICH YOU BELIEVE ARE ESPECIALLY IN NEED OF FURTHER RESEARCH?

- A lot of mentions are made about AVs being shared in fleets, but the potential positive impact on climate change is not discussed. What are the steps to get to shared vehicles and shared rides? What policies might promote this to reduce congestion and climate change emissions?
- In the topic Models for Data Sharing & Governance, further research needs to be done into the Mobility Data Specification, which was initially developed by LADOT and now handled by the Open Mobility Foundation. For example, should this spec become a standard? Also, should there be other related specs or standards such as a General Curb Lane Feed Specification (GCLFS), which could describe and communicate curb lane regulations?
- Understanding of AV operational differences between freeway and arterial environments may require further research
- Manufacturer guidance on what is needed to make vehicles truly accessible to people with physical, cognitive and sensory disabilities. This work could use the Auto Alliance's report as a starting point. https://autoalliance.org/wp-content/uploads/2019/10/AVs-Accessibility-Workshop-Series-Report-16OCT2019.pdf
- How will new mobility products communicate with each other and with infrastructure.
- The cost of travel time decreases due to the ability to do other activities during travel. How much more will people be willing to travel?

The Research Team appreciates the time and effort taken to respond to the survey and looks forward to addressing these topics further during the Forum meetings and in the papers.

SOCIETY OF ACTUARIES

Innovation and Technology

An Update on the Outlook for Automated Vehicle Systems

October 2019

An Update on the Outlook for Automated Vehicle Systems

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An Update on the Outlook for Automated Vehicle Systems

Section 1: Summary

Reality has caught up with the hype/romance of the popular press concerning the future of automated driving. Disappearing is the vision of connected swarms of driverless personal cars flowing effortlessly down our arterials and freeways. The buying public, however, is beginning to absorb the driver-assisted technologies that not only deliver safety, comfort and convenience, but also serve to embolden the traditional consumer-oriented business model. This, in turn, has helped accelerate private investment and technology partnerships that involve almost every automobile manufacturer.

On the Driverless front, reality has set in that complete removal of human oversight is a non-trivial hurdle. Except for possibly Tesla, all visions of driverless vehicles operating on public roadways involves a business model based on a professional fleet operator managing the vehicles rather than individual vehicles owned by consumers. All demonstrations and tests to date, be they for the movement of people or goods, involve some form of explicit human oversight by a trained on-board attendant or driver, or active remote-control oversight. Worldwide, only Waymo has indicated that they are about to begin testing driverless mobility services in Arizona, without a safety driver. That indication only surfaced in October of 2019.

The first large-scale commercial deployment of driver-assisted technologies is likely to involve intercity trucks. Testing by several companies is expected to transition to operational deployments later this year and in 2020. A limited number of local freight tests exist with each relying of remote human oversight or control. These include pizza delivery on college campuses and tests by larger firms (Amazon has field tests in Puget Sound,[1] for example). Low-speed shuttles continue to attract a variety of small-scale demonstrations, but few sustainable business cases (retirement communities may be an exception). Drones are being tested by several firms for local freight delivery.

Sensor costs continue to decrease, with some dramatic claims regarding Lidar costs.[2] There is general agreement, however, that these sensors need to be replaced frequently, some as soon as within two years. An active debate continues regarding the use of Lidar versus optical sensors. Tesla, for example, does not use Lidar, instead relying on radars and optical sensors.

A major event is Tesla's in-house insurance plan for California.[3] This has important implications. Tesla claims their vehicles are significantly safer so this provides an opportunity to deliver financial returns to vehicle owners, generating positive feedback.

The need for more data on safety performance continues, particularly given the rapid deployment of technology in non-automated vehicles. The industry remains dependent on the Insurance Institute for Highway Safety **(**IIHS) as the best source for information on early driver-

assistance features – what this report terms Safe and Self-vehicles. Consistent terminology is important as well, given the amount of marketing jargon that distorts the actual effectiveness of new technology and confuses consumer and industry understanding of the application, its value, and the effectiveness of new technology.

Most existing regulations are positive (not too cold and not too hot). On the other hand, New York City, Chicago, and California have undertaken efforts to limit the current business model for TNCs (Transportation Network Companies such as Uber, Lyft, etc.). While increasing the cost of ride-hailing, these changes also provide incentives to speed the transition to driverless vehicles. Sharing rides is an important part of the economic and social benefits for driverless vehicles and a vital part of the financial model for firms in the Mobility-as-a-Service (MaaS)/Ride-Hailing business.

The question becomes whether local governments will continue to discourage shared rides on driverless vehicles that appear to divert traffic from transit, or if they will see this as a service that is simply another form of transit that increases the effectiveness of the transportation system.

A review of the trigger points section of the report shows no signs of an imminent breakthrough in technology or deployment; the only exception being the very recent Waymo indication that they may actually begin transitioning their Chandler/Phoenix 'Waymo One' to Driverless operation without an attendant on-board. Sensor costs are improving, with positive implications for future development. Interest is growing in the freight market (including drones) but deployment is limited. More importantly, the enormous hurdle of removing the attendant/driver from the vehicle has yet to be achieved anywhere in the world, and today only Waymo may be in a position to actually achieve this in the near future.

The text box summarizes major trends. The impact of these changes will affect every aspect of the motor vehicle industry, including vehicle insurance (directly through changes in vehicle safety, performance, and ownership, and indirectly through total trips, the mix of trip types, intensity of use, the total number of vehicles required to meet demand, and the relative share of occupied / unoccupied vehicle miles travelled), infrastructure insurance (transit, highways), and even residential insurance.

Major Trends

- Safety will improve quickly, but incrementally. Most new cars include technology that will generate important safety gains and reduce expected financial liabilities since these safety measures are focused on crash avoidance, not just crash mitigation. In time, driverless vehicles will help, but their primary motivation is to provide mobility as broadly as possible.
- State and federal regulatory agencies have been helpful, with policies and regulations allowing innovation, but there are growing signs of local concerns for the shared mobility model.
- Vehicle-to-vehicle and vehicle-to-infrastructure communication continues to migrate away from a public-sector focus, relying instead on commercial solutions such as 5G for the infrastructure side supporting the operational, management, and commercial needs of large fleets of vehicles providing Mobility-as-a-Service to people and goods.
- Data ownership issues continue to grow in importance, with implications for safety investigations, liability determination, and the ability to identify causation.
- Driverless deployments will appear in specific Operational Design Domains (ODD) (good weather, geofenced areas, explicitly certified road segments, time-of-day, etc.), rather than broadly, for the foreseeable future.
- Fleet ownership/management will likely dominate the early stage of driverless vehicle deployment, in part due to high vehicle costs, strict adherence to the Operational Design Domain, and the need for professional maintenance of more complex vehicles. Economic viability depends on ride-sharing whenever feasible. Some states may even prohibit private, consumer-oriented ownership of these vehicles.
- Cybersecurity will continue to be a substantial technical concern.
- As per mile costs decrease, vehicle and passenger miles of travel will increase. Incentives exist for longer commutes, reduced short-haul aviation, and larger commercial markets based on reduced cost to move freight.

Section 2: Introduction

The popular press plays an important role in public perception regarding automated vehicles. In contrast to the excitement generated two to three years ago, we are now in a period of “reverse hype” with most articles focused on the slow pace of development and concerns regarding possible negative impacts on traffic congestion and growth of suburbs. At the same time, an increasing number of new cars come equipped with sensors and systems that mirror those that will be used by driverless vehicles. This means that a growing portion of the traveling public are becoming familiar with the underlying technology that will be part of autonomous vehicles.

To help describe these trends and highlight differences between the cars we see on the street today and driverless vehicles, this report relies on three market-related definitions:

- **Safe** – This category describes most new cars. The driver is solely responsible for vehicle operation, but technology can improve safety by alerting to risks or by implementing safety actions such as automatic braking and blind-spot warning. There is considerable variation in the effectiveness of these technologies among Original Equipment Manufacturers (OEMs) and individual models, creating uncertainty regarding the exact impact on safety.

- **Self-Driving** (or just “Self” since “self-driving” implies more autonomous ability) – These cars can assume responsibility for select driving tasks under specific road or weather conditions. An alert driver ready to take control is required, although over confidence in the technology means some drivers act as if they are in a driverless vehicle. Because their performance depends on driver intervention, safety benefits beyond Safe technologies are not yet well understood and, in some cases, may not be significantly better than the best Safe systems. Self-driving cars require a driver in order to provide any meaningful mobility or value. They deliver additional comfort, convenience, and safety to the auto industry's existing customer base. As such, they are a "consumer play" and require no regulations or public oversight beyond what exists today. Any safety issues can be handled through standard "product liability" and ”NHTSA recall" procedures. From outside the car, one can't tell what type of technology the vehicle may or may not have on board. These vehicles are a consumer choice at time of purchase.

- **Driverless** – This vehicle is responsible for all driving tasks, at least within well-defined locations and driving conditions (termed “Operational Design Domain” (ODD)). No driver or attendant is required during the trip. (The California Public Utilities Commission uses “Drivered” for “Driverless” vehicles that require an attendant to be on-board.) These vehicles are still under development and, to date, operated only in the Drivered mode. Waymo’s deployment outside Phoenix in early 2018 remains the first public, commercial application of Drivered Driverless. Driverless cars are a "business play" with a focus on delivering mobility to individuals. Since algorithms, rather than people, tailor the service to meet individual needs, such systems can serve large markets. From outside the car, one can tell that there isn't a driver in the driver's seat. Consequently, public oversight at all levels will be important. A broad range of organizations and individuals are likely to weigh in with perceptions and regulations. This risks a change from the generally supportive attitude of federal and state regulatory agencies. California’s Department of Motor Vehicles and Public Utilities Commission are the two leading agencies that have seriously addressed Driverless cars as a mobility business play.

Section 3: News Update

The world of autonomous vehicles is always in the midst of change. This section summarizes major events, ranging from slower deployment, new partnerships, new insurance, regulatory changes, and other news items. This section highlights major changes and is not meant to provide a full description of recent events.

3.1 Slower Deployment – with a few exceptions

A few years ago, public expectations were that driverless vehicles would soon be universally available. That has not happened and hasn't even started. Substantive "Drivered Driverless" service has started in California and Arizona by Waymo. These services could be sustainable and scale rapidly by simply removing the attendant and becoming just "Driverless." Waymo recently announced that customers in Arizona will now have the option to ride in a car without an attendant – true driverless travel. This is very encouraging since we know that "Drivered Driverless" service is economically unsustainable and doesn't scale. Even Waymo (part of Alphabet) has limited resources. Once started, deployment is likely to follow at a measured pace, with vehicles available market by market and location by location. Weather and positive local regulations will help decide where and when driverless vehicles appear. One observer characterized this as similar to a Land War, with progress made slowly and place by place.

Waymo (owned by Google) and Cruise (owned by General Motors) are viewed as the industry leaders (for cars). Cruise originally planned to operate driverless vehicles (most likely with a safety driver) in San Francisco by the end of 2019. They recently said they would not be ready and delayed deployment for some future date, not yet specified. Other companies continue to test, with a variety of promised dates for deployment, most in the 2021-2023-time frame. Recent test efforts include Waymo in Los Angeles, Uber in Dallas, and Cruise in Las Vegas.

3.2 Waymo moves forward – a bit slowly

Waymo has announced plans to purchase 82,000 vehicles, 20,000 from Jaguar and 62,000 minivans from Chrysler. No information is available regarding when actual orders will be placed. While 82,000 is not a large number relative to the overall fleet in the US, because they will be used for most of the day and provide shared rides, they are capable of carrying more than a billion rides a year – equal to about one fourth of total transit bus riders in the US. A logical assumption is that Waymo will focus these vehicles in a limited number of urban areas. This means they will have a noticeable impact in those specific locations. Waymo has not announced where or when they plan to deploy these new vehicles.

Waymo has been providing shared ride service in their automated vehicles in Chandler, Arizona since the end of 2018. They plan to begin expanding this to neighboring jurisdictions late this year, starting with Tempe (home to Arizona State University). The Chandler operation uses about 500 Chrysler Pacifica vans and includes a maintenance facility. Following a period of tests with volunteers, these vehicles are now available to the general public using an app similar to that used by TNCs such as Uber and Lyft. Trips are limited to Chandler and Tempe. Waymo just announced that their customers in Arizona will have a choice of riding with a safety attendant or riding in a fully driverless vehicle.

The Waymo Drivered Driverless vehicle is now available as an option to Lyft customers in Chandler. (Lyft is also working with Aptiv testing driverless vehicle in Las Vegas, Nevada). The City of Chandler recently announced that, rather than using the city's motor pool, employees would use Waymo to move around the city. This should represent a savings to the city. Walmart has offered to pay the costs for customers – an interesting example that could find other applications.

3.3 Trucks

Trucks have always been seen as a logical first market for driverless vehicles. Trucks are already operated by commercial firms, who would receive tangible benefits from cost savings in operations and access to larger markets. Also, the intercity truck industry faces a long-term shortage of drivers. Trucks are also substantially self-insured, a liability that is privately estimated to be roughly $10,000 per truck per year that some estimate could readily be halved by emerging automated driver-assistance technology. As a result, several well-funded technology firms are focused on developing the technology to capture this market opportunity. These include some of the big-name firms, with Waymo and Uber entering the market from time to time (Uber was involved in a major lawsuit over intellectual property on this topic).

After several years of testing, some with US Department of Transportation (DOT) funds, Peloton says they have seven trucking companies that will support a deployment either later this year or early 2020. The Peloton system calls for "truck trains" with trucks benefiting from reduced fuel use while they drive in close proximity to the leader vehicle. Drivers in the following trucks may steer the vehicles or just watch for problems – and drive the vehicle to and from the warehouse. Peloton plans to operate driverless trucks at some point as well. These "trains" may create safety concerns for other vehicles on the road. There is a clear need for systematic data collection regarding safety, including public perceptions.

Other examples include: TuSimple that has been operating trucks between Dallas and Phoenix for the Post Office and between Phoenix and Tucson for UPS. To date, all include a safety driver. UPS has invested in TuSimple. Starsky Robotics plans trucks that are "driven" by remote operators. A Swedish firm has a similar plan using a dramatic new vehicle with not only no steering wheel, but also no cab for a driver. This summer, Starsky did operate a fully driverless vehicle on a short route in Florida but, to date, the firm uses safety drivers.

Each of these firms plan commercial operations within the next year. Despite the current shortage of over-the-road drivers, there are strong public concerns about the loss of jobs. In August, truck drivers staged a demonstration in Missouri in opposition to proposed legislation to allow driverless trucks in the state.

3.4 Safety record – and the need for more data

Safety data regarding Safe and Self-vehicles is largely missing and also inconsistent. One problem is that drivers ignore (often on purpose) the new monitoring systems in their vehicle. Consumer Reports conducted a recent study of this problem that showed many drivers were confused by the large number of "beeps" and often did not know how to respond. This shows,

in part, a lack of careful thought by many auto technology firms and represents a significant gap between the potential benefit of new vehicle technology and actual practice.

Beyond this, the volume of data is limited and often inconsistent. IIHS provides one of the few sources of test data regarding technology in new vehicles. IIHS reports that the performance of intelligent cruise control, automated lane keeping, and automated emergency braking varies substantially among OEM, reflecting the amount of authority the OEM has given to the automation system. For some, system designers have chosen to ignore stationary objects above certain speeds to reduce false alarms due to overpasses, signs, and tree canopies. Related problems are the wide variety in names and claims regarding these technologies. Marketing seems to have taken precedence over technical accuracy.

In time, the National Highway Transportation Safety Administration (NHTSA) will likely become more involved. This requires a large enough sample of vehicles to identify consistent problems. At present, NHTSA is investigating a "false positive" problem with automatic brakes on Nissan cars.

Tesla stands out as a firm that promotes data regarding the safety of its vehicles. For example, they claim only one crash for every 3.27 million miles for drivers using their Autopilot system; one for every 2.19 million miles for those using Tesla's active safety features; and one for every 1.41 million miles for drivers not using these features.[4] These numbers sound very impressive (NHTSA reports an auto crash every 500,000 miles), but are the results consistent with other vehicles or with how NHTSA reports data? Tesla has yet to provide details on the nature of these data and their calculations.

3.5 Implications of Tesla Insurance package

In September, Tesla announced its own auto insurance firm for residents of California (it will be run by an insurance firm, rather than by Tesla itself). This is an important announcement, both for the automated vehicles and for the insurance industry. Tesla promises savings of 20-30% relative to existing commercial auto insurance rates for its vehicles. Tesla plans to expand this insurance program elsewhere in the US. While Tesla claims low crash rates, its cars can be expensive to repair given the aluminum construction, limited parts, and few auto body repair experts.[5]

This allows Tesla to leverage what it views as a major strength of its vehicles – its safety record. Tesla now has a clear incentive to make its safety systems (including Autopilot) even better. This benefits the insurance company – and Tesla's customers. The Tesla insurance firm will have access to detailed data that will help determine responsibility for any crashes. There appears to be implications for other OEMs with technology in their cars to follow this model. In contrast, automobile OEMs in Sweden also have proprietary insurance firms, but seem to view them solely as another profit center.

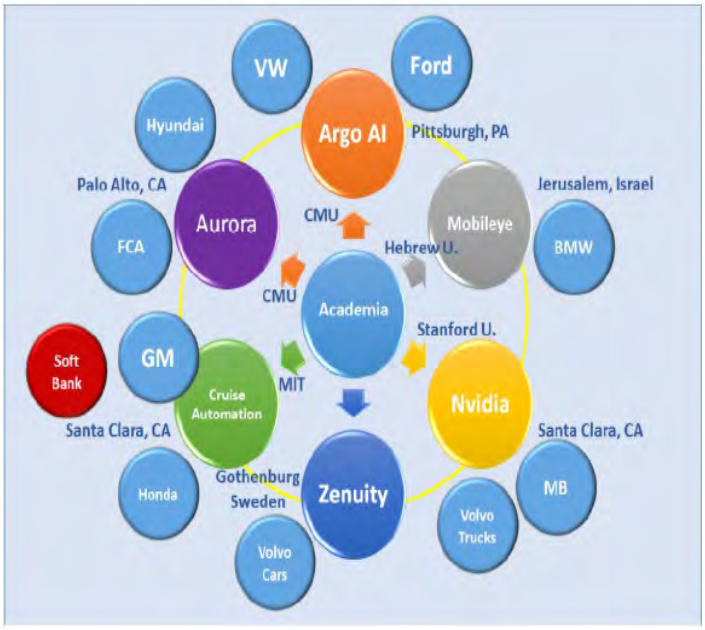
3.6 Company mergers

Over the past five years, private investment in the autonomous vehicle industry has exceeded $100 billion – a large number for any industry, but massive when compared with public

investment in transportation research. Beyond this, there are an increasing number of mergers among technology firms and large OEMs. This has important implications for the marketing of automated vehicles. These large consortia all seem focused on shared riders rather than sales to individual drivers. Serving shared rides allows full use of the vehicle.

A few relevant consortia (see below chart[6] for a summary):

- Ford and VW. Previously, Ford bought Argo AI for $1 billion. This partnership now adds another $2.6 billion in cash and staff from VW's technology group.
- Waymo has partnered with Renault-Nissan, opening up opportunities in Japan and Europe.
- Honda has joined GM/Cruise.
- Aurora (founded by the past lead for Waymo and the technology lead for Tesla) has partnered with Fiat-Chrysler and Hyundai.
- Apple purchased drive Ai – a small deal but one that shows Apple remains interested in this field.



Only a few major firms seem left out, such as Toyota, BMW, and Daimler. Beyond the money, this shows serious interest in deploying the technology on a large scale. There are no new forecasts regarding when this may occur. This discussion of partnership does not cover the truck business.

3.7 Uber and Lyft IPOs

Uber and Lyft are leaders in the business of shared mobility. Both have been able to raise huge sums of investment money despite vast financial losses. Both firms recognize that their current business models cannot be scaled – there is not a large enough supply of part-time drivers and a general lack of economies of scale. Both view autonomous vehicles as required in order to reach profitability.

Both firms underwent their initial public stock offering (IPO) this year. These have not gone well. The valuation at the IPO was substantially less than the most recent private valuation. On top of this, both stocks suffered significant drops in the weeks following the IPO. To make things worse, their initial quarterly reports showed larger than expected losses, partly due to the IPO itself.

The firms face two general options: 1) reduce the number of drivers and focus on higher margin business or 2) use driverless vehicles to reduce costs and stimulate a significant increase in business volume.

Very simply, today Uber carries 4 billion rides a year and loses about $4 billion a year – or roughly one dollar for each ride. To justify a market valuation of some $40 billion, Uber needs to generate a profit of $1 per ride rather than a loss. To be successful, option one described above implies 400 million rides a year, with a profit of $10 per ride – or a total of $4 billion. Option two implies 40 billion rides a year (stimulated by a much lower price per mile) with a profit of ten cents per mile. In fact, this autonomous vehicle model would likely support a larger profit per ride.

Following problems with their IPOs, Uber and Lyft have even larger incentives to deploy autonomous vehicles.

3.8 Regulations

Federal and state regulations regarding autonomous vehicles continue past trends. The USDOT's latest guidance document: ***Preparing for the Future of Transportation: Automated Vehicle 3.0*** (Fall, 2018) continues the position of the Trump and Obama Administrations to encourage innovation, rather than over-regulating or picking winners and losers. Most states follow this process. California has the most detailed regulations. The state's Department of Motor Vehicles recently established new rules that allow companies to test driverless vehicles without a safety driver. This is a major change for California. So far, two companies have applied for this right, but do not appear to have begun such testing. Most states have regulations in place that allow automated vehicles to test or operate. Many states (including California) are open to waivers for local deployments.

No progress has been made regarding the proposed federal legislation that would clarify federal versus state regulations. This legislation almost passed in the last Congress, but was held up by opposition regarding the effect on truck drivers and concerns by safety advocates over the number of exemptions. Another effort will be made to pass this. Meanwhile, individual states are moving forward.

3.9 Local opposition to TNCs

Over the past five (5) years, Transportation Network Companies (TNCs), of which Uber and Lyft are prime examples, have become a viable form of Mobility-as-a-Service. While on a typical day they serve less than one of the daily trips, they have become widely recognizable by the general public and especially business professionals, tech savvy individuals. Part of their allure is that for many they are known as "ride-sharing" firms, even though a very small percentage of their ridership involves real 'ride-sharing': having a single vehicle serve unrelated individuals having portions of their trips going from about the same place to about the same place at about the same time. Overwhelmingly, they serve either single riders or single groups of riders that, for reasons other than transport efficiency, were traveling together, say to go to dinner. The success of these companies has been fueled by the elegant ability of their app-based ride-hailing

features to remove the 'sketchiness' and anxiety associated with hailing a ride, getting into a car with a stranger and paying for the ride (no one touches the money), and the ability to use non-union labor on a part-time basis to substantially reduce it driver labor costs. While such services could be made substantially more affordable by completely replacing the driver with driverless technology, and even more by ride-sharing, existing Uber/Lyft from a level-of-service point of view are essentially an exact forebearer of a driverless autonomousTaxi (aTaxi) service. This correspondence provides an opportunity for aTaxi concepts to learn and improve upon challenges faced by Uber/Lyft.

One of the challenges is the growing opposition to TNCs by local governments. These arguments focus on concerns about increased traffic congestion, riders diverted from transit, lost business for existing taxi owners (often with dramatic losses in the value of taxi medallions), and concerns that drivers have been taken advantage of by the TNCs and do not receive adequate compensation. Actions include:

- Efforts by drivers to organize strikes;
- Higher fees for TNCs (in New York City and Chicago);
- Mandated hourly compensation for drivers (New York City and Chicago);
- Efforts by airports to move TNCs away from the terminals (LA and San Francisco among others); and
- Recent legislation in California that may force TNC firms to treat their drivers as employees rather than "gig" or part-time employees.

While the impact of the California legislation is uncertain, there is clear opposition in some cities to shared ride vehicles that increase vehicle miles travelled (VMT) and divert travelers from transit. This has two implications:

1) Encourages TNCs to move to driverless vehicles sooner (they already have financial incentives to do this), and
2) Worries that cities and states may attempt to limit use of future driverless vehicles to avoid increasing VMT and diverting transit riders.

3.10 AVs and Mobility Impaired

There is debate about the economic and social advantages of driverless vehicles. Safety is often mentioned, although this may be less important as technology is deployed in Safe and Self-vehicles. Shared rides are important, both because it appears to be a logical route to profit and because it can provide significant economic and social benefits by improving access. Another focus is travel for mobility-impaired people—whether due to physical handicaps, low incomes, or lack of access to reliable transit. Such a focus would also generate public support, something that might have value given the apparent growing opposition to TNCs.

In this regard, Volkswagen recently unveiled a plan called Inclusive Mobility Initiative with a focus on people with disabilities. While not yet implemented, this provides another public business model.

Section 4: Trigger Points[7]

This section describes a series of "trigger points" or factors that could hinder or accelerate the market for autonomous vehicles and, thus, shape the nature of how and when technology is deployed. Tracking these elements can provide guidance regarding the pace of deployment for each of the three parts of the general framework described above: Safe; Self; and Driverless. These trigger points are organized in three groups:

- Policy -- Institutional/regulatory change
- Technology
- Market penetration rates

Technology is the only section that shows real change in recent months. Market penetration should start to show some progress given the expected deployment of intercity trucks and the growing number of specialty vehicles (local freight delivery, drones, and low-speed shuttles).

4.1 Policy Triggers

Policy is stalled. This is not helpful, but then regulations have also not regressed other than some local governments trying to place a cap on shared ride firms (TNCs).

1. Clarification of state versus federal regulatory responsibilities
   - Results: Legislation from the last Congress stalled due, in part, to opposition by truck labor unions and concerns for stronger safety regulations. The USDOT's ***Preparing for the Future of Transportation: Automated Vehicle 3.0*** continues to promote a hands-off policy. State regulations continue past trends – that is encouraging deployment (California now allows testing of fully driverless vehicles). As part of efforts to encourage economic development, many states have encouraged deployment of autonomous vehicles, but with limited results.
   - Commentary: Worries exist today concerning the risk that inconsistent regulations among states might add to vehicle costs. Federal legislation to clarify federal and state roles could provide a more consistent playing field. There is a risk, however, of too much detail too early. Thus, the nature of legislation is at least as important as the legislation itself. Congress may make another attempt to pass legislation.

2. Regulatory requirement for a given technology promulgated
   - Results: No change. Thus, no incentive for manufacturers to wait for regulatory action. The low-speed shuttle industry has been advocating for clearer guidance from NHTSA. Some vehicles do not require a waiver, but others do (mostly US-designed vehicles). All need a local waiver from the state department of motor vehicles.
   - Commentary: Regulatory actions for specific technologies are rare today. Any specific requirements will likely speed deployment, but also could (a) slow innovation, and (b) encourage firms to slow deployment in order to wait for action by NHTSA. New regulatory actions appear unlikely in today's environment.

3. Requirement to include vehicle technology information in Vehicle Identification Number (VIN)
    - Results: This is increasingly mentioned at regulatory meetings but, so far, no movement. It likely requires a strong push by safety advocates, insurers, researchers, law enforcement, and repairers. Tesla's in-house insurance (starting with California) will provide Tesla with the equivalent information.
    - Commentary: Requiring system information in the VIN would allow accurate tracking of vehicle safety performance in consideration of installed systems, making analytic, regulatory, or risk estimation efforts more effective. This would be a positive action both in terms of encouraging deployment and supporting the analysis of technology effectiveness.

4.2 Technology Triggers

Some progress here. New Safe vehicles are increasingly equipped with safety features (emergency braking, lane tracking, etc.). The number of Self-vehicles is growing. Tesla leads the field, but other firms have begun to deploy vehicles with some self-driving abilities. A correlation suggests there may have been a positive impact of these recent trends regarding reduced auto fatalities in 2018. Sensor costs have dropped significantly (Lidar is a good example). More experience is needed regarding reliability of Lidars. Some firms say that Lidar sensors need to be replaced within two years. There is continued interest in using optical sensors, perhaps in place of Lidar. In time, this would reduce costs further.

4. Automated Emergency Braking (AEB)
    - Results: Forty-five percent of new car sales in 2018 were equipped with AEB (and other systems such as lane tracking) – a very encouraging trend – but not all drivers use AEB and AEBs can cause problems with fake positives (witness Uber crash in Tempe and several Tesla crashes) and fake negatives (witness NHTSA investigation of Nissan). One hopes that, with experience (and perhaps pressure from the insurance industry), the severity of these issues will reduce.
    - Commentary: AEB is one of the most important automation applications with value for Safe, Self, and Driverless vehicles. In addition to confusing marketing terminology, the effectiveness of current industry applications varies widely and system performance parameters are not broadly understood. Increased standardization could improve safety and speed safety gains.

5. Cost of Lidar systems
    - Results: Increased competition (more than 50 firms versus only one ten years ago) has reduced costs. At least one firm advertises a Lidar device for less than $500. More established firms talk about total Lidar costs dropping to around $10,000 per car in the next 2-3 years.
    - Commentary: Lidar units are generally considered central to effective Self-Driving and Driverless systems. A year or so ago, these costs totaled tens of thousands of dollars for each unit (down from more than one hundred thousand dollars 4-5 years ago). With increased demand and competition, prices have dropped in recent years and further

reductions are expected within the next few years, accelerating the deployment of Self-Driving and Driverless vehicles, possibly also supporting vehicle retro-fits. These changes are occurring despite recent trends toward the use of optical sensors.

6. Costs and effectiveness of other sensors
   - Results: General improvements continue as demand for optical sensors and radars increases.
   - Commentary: Optical sensors have become increasingly important as some firms begin to shift away from Lidar as the dominant type of sensor. As with AEB, no industry standards currently exist.

7. Growth in vehicle Cyber Insurance
   - Results: No significant change.
   - Commentary: Cyber Insurance is expected to become increasingly important in the AV space as applications become more advanced. Growth in this segment will reflect the rate of adoption and maturation and the degree to which confidence exists in the ability to limit potential cyber-attacks.

4.3 Vehicles and Vehicles Use

Deployment has been limited, so there is little hard data regarding vehicle use. Exceptions, including low-speed shuttles, continue to grow, but their market share is low and there are few signs of sustainable business case; intercity truck market appears ready to begin commercial use; and interesting examples of local freight delivery exist. However, to date, none of these trends show significant growth. Shared rides in TNCs (Uber, Lyft, etc.) continue to grow, although the rate of growth has slowed a bit. A few jurisdictions (individual cities plus California) have begun to add costs to TNCs in order to reduce demand and support taxis and transit. Some locations (New York City and California) have worked to restrict their flexibility. This is not yet a national trend, but important to watch since it has implications about possible efforts to limit the growth of autonomous vehicles.

8. Privately-owned light vehicles and commercial light vehicles with Safe and Self-technology
   - Results: There has been noticeable growth in safety technologies in new Safe vehicles and not just for high-end vehicles. About 45% of new cars now include automatic braking (AEB), although no guarantee exists that consumers will take advantage of this technology. More firms are promoting Self-vehicles. These help to generate comfort with the “feel” of driverless vehicles.
   - Commentary: Share of personally-owned vehicles with “Safe” and “Self-driving” systems should be tracked, with a focus on the type of technology. Within this group of vehicle types, share could be tracked by new vehicles manufactured (easiest) or VMT (more difficult) and PMT (passenger miles traveled, most difficult). Variation across type of region is important (CBD, suburban, rural, etc.). IIHS offers an opportunity to test vehicles prior to collecting large volumes of data.

9. Ride sharing – measured by total number of shared rides and average occupancy
    - Results: Growth continues, with the number of shared rides now exceeding the number of national transit bus riders. The rate of growth has slowed. Pressure from Uber and Lyft to become profitable may encourage higher fares, slowing growth further.
    - Commentary: The market share that is made up by ride sharing is a key indicator of a fundamental change in vehicle use and AV adoption. Widespread ride sharing – reflected in average vehicle occupancy – would favorably affect demands on infrastructure, safety, ownership, and insurance.

10. Driverless vehicle share of VMT or passenger miles travelled (PMT) in a given market. This should be examined by type of market – CBD, metro area, rural, etc. and by region of country (areas with poor weather versus good weather).
    - Results: These numbers round to zero – with nothing other than a few hundred vehicles in Chandler, Arizona. Major OEMs and technology firms still talk in terms of deploying automated vehicles in the near (undefined) future. Where remains a question as well.
    - Commentary: Driverless will precipitate changes in ownership models, safety, and costs. The single most important trigger point will be when Driverless earns a meaningful share – measured either in terms of given market, region, or country. These data should be tracked by type of location and by region of country.

11. Driverless commercial vehicles. Detail by region is important – Western states may grow faster than more densely populated Eastern states.
    - Results: To date, experience has involved tests. This is about to change with several firms planning deployment later this year or in 2020. Few details exist on the geographic extent of these plans.
    - Commentary: Because of its economic value, Commercial VMT should be measured in two ways:
        a. Partial automation: Commercial trucking is already pursuing platooning or operating Driverless in restricted domains, such as expressway miles only. This should lead to reduced labor costs and increased safety for the automated portion of the journey, with the risks of the remainder of the journey a function of Safe/Self technologies.
        b. Full automation: True end-to-end Driverless VMT.

Section 5: Acknowledgements

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Endnotes

[1] https://finance.yahoo.com/news/amazon-rolls-robots-trying-automated-211424167.html
[2] Luminar announces a $500 Lidar device. https://cleantechnica.com/2019/07/12/500-lidar-from-luminar-could-move-autonomous-driving-forward/
[3] https://www.tesla.com/support/insurance
[4] https://tesla-info.com/blog/tesla-safety-report-and-the-need-for-caution.html
[5] Data from IIHS, however, does not show savings in repair costs for Tesla vehicles.
[6] Chart from Michael Sena's *The Dispatcher (September **2019**.*)
[7] These were developed in a previous report by the Society of Actuaries. "Market Framework and Outlook for Automated Vehicle Systems"; (March, 2018)

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Scenario Planning for Connected and Automated Vehicles

Summary Report

October 22, 2018

U.S. Department of Transportation
Federal Highway Administration

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FHWA-PL-18-029

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16. Abstract Automated Vehicles (AVs) and Connected Vehicles (CV) promise significant opportunities for transportation planners and to society, but also present an uncertain and complex landscape for planning agencies. This report describes an exploratory scenario planning effort to create six future scenarios pertaining to CV and AV technology, as well as descriptions of the scenario components and outcomes. Exploratory scenario planning is a tool for dealing with uncertainty that involves planning for a range of plausible futures to prepare for a wide range of impacts. This research report serves as the technical basis for a separate "Practitioner Guidance" document intended to guide transportation agencies through the process of tailoring these scenarios to their regions and conducting their own scenario planning exercises for CV/AV deployment considerations.			
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EXECUTIVE SUMMARY

Across the nation, metropolitan planning organizations (MPOs), State departments of transportation (DOTs), and other transportation agencies are facing increasing pressure from constituents, political leaders, and regulatory agencies to develop performance-oriented policies, plans, and investment decisions that take into account a rapidly changing and increasingly complex transportation landscape. Transportation planners and policy makers today need to consider the wide range of impacts made by evolving forces and market developments whose trajectories are highly uncertain. In particular, transportation professionals need to consider (although cannot yet accurately predict) the potential transformational influences of connected vehicle (CV) and automated vehicle (AV) technologies on driver behaviors, safety risk factors, land use, roadway network design requirements, economic development trends, system performance, travel demand distribution, and other factors.

Numerous AV and CV pilot programs are already undergoing testing in the United States and abroad. In some cities where testing is underway, AVs are becoming a common sight on the roads. AV and CV technology could potentially yield one of the most profound transformations in transportation history. These technologies have the potential to improve safety, reduce operational costs, and provide new mobility options for many population groups, among other outcomes.

Although some forms of CV and AV are already being deployed across the United States, significant unknowns exist regarding the rate of technology adoption, which types of technologies will prevail in the marketplace, the interaction between CV/AV technologies and various forms of shared mobility services, and the effects of interim and widespread levels of CV/AV usage.

Exploratory "scenario planning" is an excellent method for examining the ways in which these types of forces, variables, and outcomes relate to one another. Scenario planning is defined as "an approach to strategic planning that uses alternate narratives of plausible futures (or future states) to play out decisions in an effort to make more informed choices and create plans for the future" (FHWA, 2015).

ES-1. Project Goals

This project sought to apply a scenario-planning framework to CV and AV technological development. Notably, this project did *not* seek to develop normative scenarios, which are used to determine priorities, but rather developed exploratory scenarios, which are used for informing strategy.

This project had two primary goals:

1. Develop a set of plausible future scenarios that collectively portray the possible trajectories of CV and AV technology in terms of their capability, availability, and usage.
2. Provide guidance to transportation planners on conducting their own CV/AV scenario planning processes by tailoring the project materials to local, regional, or statewide goals, needs, issues, opportunities, and resources.

The first goal is important in that the scenarios themselves could be of value to State and local planners who lack the resources and knowledge to develop technology-based scenarios. The second goal provides a defined structure to practitioners for interpreting the six scenarios, and for gleaning insights to support planning, policy, and decision-making.

ES-2. Scenario Development Process

The project team developed, refined, and tested six scenarios of potential futures related to CV/AV deployment, adoption, use, and likely outcomes. These scenarios were formulated from a fresh slate; although prior efforts and guidance were examined for reference, the intention was to develop a new list of scenarios that provided more robust, detailed concepts than those available from other research to date. To ensure that these scenarios were plausible and internally consistent, opinions of industry experts were collected in a workshop conducted as part of this project.

Defining Connected Vehicles for the purpose of this report

Vehicles are increasingly connected to the outside world through both vehicle equipment from the manufacturer for system and performance data to nomadic devices brought into the vehicle by the traveler. Through these links, real-time information can be broadcast to the vehicle or driver as it/they navigate their route.

In this report, the term Connected Vehicles (CV) refers to the **ability of a vehicle to communicate with other nearby vehicles (V2V) and the infrastructure (V2I).**

Since this communication could be enabled by many different technologies, this report defines the degree of connectivity in a technology-neutral manner. The report focuses on the *capability* of vehicles to send and receive data from nearby vehicles and infrastructure in a standard, interoperable manner with desired performance requirements to support applications such as:

- Providing safety warnings (forward collisions, unsafe speed heading into a turn, weather notices, intersection movement assists, red light warnings)
- Sending distress messages to authorities
- Harmonizing traffic speed with trailing or leading vehicles to improve efficiency
- Receiving real-time traffic information to improve routing
- Submitting speed and destination data to provide traffic flow estimates to a data center and to other vehicles

To maximize the scenarios' usefulness to planners and decision makers, the research focused on defining the effects of potential scenarios on agency operations and planning decisions. This involved hosting a second workshop with State and local transportation technology professionals from various organizations around the country. Over a day and a half, these planners shared their insights into how these scenarios could affect decisions about critical concerns, such as infrastructure investment choices, policies, and agency staffing and technical capabilities.

The project team completed the process of developing, refining, and analyzing the scenarios over many months and included contributions from many industry experts. The effort involved several steps:

1. **Conducting a literature review**
   The literature review helped to gain general understanding of the CV/AV arena and relevant factors shaping the technology's evolution and impact.
2. **Compiling a list of factors shaping CV/AV deployment ("drivers" and "levers")**
   This phase of the scenario development process consisted of identifying the major exogenous factors that influence CV/AV deployment, termed "drivers," and the policy decisions, termed "levers," that might affect transportation systems and planning.
3. **Identifying the most important and uncertain forces**
   Given the many permutations of drivers and levers, it is impractical to build scenarios unique to each potential combination of forces. The team focused its attention on three fundamental elements, the trajectories of which are highly uncertain. Automation is the degree to which vehicles can operate without driver intervention.[1] Connectivity refers to the facility with which data are transmitted to and from vehicles, services, infrastructure, and other key elements of the transportation network. Cooperation is the degree to which policies, business models, and infrastructure reflect coordinated efforts to improve system efficiency. Each of the six scenarios developed under Step 5 feature a unique combination of High, Medium, and Low levels for these three key forces.
4. **Determining a consistent future year and developing a baseline future scenario**
   For simplicity and for improved comparability, the project team assigned the same base year (2035) for all scenarios. The year 2035 was considered to balance two opposing concerns: being far enough in the future to allow for substantial change, while not being so far that problems could be "wished away." This year also parallels the 20-year horizon typically applied to regional and statewide long-range transportation plans. To establish a foundation against which the alternative future scenarios could be compared, the team developed a baseline scenario that assumed the minimum plausible change among the three key forces.
5. **Developing a list of scenarios**
   A draft list of scenarios was created, then refined and expanded at the first workshop, based on the opinions of leading experts. The following factors were considered when making this list:
   a. Ensuring coverage of the full range of uncertainty among the three key elements of Automation, Connectivity, and Cooperation;
   b. Making each scenario distinctly different from the others to allow for meaningful comparisons;
   c. Affirming that each scenario was plausible and internally consistent, regardless of how likely it was to occur; and
   d. Limiting the list of scenarios to a manageable number between three and six (fewer than three does not allow for meaningful comparisons, while more than six tends to produce redundant or confusing scenarios).
6. **Examining, stress-testing, and validating the scenarios (Workshop 1)**
   The literature review and the first workshop sought to validate the plausibility of the technological, cultural, socioeconomic, and policy drivers and to validate the importance

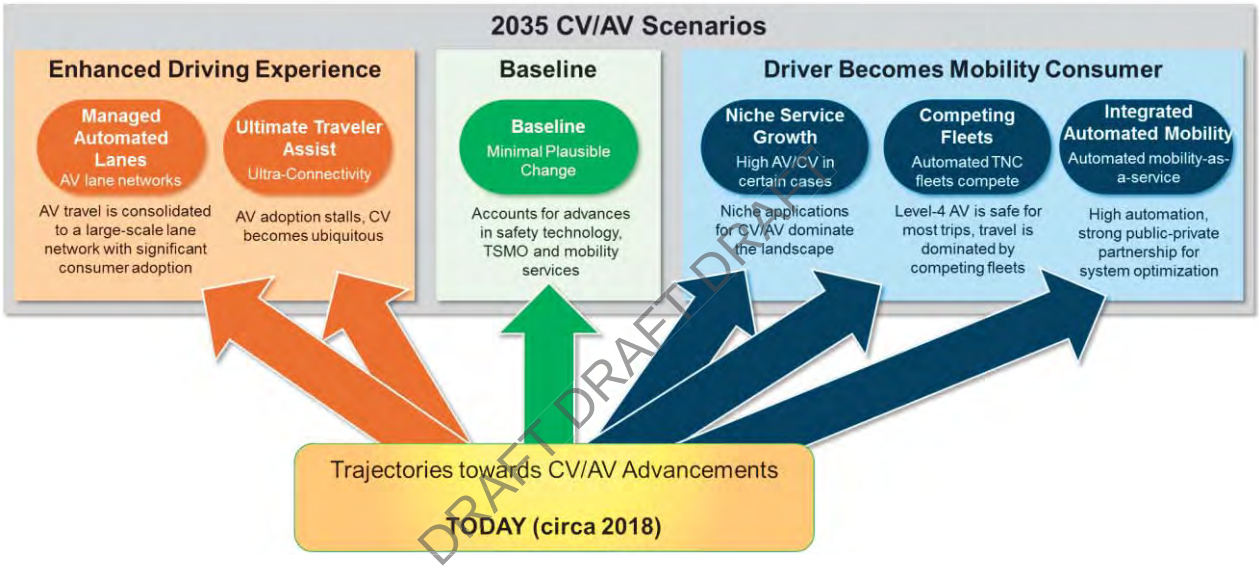
[1] Levels of automation mentioned in the report are based on SAE International's six levels of automation.

and definitions of the three key uncertain elements (Automation, Connectivity, and Cooperation). Workshop participants also discussed expected outcomes and refined the "Baseline" scenario by determining a minimum plausible level of change.

7. **Identifying scenario planning implications and applications for planners and policymakers (Workshop 2)**
   In the second workshop, planners and policymakers from State and local agencies across the country provided input on how each scenario could affect agency operations and plans, and how they might apply the scenarios to their decision-making.

ES-3. Scenario Descriptions

Figure ES-1 provides an overview of the six scenarios relative to 2018.



Note: Managed Automated Lanes, Competing Fleets, and Integrated Automated Mobility are each characterized by high automation and high connectivity. However, unlike the Ultimate Traveler Assist scenario, the degree of connectivity in these three scenarios is less certain; a theoretical variant of them exists with less connectivity, as some CV applications are not a necessary prerequisite for the fundamentals of these scenarios.

Figure ES-1: Diagram. CV/AV Scenarios as Compared to Today (Source: FHWA)

Table ES-1 shows how the scenarios relate to one another in terms of the three key uncertain elements. The first workshop refined many details of the CV/AV scenarios, and resulted in the addition of the Managed Automated Lanes scenario. The second workshop provided insight on the impacts to planning of each scenario.

Table ES-1: Scenario Scale Ratings

Scenario Name	Scale Ratings			Brief Description
	Connectivity	Automation	Cooperation	
Baseline	Low	Low	Low	Minimum plausible change; nothing beyond currently available technology and investments already in motion
Niche Service Growth				Innovation proliferates, but only in special purpose or "niche" applications
Overall System	Low	Low	Low	
Niche Services	High	High	High	
Ultimate Traveler Assist	High	Low	Medium	CV technology progresses rapidly, but AV stagnates
Managed Automated Lanes				Certain lanes become integrated with CV and AV, and managed for consistent speeds
Overall System	High	Medium	Low	
AV lanes	High	High	High	
Competing Fleets	High	High	Low	Transportation network company-like services proliferate rapidly, freight automation grows but none of these services operate cooperatively
Integrated Automated Mobility	High	High	High	On-demand shared services proliferate and integrate with other modes via cooperative data sharing, policies, and infrastructure

Automation, Connectivity or Both

This report describes three scenarios with widespread adoption of high levels of automation: Managed Automated Lanes, Competing Fleets, and Integrated Automated Mobility. In each of these scenarios, there is an assumption of the broad availability and use of Level 4 automated vehicles.

While each of these three scenarios could be realized with AV only, in this report, these scenarios include assumptions of high connectivity between vehicles and the infrastructure in addition to automation. For example, in the Managed Automated Lanes scenario, connectivity enables the inclusion of applications (such as cooperative speed management) that provide system-level benefits. In the Competing Fleets scenario, connectivity may enable some improved mobility benefits through transportation systems management and operations. And in the Integrated Automated Mobility scenario, connectivity enables better optimization of routes and services beyond immediate automation.

Baseline

The Baseline scenario reflects the minimum plausible change in 2035, assuming that the investments, policy decisions, and technology trends of today (circa 2017) continue to evolve along their current trajectories. No significant breakthroughs would occur in CV or AV technology, and no major changes would be made to policies or regulations. All other scenarios can be differentiated against this scenario. Although it is the least transformative of all the scenarios, the Baseline trajectory is still substantively different from the conditions in 2017, largely due to increases in market shares and applications of existing technologies. Notable aspects of the Baseline scenario are summarized in Table ES-2.

Table ES-2. Key Markers of the Baseline Scenario

• There are no revolutionary breakthroughs in CV or AV technology.
• CV and AV technology that exists or is in development in 2017 is refined and brought to market at a modest pace. o Level 2 automated vehicles make up about 30 to 40 percent of the market. o Level 3 and 4 AVs are not commercially available. o Forty percent of vehicles have vehicle-to-vehicle/vehicle-to-infrastructure/vehicle-to-everything (V2V/V2I/V2X) capability.
• Electric Vehicles (EVs) gain market share only gradually, continuing at their current pace, comprising approximately 5 percent of new vehicle sales overall (15 percent in urban settings).
• Five to ten percent of trips use mobility-on-demand service providers (rising to 20 percent in major cities).
• There are no rulemakings mandating CV technology in light-duty vehicles. There is uncertainty about the roles of technologies such as Dedicated Short Range Communications (DSRC) and 5G cellular networks in supporting transportation-related communications connectivity and cooperation.

Niche Service Growth

In this scenario, due to a mixture of technological, financial, and regulatory hurdles, advanced levels of automation (Levels 3 and 4) are restricted to local niche services but are transformative in certain settings like retirement communities, neighborhoods, congested downtown areas, and some first-mile/ last-mile services. Connectivity and cooperation also progress in those applications, but with the exception of these niche areas, the world is unchanged from the Baseline scenario.

Table ES-3. Key Markers of the Niche Growth Scenario

• CV and AV technology that exists or is in development in 2017 is refined and brought to market at a modest pace. o Level 2 automated vehicles make up about 30 to 40 percent of the market. o Level 3 and 4 AV technology becomes commercially available, but is not able to perform safely in unmapped, unequipped, or unpredictable conditions and therefore cannot be used in the majority of contexts. o Forty percent of vehicles have V2V/V2I/V2X capability.

Table ES-3. Key Markers of the Niche Growth Scenario

• AV Zones are created where Level 3-4 AVs provide niche services in a coordinated fashion within a cordoned area or along a limited number of intercity corridors.
• No industry-wide agreement on data ownership or sharing models arises; rather, a patchwork of agreements even within States results in significant regional variation. Each niche AV fleet has different data formats and sharing practices, and different combinations of public and private partners.
• Fleet automation grows. o Commercial platooning in freight fleets is widespread. o Public transit vehicles generally have Level 2 automation (except for those involved in niche programs).

Ultimate Traveler Assist

The Ultimate Traveler Assist scenario is characterized by significant advancement in vehicle and traveler communication systems beyond the Baseline scenario. Through technological advancements, investments in infrastructure, and data-sharing and privacy agreements, vehicle connectivity becomes almost ubiquitous, giving State and local agencies the ability to manage demand and operations precisely and thereby greatly reduce congestion. However, automation does not progress past the Baseline scenario.

From the perspective of a driver or multimodal traveler, trip making is made easier than ever before; information on route times and prices is easily accessible across modes, and congestion is substantially mitigated compared with the Baseline scenario (and with today). Although the usability of modes improves, and system coordination is improved through central management, the underlying transportation patterns and paradigms are mostly unchanged from the Baseline, since automation is no more prevalent.

Table ES-4. Key Markers of the Ultimate Traveler Assist Scenario

• AV technology that exists or is in development in 2017 is refined and brought to market at a modest pace. o Level 2 automated vehicles make up about 30 to 40 percent of the market. o Level 3 and 4 AVs are not commercially available.
• Eighty-five percent of all vehicles have V2X capability through a mixture CV technologies, allowing them to communicate both immediate safety information and mobility information to other CVs and infrastructure.
• The vast majority of people trust the CV system and privacy, security, and safety concerns have been eliminated.
• There is a rulemaking that mandates V2V, V2I, and V2X capability in new vehicles and creates incentives for retrofitting older vehicles. 5G networks also come to market, and a mixture of technologies serve CV needs.
• Agencies aggressively invest in CV infrastructure. o Data are used cooperatively to manage the transportation system.
• Institutional agreements on data sharing and ownership have been created between public and private sector entities.
• Road pricing policies become common in congested areas.

Managed Automated Lanes
In the Managed Automated Lanes scenario, Level 1-4 automation is present to varying degrees in vehicles, and is used primarily in designated lanes. These lanes also include roadside CV infrastructure to support safety and traffic flow operations, and individual vehicles have a high degree of V2X connectivity.

Collectively, these lanes form a managed lane network, spanning many of the nation's most highly traveled highways and arterials. A strong role for transportation systems management and operations (TSMO) is present for the infrastructure owner operators, allowing for safe and efficient road travel. Because these lanes do not reach final destinations, virtually all travel still requires a driver for some portion of the trip. The inability to automate trips fully prevents a significant upheaval in overall transportation paradigms. Ownership rates and models are unchanged from the Baseline.

Table ES-5. Key Markers of the Managed Automated Lanes Scenario

• AV technology is approved by safety regulators and is commercially available; **50 to 60 percent** of vehicles have some form of automation. o Level 2 AVs make up 30 to 40 percent of the market overall. o Level 3 AVs make up 20 percent of the market. o Level 4 AVs are commercially available but rare.
• Seventy-five percent of all vehicles, including all AVs, have V2X capability allowing them to communicate both immediate safety information and mobility information to other CVs and infrastructure.
• People buy AVs of varying levels of automation, but restrictions on automated driving outside of controlled settings result in different mixes of automation and market share of AVs in different areas.
• Fleet automation grows significantly. o Freight fleets are highly connected and automated with 75 percent of freight highway miles being Level 3 or 4; platooning is nearly ubiquitous. o Freight fleets are highly connected and automated with 75 percent of freight highway miles being Level 3 or 4; platooning is nearly ubiquitous.
• EV market share is unchanged from the Baseline.
• Usage of transportation network companies (TNCs) and shared mobility is unchanged from the Baseline.

Competing Fleets
In the Competing Fleets scenario, breakthroughs in AV technology occur led by fleet operators, allowing on-demand services to automate the majority of travel without drivers, reducing operational costs, slashing fares, and vastly increasing their market share. Many different services operate independently and competitively, with no cooperation or centralized management. Travel and ownership paradigms are drastically changed, particularly in urban centers and dense suburbs, where trip density allows for low-cost fares due to efficient routing.

The cheap cost of personal travel, the availability of travel to previously underserved demographics (disabled, elderly, adolescent, intoxicated, etc.), and the possibility of empty miles all collectively combine to increase vehicle miles traveled (VMT) substantially. Because vehicles

are used nearly non-stop, their high utilization incentivizes TNCs to use EVs, meaning that the majority of VMT in urban centers is electric powered.

Individual services make information on trip times, pick-up and drop-off locations, and prices easily available to passengers and highly accurate. However, agreements between various services and with agencies are slim; fierce competition and institutional hurdles preclude wide-scale agreements in data sharing and integration between services and modes.

Table ES-6. Key Markers of the Competing Fleets Scenario

• AV technology is approved by safety regulators and is commercially available; 70 percent of vehicles have some form of automation. o Level 2 AVs make up 30 to 40 percent of the market overall. o Level 3 share is negligible. o Level 4 AVs are adopted by fleets and make up 30 percent of the market.
• Seventy-five percent of all vehicles, including all AVs, have V2X capability allowing them to communicate both immediate safety information and mobility information to other CVs and infrastructure.
• Vehicle ownership declines heavily in cities and suburbs because the price of owning and operating a personal vehicle is much more than using TNCs for road-travel needs.
• Fleets are fully automated. o All heavy-duty freight travel is done with connected and automated vehicles (CAVs); freight costs reduce dramatically due to lower workforce costs and reduced fuel prices because of platooning. o Public transit vehicles are fully connected and automated. o TNCs are fully connected and automated.
• TNC costs plummet: Single-occupancy rides are less than $1 per mile, and shared rides less than 50 cents per mile. o Rates of concurrently shared rides (e.g., Lyft Line versus regular Lyft) remain at 2017 levels of 0 to 40 percent depending on region. o As a result, in urban and suburban areas, up to 85 percent of VMT is completed by CAVs operated by private TNCs.
• EV market share sharply increases, particularly in terms of VMT; all TNC rides are electric.

Integrated Automated Mobility

In the Integrated Automated Mobility scenario, breakthroughs in AV technology allow on-demand services to automate the majority of travel without drivers, reducing costs, improving efficiency, and vastly increasing their market share. There is a strong public sector role to support system optimization and governments implement policies to actively manage multimodal travel. Industry standards for data sharing, combined with a commitment from government and industry stakeholders to collaborate, allow for robust data-sharing agreements and informed operational strategies.

In this scenario, mobility is a service or a commodity, and real-time dynamic pricing structures emerge to reduce congestion and optimize traffic flow. The availability and accuracy of data, combined with trips being ordered in the moment, allows for pricing schemes to be varied by time of day, precise geography, vehicle route choice, trip service type, or user demographics, all in response to real-time system conditions. This flexibility allows for the transportation system to

absorb increased road travel demand in a highly efficient manner. Further, the integrated nature of various modes and services is reflected in infrastructure; parking spaces are reallocated for pickup lanes at key transit stations, and curb space is reconfigured. Because vehicles are used nearly non-stop, their high utilization incentivizes TNCs to use EVs, meaning that the majority of VMT in urban centers is electric powered.

Table ES-7. Key Markers of the Integrated Automated Mobility Scenario

• AV technology is approved by safety regulators and is commercially available; 70 percent of vehicles have some form of automation. o Level 2 AVs make up 30 to 40 percent of the market overall. o Level 3 share is negligible. o Level 4 AVs make up 30 percent of the market.
• The per-mile cost of travel on connected, shared, automated vehicles drops to below 50 cents per mile. o Eighty percent of on-demand CAV rides are concurrently shared
• As a result, up to 85 percent of VMT is completed by CAVs in urban and suburban areas.
• There is concerted policy intervention to coordinate all on-demand AV ride services through real-time dynamic pricing, managing both immediate movements as well as long-term trip planning in concert with other modes, such as rail transport, large buses, and air travel.
• Fleets are fully automated. o All heavy-duty freight travel is done with CAVs; freight costs reduce dramatically due to lower workforce costs and reduced fuel prices because of platooning. o Public transit vehicles (both light-duty CAVs and traditional rail/bus) are fully connected and automated. o TNC-like services are fully connected and automated.
• EV market share sharply increases, particularly in terms of VMT; all on-demand CAV rides are electric.

ES-4. Common Themes

When asked to specify what information would be useful to planners at the second workshop, participants noted that seeing which risks are present under multiple scenarios can help give a sense as to which risks are mostly likely to occur, and which ones will occur regardless of certain assumptions. Table ES-8 details the common risks posed to agency operations across the scenarios.

Some risks are present across all scenarios. For example, increased infrastructure maintenance costs are expected in each scenario, because even low-level automation and connectivity will result in decreased following distances (and increased bridge strain), and higher demand for clear street markings. Additionally, because all of these scenarios are characterized by private sector changes, ensuring equitable application of the technologies is a substantial risk in all scenarios.

Table ES-8: Common Risks to Agency Operations in the Scenarios

Common Risks	Relevant Scenarios					
	Baseline	Niche Service Growth	Ultimate traveler assist	Managed Automated Lanes	Competing Fleets	Integrated Automated Mobility
Decreased value of roadway capacity expansion			X	X	X	X
Equity – benefits felt only by certain groups	X	X	X	X	X	X
Higher fixed-route transit operating costs				X	X	
Inadequate EV charging					X	X
Increased infrastructure maintenance cost	X	X	X	X	X	X
Investments in data collection infrastructure may be obviated; although purchasing private data may be necessary			X	X	X	X
Mismatch between parking supply and demand				X	X	X
Reduced Funds – less gas tax revenue					X	X
Reduced funds – parking and tickets				X	X	X
Wasted transit investments (less than expected usage of bus and rail)		X		X	X	
Weight limit concerns on bridges because vehicles may travel closer together	X	X	X	X	X	X

**Note that the table indicates the presence of risk, but not the magnitude of risk*

Based on the common risks and elements of the scenarios, several agency actions are likely to be relevant across many or all the different scenarios (Table ES-9). For example, digitizing street signs, markings, and restrictions is a precursor to supporting CV and AV usage in all the scenarios. The actions listed below are generally in the purview of MPOs, but also may require State or city government involvement. Some of these actions can be implemented immediately by the appropriate agencies, but others could merely be planned for now and enacted later (such as incentives for CV retrofits).

It should be noted that the actions in the table are not necessarily the most important actions to be taken in any given scenario. For example, development of pricing policies and data collection agreements is fundamental to the Integrated Automated Mobility, but this action is excluded from Table ES-9 because of little relevance to other scenarios.

Table ES-9: Agency Actions Relevant in Multiple Scenarios

Agency Actions	Relevant Scenarios					
	Baseline	Niche Service Growth	Ultimate Traveler Assist	Managed Automated Lanes	Competing Fleets	Integrated Automated Mobility
Begin piloting and testing V2I systems (e.g., signal time and phasing challenge)	X	X	X	X	X	X

Agency Actions	Relevant Scenarios					
	Baseline	Niche Service Growth	Ultimate Traveler Assist	Managed Automated Lanes	Competing Fleets	Integrated Automated Mobility
Digitize road signage, speeds, markings	X	X	X	X	X	X
Provide incentives for CV retrofits	X	X	X	X	X	X
Include technology use and consideration in project prioritization		X				X
Invest in multimodal connection infrastructure and programs (e.g., pickup lanes, integrated payment)	X	X			X	X
Investment in data management systems and staff	X	X	X	X	X	X
Make equity considerations a priority for CV and AV development	X	X	X	X	X	X
Rapid increase in EV infrastructure (beyond investments supporting more linear growth)		X			X	X
Reevaluate parking needs and policy (needing less of it in some scenarios and more in others)	X	X	X	X	X	X
Update models to account for change in travel time cost		X	X	X	X	X
Update models to account for empty VMT		X			X	X
Update models to account for TNCs	X	X	X	X	X	X
Update models to be based on individuals, not households					X	X
Update to advanced signal control systems		X	X	X		X
Use and maintain nationally uniform striping and signage	X	X	X	X	X	X
Consider new funding sources to replace potential lost revenue from parking and traffic violations as well as gas tax revenue		X	X	X	X	X
Develop standards and/or guidelines for vehicle operations		X	X	X	X	X

ES-5. Transitioning to Practitioner Guidance

In addition to formulating new scenarios, a primary goal of this project is to provide guidance to transportation planners on conducting their own CV/AV scenario planning processes, using these new scenarios as a basis for their planning efforts. Insights generated from this project have been compiled into a separate practitioner guidance document for transportation planners to use scenario planning to support informed decision-making in light of the changing realm of transportation technologies and business models.

At the second workshop, which was composed of State and local planners, participants were asked to provide feedback on the format of the guidance. Participants gave advice to the project

team to develop guidance on how an MPO should start incorporating these scenarios into their planning process. Some of the key suggestions include:

- **Set the stage:** Provide background to CV and AV technologies and their importance to planning, referencing past changes to transportation.
- **Frame the scenarios carefully:** Make clear that they are not predictions.
- **Focus on the core business of an MPO:** Note which aspects of scenarios are clearly under MPO control, and that no other entity could/would do.
- **Note key MPO and State considerations for each scenario:** For example, what are the implications for rural areas? For pedestrians? For areas of agency control?
- **Develop a framework for evaluating CV and AV into the planning process.**
- **Provide a qualitative assessment of the impacts to planning tools.**
- **Provide guidance** on:
    - Collaboration
    - Staffing allocation
    - Current investments that will be useful in all scenarios, such as digitizing transportation infrastructure
    - Incorporating private sector pronouncements about technology into MPO decision-making
    - Public engagement, including outreach to county officials and residents; surveys; and other educational outreach about CVs/AVs

Each of these components is included in the practitioner guidance document. When using this guidance, it is expected that practitioners will view each scenario through the lens of their specific planning geography. For example, a planner considering adjustments to the long-range plan of his or her city would look at the Niche Services scenario and examine how those underlying attributes would manifest in the city. This would mean, for example, identifying areas that would be ripe for niche services, and examining how the possibility for targeted AV services could be valued in project prioritization. The practitioner guidance includes a checklist of questions that agencies should ask about their region to successfully tailor the scenarios to their locality, thereby converting their more abstract components to scenarios involving specific transit agencies, committees, plans, neighborhoods, etc. that are in their region.

As each scenario presents a unique mixture of risks and opportunities, the practitioner guidance essentially operates as a risk/opportunity assessment of current agency activities. The practitioner guidance assists with all steps in the exploratory scenario process shown in Figure ES-2.

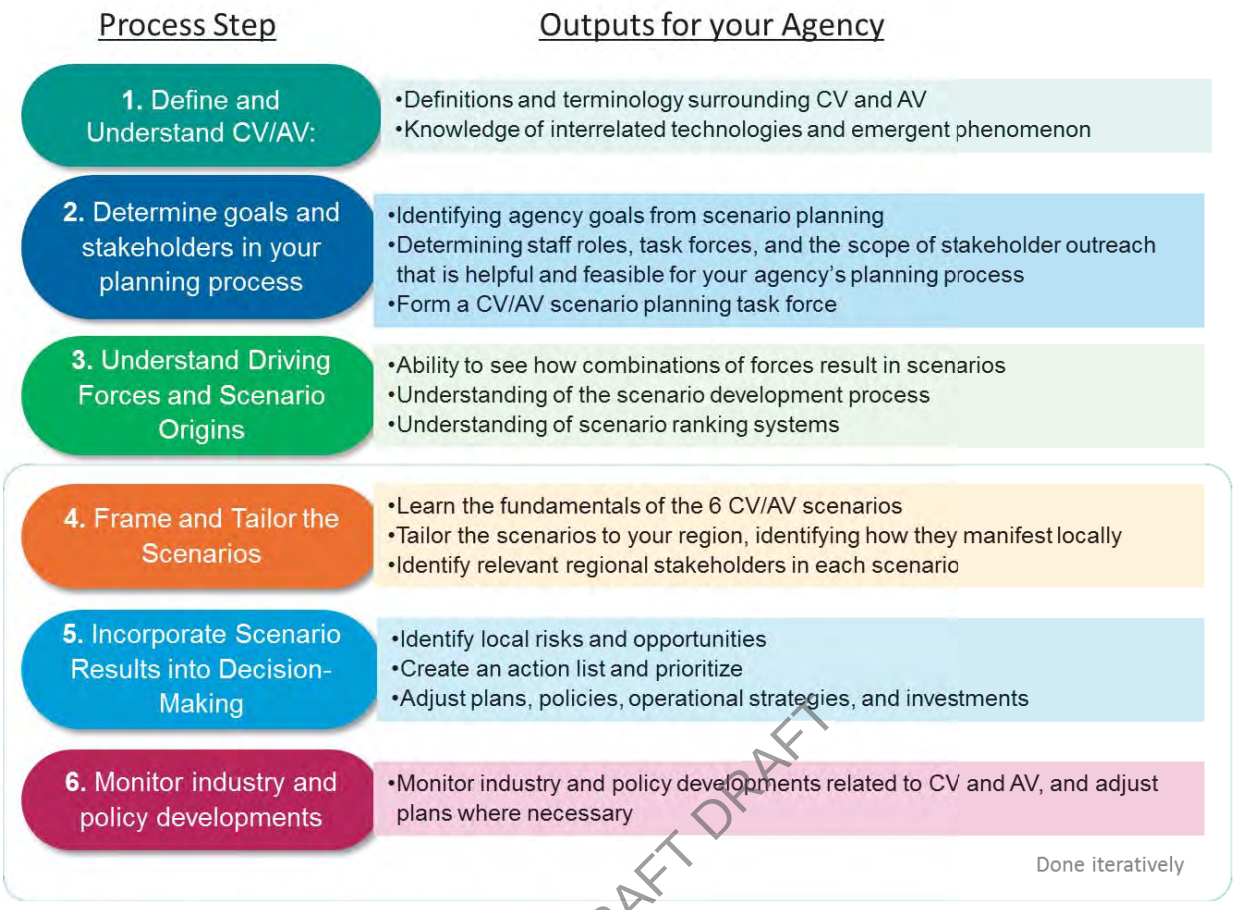


Figure ES-2: Diagram. The Process for Using CV/AV Exploratory Scenarios (Source: FHWA)

The immense potential for CV and AV technology to transform agency operations warrants robust consideration of their trajectories and effects. This research aims to provide planners with a base of knowledge and potential scenarios, representing a starting point for agencies to begin planning for connected and automated vehicles (CAVs). Using the provided scenarios and guidance, agencies may be able to better prioritize investments, arrange internal staff, formulate policy, and act proactively rather than reactively to developments in this arena.

BOSTON CONSULTING GROUP

Future Mobility Scenario Project

Pre-read for TRB AVSM Forum Meeting

FEBRUARY 24, 2020

Agenda

- How BCG thinks about scenarios
- Approach for TRB AVSM Forum
- Introduction to BCG Team

Scenario: Definition

Dictionary

Scenario (noun)
1. An outline or synopsis of a play
2. Screenplay
3. A sequence of events especially when imagined

BCG definition

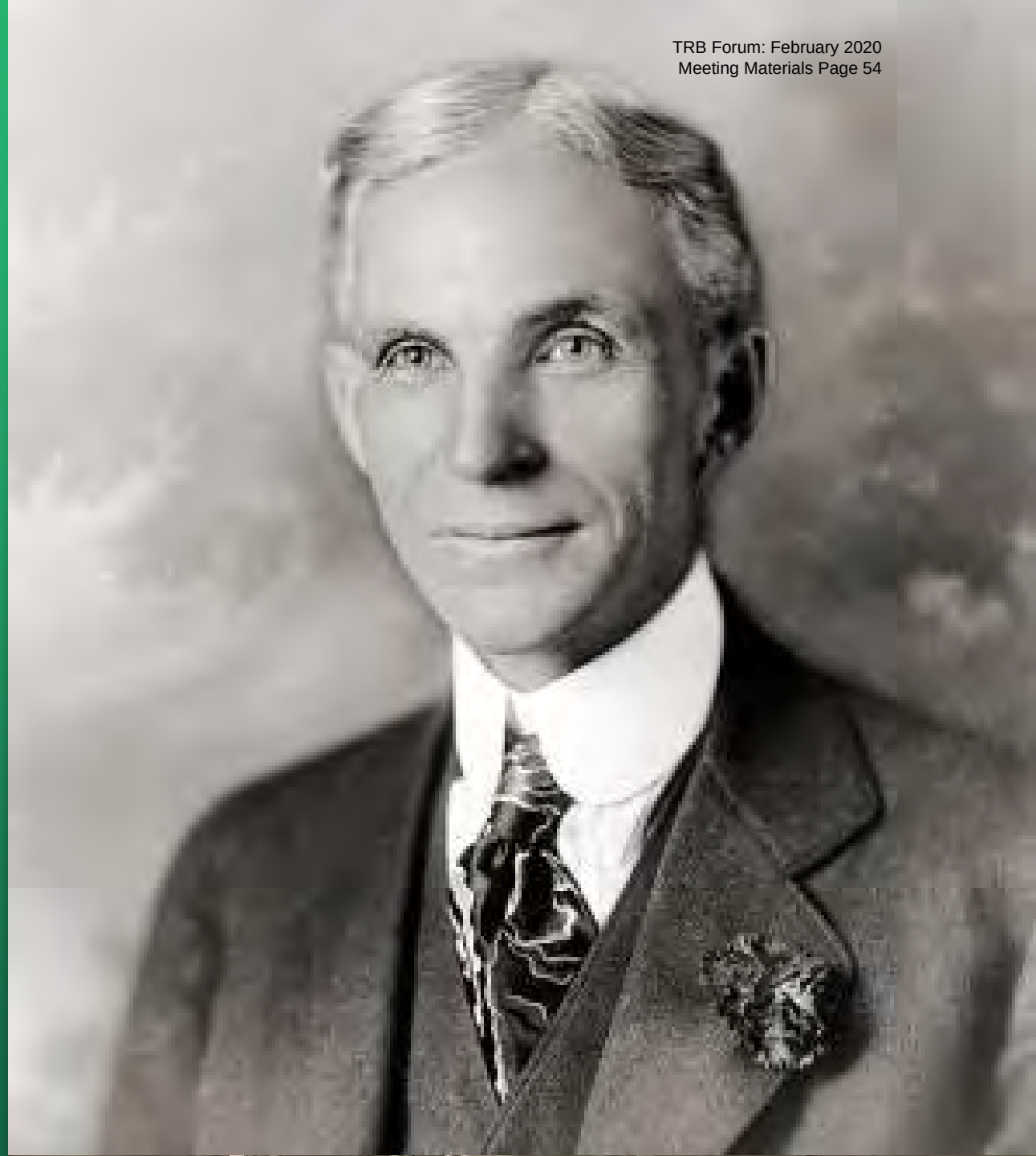
A story about how the future of the business environment could unfold

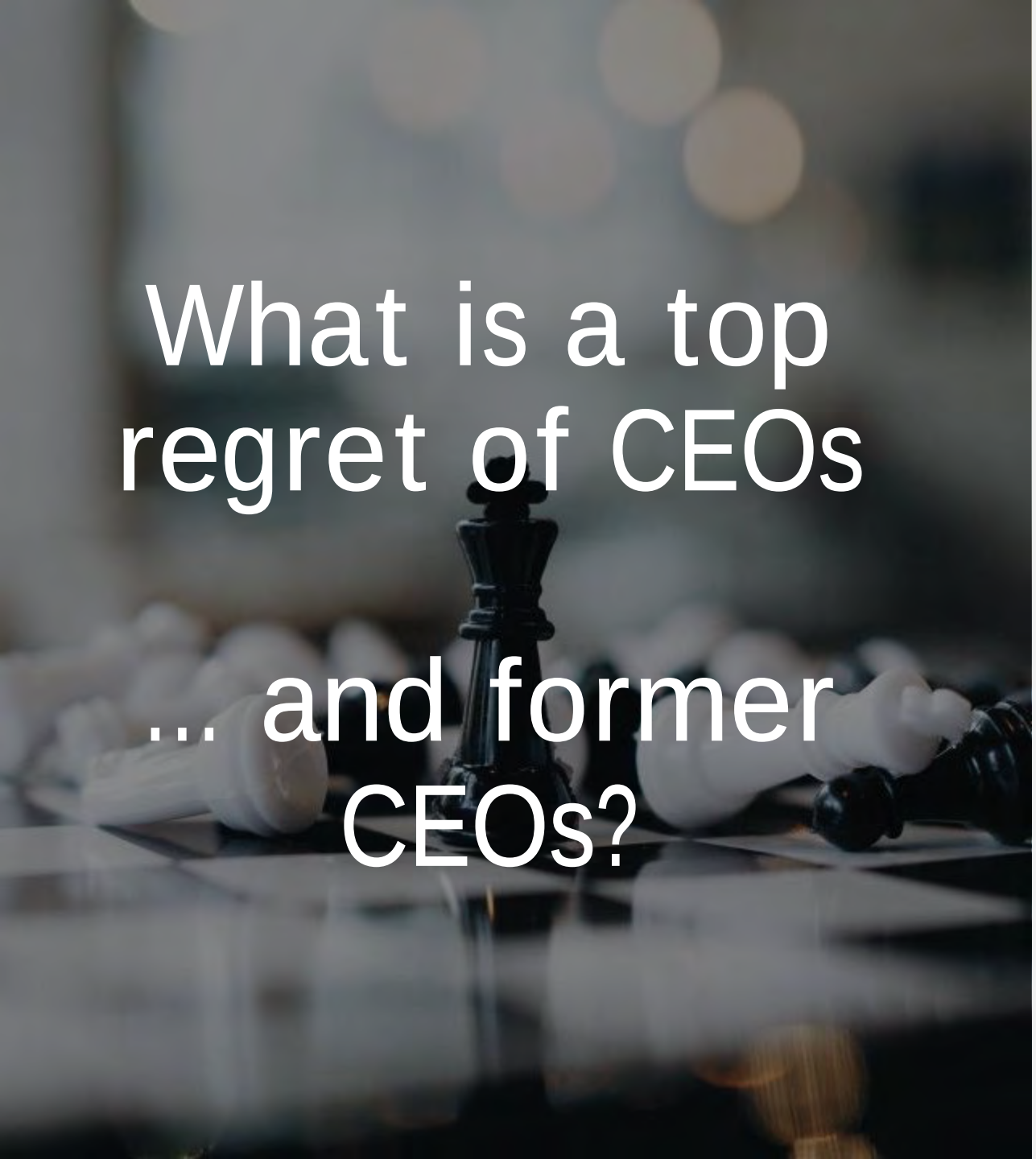
Consists of the description of an end state, a related interpretation of current reality, and an account of how the world gets from one state to the other

A scenario is a caricature, by definition unlikely to happen – it encourages you to explore what might happen

We are not good at judging the prospects of uncertainties, and what's worse, we are overconfident in our judgments

> Horses will always remain while auto-mobiles are but novelties that will disappear
>
> - CEO of Michigan Savings Bank, advising Henry Ford's lawyer against investing in the automobile industry (1903)





What is a top regret of CEOs

… and former CEOs?

Thinking they knew what the future would look like

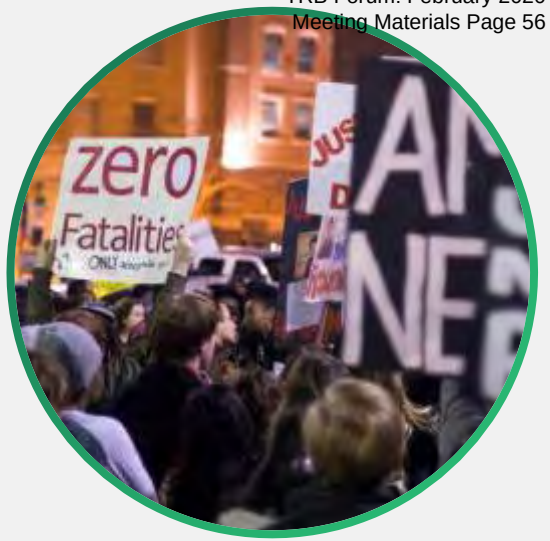
Understanding change and seeing the future early requires a wide-angle lens rather than a telescope

Navigating uncertainty has always been critical for top management: what has changed?

Uncertainty comes from new sources

Environmental, geopolitical and cyber risk have intertwined with economic, competitive and technological risk

It is essentially impossible to track everything as the landscape of potential impacts becomes more complex



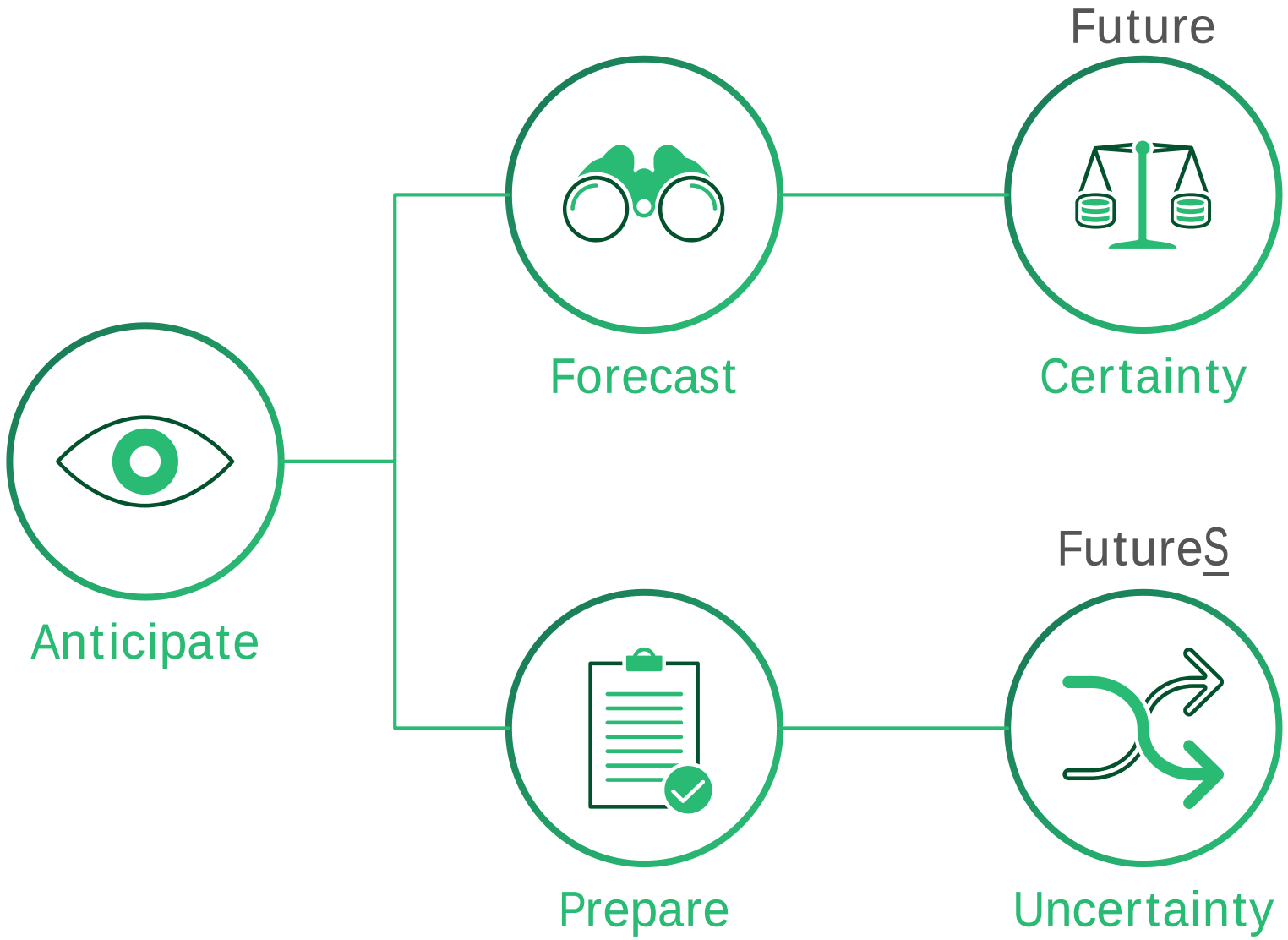
Uncertainty can result in surprises more quickly

Accelerants have increased the pace of uncertainty (e.g. new technologies, climate change, high levels of debt, even social media)

The interconnected nature of risks leads to spirals and network effects, often increasing the impact as well

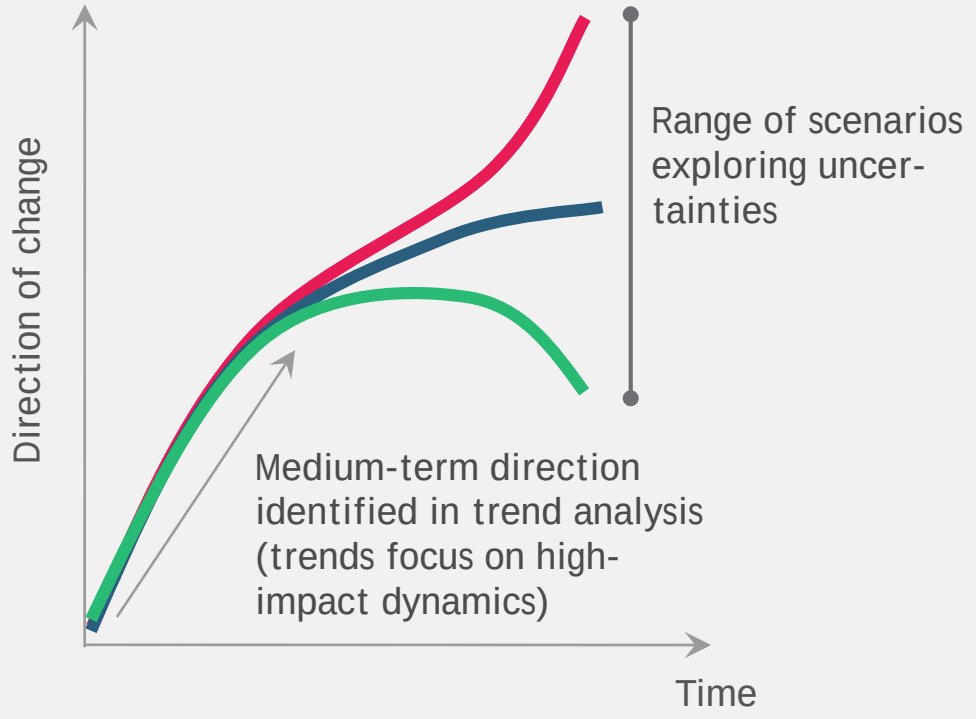
Often our corporate strategy only performs well in expected future; scenarios can help develop a more resilient strategy

Scenarios are one way to help organizations understand the uncertainty, or "futures", they are facing



Scenarios: forecasting is necessary, but not sufficient to build robust long-term strategy

Facing uncertainties means …



… going from forecasts to scenarios

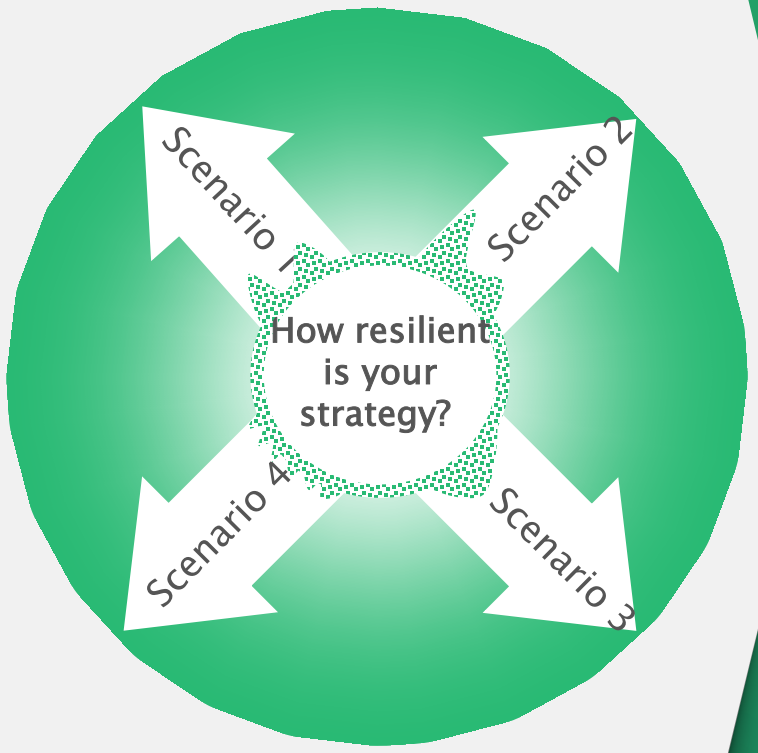
Trend data alone is not enough to build a scenario, as some aspects of the future will not fit

- Known unknowns, e.g., how climate change will be addressed
- Unknown unknowns we cannot even imagine, e.g., a specific epidemic or terrorist incident, a breakdown in norms

Even if our predictions could cover every eventuality, they would still be subject to our perception

- There is no perfectly objective look
- We always have to interpret

Scenarios help stretch, challenge & enrich our strategy



Key questions addressed

- What are the assumptions built into our current strategy?
- How could the world around us evolve in the future? What are the implications for us?
- Do shareholders support our strategy? Are we vulnerable?
- Can we defend against industry disruptors? Are we correctly partnered to avoid disintermediation?
- How robust are our current plans to face the uncertainties?
- How can we turn these uncertainties into opportunities?
- How can we position ourselves ahead of the competition? Which business model innovations and technologies could emerge?
- In what ways will sustainable development change the industry landscape?
- What actions do we take today? Are there “no regret” moves?
- How and when do we shift course? What are the signs that we should monitor?
- Etc …

During the process of scenario selection and refinement these key criteria should be top of mind

Criteria to refine each individual scenario

Each scenario must be

- Internally consistent—no inherent contradictions
- Clear and easy to explain
- Visual and evocative ("picture of the future") with an evocative title
- A plausible evolution of relevant megatrends, current events or other inputs
- Surprising in some way, rather than continuation of the status quo
- A blend of challenges and success stories, not utopia or disaster, not black or white
- Useful, relevant for the strategic decisions to be considered

Criteria to finalize full set of scenarios

The full set of scenarios must

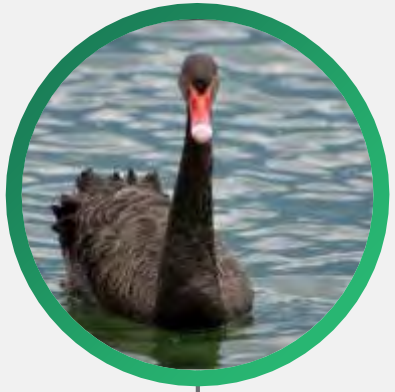
- Cover all key topics (e.g., politics, society, sustainability, technology, etc.)
- Cover the full range of priority megatrends and any other inputs selected
- Contain fundamentally different scenarios
- Be representative of as many alternative futures and opinions possible
- Not contain scenarios that are much more or less extreme than others (all scenarios should be roughly same level of plausibility)

Source: BCG

BCG has a menu of scenario approaches

Most frequently used scenarios approaches

War gaming



1. Black swan

BCG proprietary approach

2. Axes of uncertainty

3. Morphological

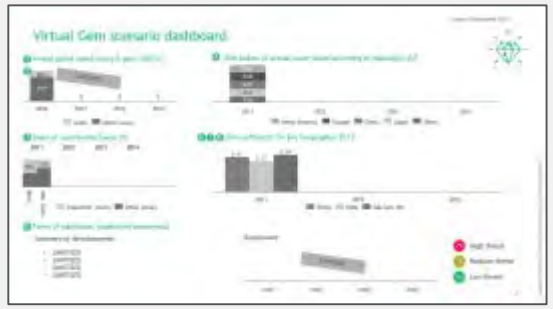
Sensitivities

A scenarios effort can deliver tangible business outcomes

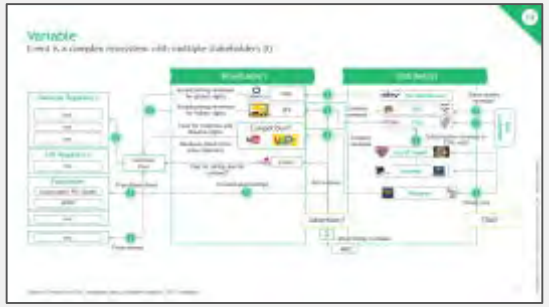
Range of future visions

New opportunities

Business implications

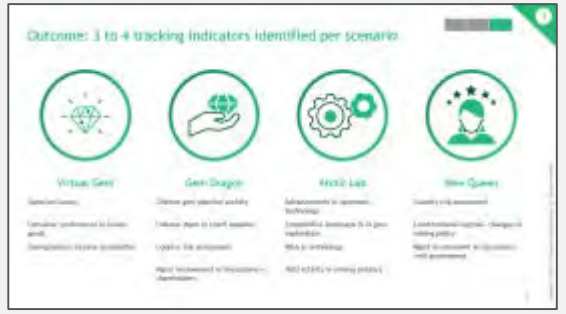


Risk assessment



Action plan with specific strategic moves to respond to potential impact and improve agility

Leading indicators to track key exposures to uncertainty



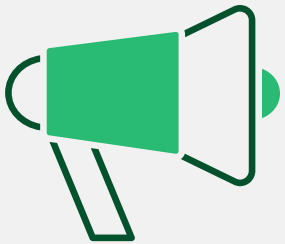
Agenda

How BCG thinks about scenarios

Approach for TRB AVSM Forum

Introduction to BCG Team

Key outputs from this joint effort



Call to action on the future of mobility for key stakeholders

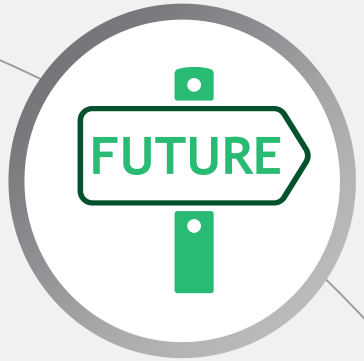
- **Cities & public policy makers:** stakeholders who will require paradigm shifts on urban mobility and will need to proactively plan policy and readiness
- **Industry players:** stakeholders who will be participating in the autonomous mobility value chain and need to proactively decide how to engage with consumers, governments, and other industry players

Concrete recommendations and risk in various scenarios

- **No-regrets moves:** decisions to be taken toward achieving autonomous mobility readiness regardless of scenario
- **Bold moves:** potential bold courses of action to better position stakeholders for the future in given scenarios to be ahead of the pack

We will use an immersive and highly participative process

Applied successfully in many similar situations

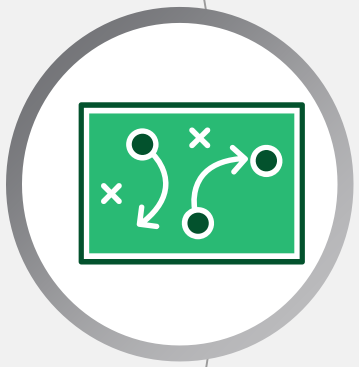


Understand the trends shaping the future

- What are the relevant trends for Client to consider in the future?
- How will these impact demand, supply, business models and the basis of competition in our broader field of play?

Visualise potential futures

- What are possible scenarios that Client will operate in by 2030?
- What will demand, business models and competition look like in these scenarios?



Decide our strategic response

- What are the implications of each scenario for Client's medium-long term strategy?
- So what will we do: No regret actions, likely moves to explore now, options to keep on radar

We will hold two workshops

	Workshop #1: Scenario Development	Workshop #2: Implications
	Feb 24 Washington DC	July 26-27 San Diego
Pre-work	Cluster trends into themes and develop variables representing range of trends and uncertainties we face	Detail story and build visual for each scenario
Workshop	Develop matrix of hypotheses and combine to create scenarios	Identify opportunities, challenges and risks
Outputs	Name and initial story for each scenario	Final scenarios (story, visual, metrics) and FP implications

Agenda

How BCG thinks about scenarios

Approach for TRB AVSM Forum

Introduction to BCG Team

Augustin K. Wegscheider

Partner,
Chicago

Role

- Leader of Center for Mobility Innovation in North America

Key expertise

- Sales & distribution topics at automotive OEMs and suppliers
- Autonomous driving
- Urban Mobility

Relevant BCG experience

- Evaluated HD mapping market dynamics for global automotive supplier
- Developed commercial strategy and revised processes for global automotive supplier
- Devised electric & autonomous growth strategy for global automotive supplier
- Developed inventory excellence program & market intelligence tool for global OEM
- Led World Economic Forum project on Future of Urban and Autonomous Mobility
- Identified levers to restore profitability at North American tire distributor
- Assessed Finished Vehicle Logistics market for an automotive logistics provider
- Transformed Americas front-end organization for a European cleaning equipment OEM
- Analyzed US fastener market and provided M&A recommendation for conglomerate
- Studied US automotive aftermarket and derived implications for premium OEM
- Developed business unit strategy for a leading Tier 1 automotive OEM

Prior experience and education

Augustin worked at Audi of America for 4 years

- Led Sales Planning, Order Management and Distribution team
- Drove improvements in vehicle ordering process, introduced best-selling configurations
- Supported President in definition and execution of sales company strategy

He spent 5 years at Siemens Management Consulting in both Munich and New York offices.
Selected project experience:

- Set up new organizational entity 'Infrastructure & Cities' in US with >$4bn in sales
- Ensured operational readiness of Wind Power business for further internationalization
- Facilitated negotiations with both European rail operator and OEM for joint factory

Education

- Augustin holds an MBA from the University of Cambridge, Judge Business School.
- He holds undergraduate degrees in European Business from both Dublin City University
- Business School as well as European School of Business in Reutlingen, Germany

Rich Davey

Partner and Associate Director
New York

Role

Expert in state and local government

Key expertise

- A core member of the Public Sector Practice Area, focusing on transportation and infrastructure
- Leads the state and local practice in North America

Profile summary

Rich Davey is an Associate Director and the Lead for BCG's US State and Local Public Sector Practice Group. He has over 15 years of C-suite transportation and infrastructure experience in high profile, publicly accountable organizations in state government and the private sector. Rich has served as the Secretary and CEO for the Massachusetts Department of Transportation (2011-2014) and the General Manager of the Massachusetts Bay Transportation Authority (2010-2011).

Relevant BCG experience

- Oversaw the successful implementation of Massachusetts' $3B Accelerated Bridge Program, introducing accelerated procurement, construction and design techniques that dramatically improved department's on-time and on-budget delivery
- Architect of MBTA's successful $1B+ Orange and Red Line rail vehicle procurement
- Widely credited for championing with stakeholders and thus securing gas tax increase in 2013 for new resources for transportation in MA, the first increase in 25 years
- Provided expert support in procurement and organizational transformation for one of the largest passenger railroads in the US
- Leading project team that is developing strategic plan and road map and for a bus mobility transformation plan for major US based transit system
- Led strategic plan development and governance model review for one of the largest metropolitan transit systems in the US. Established mission and vision, baseline, and benchmarked best practices. Synthesized and refined goals and developed strategic priorities
- Provided expert support in procurement and vendor renegotiation for large US port authority; Provided deep expertise for railcar vehicle manufacturer's US market repositioning

Prior experience and education

- Rich holds a JD, summa cum laude, from Gonzaga University School of Law and a BA in political science from the College of the Holy Cross

Alan Iny

Global Leader for Creativity and Scenarios, New York

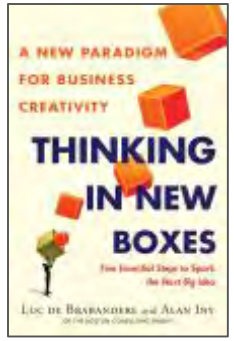
Alan Iny is BCG's Global Lead for creativity and scenarios, based in New York. He is a member of the Corporate Finance & Strategy Practice management team, with expertise in innovation, transformation, uncertainty and change management across industries

Alan is the coauthor of *Thinking in New Boxes: A New Paradigm for Business Creativity* (Random House, September 2013), which Publishers Weekly, in a starred review, called "a must-read for anyone in a leadership position who dares to look at the world in new ways," and which is available in twelve languages. He also co-wrote BCG's perspective on practical creativity, and *Rethinking Scenarios*, BCG's approach to scenario planning. His TED talk and speaking engagements around the world are acclaimed for their storytelling and liveliness, and he runs dozens of interactive client workshops with leading organizations every year.

Alan's project experience while at BCG since 2003 has focused on issues of strategy, creativity and growth for companies across every industry. Recent project highlights include:

- Planning and executing scenario planning exercises for an insurance player pondering cyberattacks, a food player exploring the future of snacking, a technology company focused on the Chinese market, a Scandinavian energy company, a global automotive player, the Gates Foundation, four WEF efforts, and many more across industries
- Preparing and facilitating ideation workshops for a major global beverage player, a Brazilian beauty company, a global pharmaceutical company focused on growing its vaccine business, a South American bank exploring new opportunities, a multinational food producer, and hundreds of others across every industry
- Arriving at a new strategic vision using creative approaches with a Middle Eastern tourism board, an Indian cement company, an Asian conglomerate, major foundations, and dozens of others
- Developing and delivering training on creativity in business, for junior and senior audiences within BCG, for leading clients and in academic settings

Alan is also the social impact lead for BCG's New York office, and coordinates significant investments in the sector and dozens of passionate colleagues



Alan received his M.B.A. from Columbia Business School, with a focus in management and social enterprise. He holds an Honours Bachelor of Science degree in Mathematics and Management from McGill University

His writing with Luc de Brabandere has also appeared in various academic journals, including *Strategy & Leadership* and *Technological Forecasting & Social Change*

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TRB Forum on Preparing for Automated Vehicles and Shared Mobility

Mini-Workshop on the Importance and Role of Connectivity

February 14, 2019
Keck Center of the National Academies of Sciences, Engineering, and Medicine
Washington, D.C.

The National Academies of
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TRANSPORTATION RESEARCH CIRCULAR E-C247

TRB Forum on Preparing for Automated Vehicles and Shared Mobility

Mini-Workshop on the Importance and Role of Connectivity

February 14, 2019

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Transportation Research Board
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Preface

The deployments of automated vehicles, shared mobility services, and other transformational transportation technologies have the potential to dramatically increase safety, reduce congestion, improve access, enhance sustainability, and spur economic development. However, success in meeting these goals is not assured, and there are significant risks that these deployments could cause unintended consequences.

The National Academies–TRB Forum on Preparing for Automated Vehicles and Shared Mobility was officially launched in early 2018 to facilitate evidence-based research needed to deploy these technologies in a manner and timeframe that informs policy to meet these long-term goals. The Forum has held five meetings since then, promoting discussion among its members and the public, creating white papers, developing research priority lists, and engaging in workshops dedicated to specific questions around automated vehicles and shared mobility. This paper was developed as a summary of a one such workshop held for this Forum. Jeff Lindley, Katherine Kortum, and Mark Norman authored the paper, and it was reviewed by Chandra Bhat, The University of Texas at Austin.

ACKNOWLEDGMENTS

A small volunteer group of Forum members and TRB staff planned and organized the mini-workshop described in this report. Members of this working group were:

- Jeff Lindley, Institute of Transportation Engineers (cochair)
- Ed Straub, SAE International (cochair)
- Chandra Bhat, The University of Texas at Austin
- Dan Blais, Transport Canada
- Annie Chang, SAE International
- Steven Dellenback, Southwest Research Institute
- Kevin Dopart, U.S. Department of Transportation
- Larry Head, University of Arizona
- Katherine Kortum, TRB staff
- Mark Norman, TRB staff
- Faisal Saleem, Maricopa County Department of Transportation
- Larry Yermack, Cubic

PUBLISHER'S NOTE

The views expressed in this E-Circular do not necessarily represent the views of all Forum participants or members, the Transportation Research Board, or the National Academies of Science, Engineering, and Medicine. This E-Circular has not been subjected to the formal TRB peer-review process.

Contents

Introduction

In order to better inform all Forum members and generate discussion on strategic crosscutting issues, members are holding a series of "mini-workshops" in 2019. These mini-workshops focus on answering three main questions: (1) why the subject area is of critical importance, (2) what the current state of play is, and (3) what the future might hold. The mini-workshop on the "Importance and Role of Connectivity" occurred on February 14, 2019 in Washington, DC. This report contains a summary of the workshop, including key takeaways, panelist remarks, summaries of breakout group discussions, and a set of proposed research questions.

WORKSHOP FORMAT AND AGENDA

The workshop consisted of six panelists representing various points of view on the role of vehicle connectivity, followed by four breakout sessions to elicit input on the three main questions noted above. The workshop concluded with brief breakout session summary reports and closing remarks. A key outcome of the workshop was identification of specific research questions in this area that those in the transportation field could pursue.

KEY TAKEAWAYS

Key takeaways from the workshop included the following.

There is considerable popular press about autonomy, but only industry insiders are talking about connectivity. More needs to be done to create consumer awareness of the differences between and the benefits of both connected and automated vehicles. Although automated vehicles and connected vehicles are often grouped together, their situations are different in terms of technological maturity and uncertainty.

It is important to ensure that both the deployment of both connected and automated vehicles, in addition to shared mobility services, focus on a user perspective, not on a vehicle or infrastructure perspective.

Connected automation is critical to enable the transportation system to function most safely and effectively. Two critically important reasons for connectivity include redundancy and the ability to see what sensors cannot. On-board sensors work for immediate vicinity sensing to support collision mitigation and avoidance; cellular communications and dedicated short range communications (DSRC) can support a broader range of applications and over longer distances (such as avoiding collisions due to overtaking maneuvers on high-speed rural two-lane roadways). Also, pricing of streets and managing of curbs will require connectivity.

Connectivity may require a different legislative and regulatory framework than exists today, particularly with respect to public and private sector relationships and to funding and risk assignment and liability.

Consistency and interoperability are critical to the successful deployment of connectivity. Standards development processes may need to be streamlined and accelerated. Vehicle manufacturers are concerned over state DOT inconsistencies in deploying DSRC. On the other hand, state DOTs cannot be dependent on proprietary clouds of data housed within each vehicle manufacturer.

There is significant fear regarding the liability of a failure in connectivity. Failures might include a complete breakdown in the connectivity or the speed being too slow, resulting in injury or death. Even if the technology works perfectly, approximately one-third of all crashes involve driver impairment, and impaired drivers cannot be expected to be able to react to the alerts provided by a vehicle.

The technology debate will rage on, but it is important to focus on the use cases. Each use case is likely to require something different.

The number of devices on the road should not be the sole measure of readiness. Policy, maintenance, and workforce issues matter as well, and pilot projects are the means to determine how these will work. In addition, connectivity is not free. Industry and the public sector need a better understanding of overall costs of the technology, including maintenance costs, before the system is truly ready to accept widespread connectivity.

There will continue to be more questions than answers for the foreseeable future, and ongoing research will be needed.

Opening Panel Session

The opening panel consisted of six panelists representing a variety of points of view on the importance and role of connectivity, both from automated vehicle and shared mobility perspectives. Panelists spoke about why the subject area is of critical importance, the current state of play, and what the future might hold. A primary purpose of the panel presentations was to frame key technical and policy issues in advance of further discussion in breakout groups.

JEFF LINDLEY
Institute of Transportation Engineers

Jeff Lindley opened the workshop by outlining the overall plan for the workshop and introducing the panel session. There is an understandably high level of current interest in technical and policy issues related to the communications medium (e.g., DSRC, 5G cellular) used to connect vehicles and vehicles, vehicles and infrastructure, and vehicles and other system users to enable mobility and safety applications. This level of interest is so high that it had the potential to completely dominate the workshop discussions. Both panelists and breakout session facilitators were asked to keep this in mind and cover the issues in as much of a connectivity medium neutral mode as possible. Lindley then introduced the six panelists, and a summary of each panelist's remarks appears below.

BLAINE LEONARD
Utah Department of Transportation

There is a great deal of popular press about autonomy, but only industry insiders are talking about connectivity. There are two primary reasons that connectivity is so important. First is redundancy: it provides verification of sensor data that is on-board vehicles. An automated vehicle (AV) bases its decision based on what it can see. A connected vehicle (CV) makes decisions based on what it can learn.

Second, connectivity has inherent value that seeing sensors cannot. Connectivity can do five specific tasks better than sensors:

- Signal phase and timing information. Sensors know what the signal state currently is, but connectivity to the infrastructure allows the vehicle to know what the signal is about to do.
- Lane closures. Connectivity can provide much more advance notice than vehicle sensors about lane closures or other diversions.
- Platooning. This is currently focused on use in trucking, but it needs to be in passenger vehicles too. What is an agency's role in platooning? Will vehicles act like a swarm of bees and use self-crowdsourcing to form their own platoon, or should agencies communicate some kind of permission or facilitation to the vehicles?
- Freeway queue detection. Will sensors warn vehicles about queues in time? Sensors might not but connectivity likely will.
- Icy road conditions. As with road closures, connectivity can provide better

information to the vehicle about current or upcoming icy conditions than can sensors, including in areas where the conditions may not be immediately visible ("black ice").

The DSRC/5G argument is not analogous to the VHS/Beta situation several decades ago. Both VHS and Beta existed in the marketplace at the same time and were competing for dominance. With connectivity, DSRC exists and 5G does not. To accelerate the benefits of connectivity, agencies and other practitioners will need to deploy using the technology available now. Some agencies still deploy Highway Advisory Radio, which was cutting edge technology in the 1940s.

Automakers are worried about DSRC because some state DOTs are deploying it and others are not. Some signal systems are connected, and some are still hardwired/manual. An automaker cannot count on agencies around the country to deploy DSRC uniformly. It is more likely they will be able to count on cellular companies to deploy 5G uniformly. However, there are still parts of the country with 3G or "no G." In addition, if users have to pay for the subscription in order for their vehicles to have the benefit, many will not.

In order to be interoperable, agencies cannot depend solely on proprietary clouds of data housed with each automaker. There is no obvious honest broker to bring it all together. State DOTs could perhaps be the common cloud in the future, but if they are not, there is no clear candidate. Interoperability is often meant to be cross-jurisdictional, but it is also cross-automaker.

BRIAN CRONIN
Federal Highway Administration

The FHWA role is often about making information available for research. For connectivity, there are several different use cases.

- Safety. Need low-latency reliable communication.
- Maintenance. Need connectivity back to corporate cloud.
- Traveler info. Info can be delayed by a couple of minutes.
- User info. About a 20-s delay for Audi (for example) for signal timing information into vehicles.
- Work zones. How far upstream can we provide info and have it be useful?
- Signal operations. Real-time at intersections; more delayed for optimization of routes/systems.

FHWA is currently considering the data and potential effects of market failures. The administration has done a great deal of work with DSRC and is trying to better understand 5G options and capabilities, not only for FHWA but also for all stakeholders.

FHWA is focusing on different applications and situations in which deployment of connectivity will provide benefits to transportation systems. Cooperative automation is making it possible for CVs and AVs to work together, and Cooperative Automation Research Mobility Applications is a key FHWA research project. During the summer of 2018, the administration tested platooning with other capabilities on I-95 express lanes in Virginia. Four vehicles in a platoon on the Interstate approached an on-ramp. An entering vehicle wanted to join the platoon, and it did so successfully. For a (faux) work zone, FHWA staff sent a command for the platoon

to change speeds from 65 to 45 and change lanes, and they automatically did while staying in platoon. FHWA staff then sent a command to resume the previous speed. This type of effort only works with connectivity.

BRIAN KELLER
AT&T

AT&T is a one of the companies working in the CV industry, with 31 automakers purchasing their connectivity from AT&T. These automakers include GM, Ford, Tesla, Audi, and others. AT&T has learned from the automakers' activities, which are primarily telemetry and consumer services like navigation or Spotify. To date, these activities enhance the driver experience but are not yet life-critical.

When there were many small wireless companies, they performed at varying levels of effectiveness. When AT&T brought all the companies together, the parent company had to normalize them. Different chipsets and operating systems made for many different possible deployment combinations, which is part of why DSRC has not taken off as much as it could. Chipsets that end up in products also exist along an evolution spectrum. Those in smart phones are among the most advanced on the market, because people are willing to pay a lot and do so often to have the best technology. Automakers are slower to get new technology into their vehicles, with most taking about 3 years.

Connectivity is not free. Qualcomm is a market leader in research on chipsets, and they expect compensation for their intellectual property. Other steps in the process include manufacturing the silicon, packaging it into a chip, putting the chip into a module, putting the module into a unit, and connecting the unit to a cell network; each of these steps comes with a cost.

The most important consideration is what a customer wants from connectivity. AT&T is aware that cellular is not the only option. The company wants to have DSRC available because its customers, both the state DOTs and vehicle manufacturers, like it. AT&T has made investments in centers where AV testing is occurring and is trying to understand what the state DOTs need.

AT&T is fearful of liability for a failure in connectivity, whether it be a complete failure or whether the connectivity does not work quickly enough, especially if that failure leads to injury or death.

STEVE KUCIEMBA
WSP

The technology debate will continue to rage on, but Forum members and practitioners should focus on use cases, each of which is likely to require something different. An analogy is to work on the edges of the puzzle instead of the middle.

Many infrastructure owners and operators are afraid to take any action because of the uncertainty around the technology and its deployment. The number of devices on the road should not be a measure of readiness. Policy and maintenance and workforce issues matter too, and we have to figure those out through pilot projects. While procurement processes are longer than tech lifecycles, which creates significant challenges for public agencies, we can begin by outlining steps to move forward.

TIM PAPANDREOU
Emerging Transport Advisors

Technology does not understand boundaries, but cities and states have boundaries.

Mobile application programming interfaces are a current barrier to getting something like Mobility as a Service up and running. This is currently the main missing piece in the shared mobility system.

How do state agencies become platform managers to accomplish more than making bad things work better? Many experts feel people are no longer able to operate vehicles, as smartphones are making people into dumb drivers.

How does shared mobility prepare us for automation? The answers are not yet clear.

Pricing of the streets and managing of the curbs will require connectivity. Cities need to understand the price signals for delivery and service providers to use our streets efficiently.

ED BRADLEY
Toyota

On-board sensors are intended for collision mitigation and avoidance, but cellular and DSRC is intended for the longer-distance issues. Some of the Toyota applications of connectivity include intersection assistance and emergency vehicle notification.

In terms of addressing crash risks, DSRC and vehicle-to-infrastructure connectivity may address up to 80% of the non-impaired crashes. About one-third of all crashes have driver impairment as a factor, but Toyota does not expect impaired drivers to be able to react to the alerts.

Breakout Sessions

After the panel session, the workshop moved on to a series of four breakout sessions of approximately 75 minutes each. Each breakout session considered the following questions:

1. What types of connectivity are most important and why?
   - Vehicle-to-vehicle (e.g., for better car following);
   - Vehicle-to-road side infrastructure (e.g., going through traffic signal more efficiently, weather/congestion alerts);
   - Vehicle-to-other road user (e.g., pedestrian, bicycle); and
   - Connectivity between shared mobility providers, vehicles and shared mobility users.
2. What are the most significant challenges in providing each type of connectivity?
   - Latency, reliability;
   - Privacy;
   - Cybersecurity;
   - Institutional (e.g., who pays for maintaining the system);
   - Equity (e.g., a connectivity that requires smart phones, that excludes some people); and
   - Interoperability.
   - Others?
3. If full connectivity is never realized, how would that limit the potential benefits of autonomous vehicles and shared mobility?
4. What questions in this space need more investigation (i.e. research)?

Brief summaries of the discussion and key points from individuals in each breakout session appear below.

BREAKOUT GROUP 1

Much of the analysis to date on CVs has assumed that there is a government mandate to install the technology to enable the necessary communications at some point. What if that does not happen? Does that change the benefits equation? Is there research that needs to be done assuming no CV technology mandate, but also assuming a gradual introduction of AVs? Are multiple ecosystems operating in parallel viable technologically and economically?

What more needs to be done to create more consumer awareness of the differences between and benefits of both connected and AVs. What needs to be done to create public trust in these vehicles as they transfer some level of driver "control" to the vehicle or to the "system"? How do we explain the value proposition?

How do we ensure that both the deployment of autonomous vehicles and shared mobility services focus on a user perspective, not just on a vehicle or infrastructure perspective?

There will be some level of unintended consequences along the autonomous vehicle deployment path, similar to the equity issues that have arisen in the deployment of shared mobility services. How can we be better prepared to deal with these unintended consequences when they inevitably happen?

BREAKOUT GROUP 2

Infrastructure-to-vehicle vehicle communication is important. It will also be important to avoid putting the burden of connectivity on vulnerable road users (e.g., pedestrians and bicyclists).

Current understanding of the overall cost, including maintenance cost, of the technology is limited.

Equity about types of technology in different vehicles is a concern. Will potentially life-saving technology initially or permanently only be available in higher-end vehicles?

What are the incremental benefits of deploying connected AVs beyond deploying just (unconnected) AVs?

Economic analysis and use cases will be important. These will need to include business models for sustainment and consider a services model versus a built network

Interoperability will be important for connectivity to be successful. How do we develop standards and turn data into information and disseminate it widely? What institutional issues are created when crossing jurisdictional boundaries and across companies?

What legislative frameworks are necessary to support the deployment of connectivity for both shared mobility and autonomous vehicles?

BREAKOUT GROUP 3

Use cases will be key to understanding and addressing connectivity issues. Ensuring that use cases robustly reflect the various dimensions of AV and shared mobility deployment and the benefits of connectivity (and issues created if connectivity does not exist) will be critical.

Connected technologies must be interoperable. Standards development processes need to be streamlined and accelerated. System considerations need to be given equal weight with equipment and data sharing interoperability concerns.

Connectivity may require a different legislative and regulatory framework than we have today, particularly with respect to public–private-sector relationships, funding and risk assignment/liability.

BREAKOUT GROUP 4

Connectivity types are different in AV and shared mobility contexts.

It is important to consider different levels of communication - very near, mid-distance, and long distance. This is akin to communicating information for the three layers of the dynamic driving task, which are

- A strategic layer with a long time horizon for trip planning, route redirection, etc.;
- A tactical layer, measured in seconds for maneuvering on the roadway; and
- An operational layer, measured in milliseconds for the vehicle control level (i.e. horizontal and longitudinal control).

Why are we communicating with others? Safety is a big reason, but it is important to remember other reasons as well. We need to connect people, not just vehicles, and consider

which stakeholders are missing from the discussion.

Where will connectivity change behavior the most? First in the infrastructure, then the vehicles, or vice versa?

Scalability and time-to-market are both important to remember. How long until we realize the benefit?

"Immunity to change" is a problem, as are different market forces. Are market acceptance and profitability key considerations?

What are the definitions of "connectivity" and "fully connected"?

What risks are created without full connectivity? What additional or new risks exist if we reach full connectivity? A disconnected computer is useful, but it is far more useful when connected to the internet.

Active safety assessment is important. In a data-rich environment, measuring data will change. We can measure hot spots of conflict instead of just crashes.

What are the potential models for the honest data broker?

Interoperability and accessibility may prove to be challenges. Many authorities are responsible for the decisions in these areas, and many different market forces (including supply chain and users) influence penetration.

Key Research Questions

The panel and breakout sessions included a rich discussion of issues. This discussion did not directly lead to the identification of specific research questions in most cases, but the following research questions are raised for consideration by those in the AVs and shared mobility industries.

- What use cases need to be analyzed to create a full understanding of the potential benefits and other implications of connectivity?
- How do predicted benefits of deployment of autonomous and shared vehicles change if connectivity is limited or does not exist? Phrased another way: What are the incremental benefits of deploying connected AVs beyond deploying just (unconnected) AVs?
- How do connectivity needs and benefits change between very near, mid-distance, and long distance applications?
- How can the needs of vulnerable users (e.g. pedestrians and bicyclists) be accommodated without requiring them to bear the full responsibility of always being "connected"?
- How will the ability to assess safety issues be different / improved in a fully connected environment?
- What viable options exist for managing and providing access to the data that will be generated in a fully connected environment without compromising privacy or creating cybersecurity risks?
- What is the consequence of sharing information such as a wrong-way driver with human drivers or human AV safety operators? How do humans react when they receive messages that are time critical and potentially life-threatening?

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TRANSPORTATION RESEARCH
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TRB Forum on Preparing for Automated Vehicles and Shared Mobility

Mini-Workshop on the Transition Toward Shared Automated Vehicles

February 13, 2019
Washington, D.C.

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Preface

The deployment of automated vehicles, shared mobility services, and other transformational transportation technologies has the potential to dramatically increase safety, reduce congestion, improve access, enhance sustainability, and spur economic development. However, success in meeting these goals is not assured and there are significant risks that these deployments could cause unintended consequences.

The National Academies–TRB Forum on Preparing for Automated Vehicles and Shared Mobility was officially launched in early 2018 to facilitate evidence-based research needed to deploy these technologies in a manner and a timeframe that informs policy to meet these long-term goals. The Forum has held five meetings since then, promoting discussion among its members and the public, creating white papers, developing research priority lists, and engaging in workshops dedicated to specific questions around automated vehicles and shared mobility. This paper was developed as a summary of one such workshop held by this Forum. Tim Papandreou and Katherine Kortum authored the paper. Susan Shaheen and Steve Shladover of the University of California, Berkeley, and Carol Schweiger of Schweiger Consulting reviewed the paper.

PUBLISHER'S NOTE

ACKNOWLEDGMENTS

A small volunteer group of Forum members and TRB staff planned and organized the mini-workshop described in this report. Members of this working group were

- Tim Papandreou, Emerging Transport Advisors (co-chair);
- Susan Shaheen, UC Berkeley (co-chair);
- Jean Crowther, Alta Planning and Design;
- George Ivanov, Waymo;
- Greg Krueger, TRB Standing Committee on ITS;
- Carol Schweiger, TRB Standing Committee on Emerging and Innovative Public Transportation Technology;
- Steven Shladover, TRB Vehicle-Highway Automation Committee;
- Bernard Soriano, California DMV; and
- Prachi Vakharia, Steer.

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Introduction

In order to better inform all Forum members and generate discussion on strategic crosscutting issues, members are holding a series of mini-workshops in 2019. These mini-workshops focus on answering three main questions: 1) why the subject area is of critical importance; 2) what the current state of play is; and 3) what the future might hold. The Transition Toward Shared and Automated Vehicles Mini-Workshop occurred on February 13, 2019 in Washington, D.C. This report contains a summary of the mini-workshop, including key takeaways, panelist remarks, summaries of breakout group discussions, and a set of proposed research questions.

Workshop Format and Agenda

The workshop began with remarks by Tim Papandreou, who reminded participants that there are still a wide variety of questions about automated vehicles (AVs) and shared and automated vehicles (SAVs), and how they will affect the future. After his opening statements, the group separated into three breakout groups, each of which focused on a particular SAV theme: regulation, equity, and streets and land use. After the breakout discussions, the groups reconvened with breakout summary reports and closing remarks. A key outcome of the workshop was the identification of specific research questions.

Key Takeaways

Trends in transportation and digital transformation are upending our traditional notion of transportation and bringing unprecedented opportunities and challenges. This shift will not happen all at once. It is clear it will be a transition. This transition will have visibly different geospatial and temporal effects depending on the physical, political, and social situation of each region.

The mini-workshop identified what research is needed to transition to the vision (emphasizing the transition itself and need for immediate actions to facilitate the transition in the short term). Key research questions identified for regulation, equity, and land use and streets are listed below.

Opening Session

Timothy Papandreou opened the mini-workshop and shared mega trends around:

- Transportation issues requiring a change from business as usual—rapid urbanization, safety, demographics, emissions, access, congestion, and efficiency.
- Digital transformation trends: e-commerce digitization, platforms, and connected devices, shared mobility scaling, and mobility as a service/mobility on demand.

These trends are upending our traditional notion of transportation and bringing unprecedented opportunities and challenges to travel modes, urban form and land use, propulsion, employment, safety, data management, and ultimately governance. This shift will not happen all at once, and it is clear it will be a transition—one that will have visibly different geo-spatial and temporal effects depending on the physical, political, and social situation of each urban region.

This Forum focuses on sharing specifically in the context of SAVs, which includes passenger, delivery/commercial and municipal services, shared fleets, and shared rides (sequential and concurrent sharing), along with ground, sea, and air systems.

Data technology companies are dominating market share of traditional industries with a platform approach. By linking producers of services with customers who purchase those services, the data transaction exchange creates value for the company, producer, and customer; it can scale to all parts of the economy.

The key question raised was how to bring governance into the era of digitization, so they are able to manage demand and supply digitally. At the same time, it is necessary to correct for the existing inequities in our system, working closer with public and private sector partners, and developing the infrastructure needed to ensure that the transition to SAVs minimizes the potential challenges and takes advantage of those opportunities that may come out of this transportation transformation.

This transition and its effects will not happen tomorrow, and there are several unknowns. The purpose of the forum is to map out what is known, what is not known, and what needs and what people want to happen to get to the point where SAVs are on the roads and providing overall benefits to society.

Breakout Summaries

REGULATION

This breakout session addressed safety readiness, vulnerable road users, public acceptance, rights-of-way (ROWs) access and pricing, Mobility as a Service (MaaS)/Mobility on Demand (MOD), interoperability, curb management, and mixed fleets.

Figure 1 below depicts the direct impacts of various SAV factors on safety and vice versa. Since safety is the realm within which regulations are being developed, the figure could be used as a framework within which SAV research is conducted.

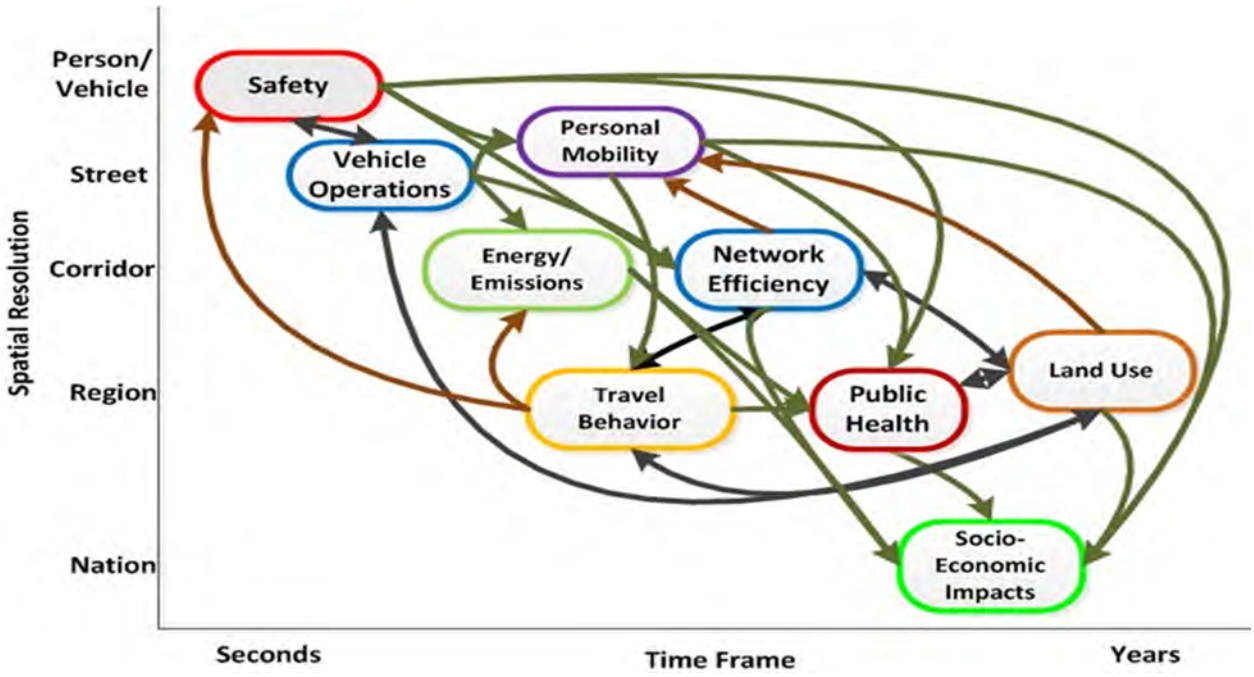

FIGURE 1 Impacts of various SAV factors on safety and vice versa.
(Source: Smith, Scott, Jonathan Koopmann, Hannah Rakoff, Sean Peirce, George Noel, Andrew Eilbert, and Mikio Yanagisawa. "Benefits Estimation Model for Automated Vehicle Operations: Phase 2 Final Report," January 1, 2018. https://rosap.ntl.bts.gov/view/dot/34458.)

Potential research topics include developing a better understanding of the degree to which public acceptance of SAVs is impacted by perceptions of SAV safety. The public's adoption and acceptance of SAVs has implications for establishing regulations around their ownership and use.

Another research topic is understanding the balance between overall safety outcomes for vehicles versus prescriptive regulations that attempt to cover every possible dimension of safety. Naturally, a patchwork of regulations would be difficult for original equipment manufacturers to accommodate. While states are looking to the federal government to set regulations on the vehicle side, some are moving ahead in the absence of these regulations in order to provide some degree of safety protection for their road users. This research would involve the assessment of well-controlled SAV pilot demonstrations to develop a framework for safety and other regulations at the state and local level. The research would include assessing the ability of public agencies to digest and use data and information resulting from the SAV demonstrations.

Current U.S. Department of Transportation (DOT) standards research efforts in the SAV area, including the MOD Multimodal and Accessible Travel Standards Assessment (MATSA), could be identified and reviewed to ensure that future research does not duplicate any of these existing efforts. The current research being conducted by the U.S. DOT MOD Sandbox, Accessible Transportation Technologies Research Initiative (ATTRI), and the Federal Transit Administration's Strategic Transit Automation Research (STAR) programs, along with consultant-led MOD efforts, will have an impact on SAV standards development in the future and should ideally be evaluated in developing SAV regulations. For example, how will public transit agencies comply with the Americans with Disabilities Act (ADA) in an automated world (e.g., assisting a wheelchair passenger to board or alight a vehicle and perform a wheelchair tie down)?

While it is unlikely that SAV impacts on public health will directly affect SAV standards or regulation development, research is needed to better understand the influences of SAVs on travel behavior, inclusivity/accessibility, equity, congestion, and their impacts on policy development.

Scenario analyses, such as those that depict mixed fleets (SAVs and nonautomated vehicles, both shared and privately owned), are needed to ensure that safety regulations consider a range of possible situations. Further, research should consider safety "tipping points" related to different penetration levels of SAVs in different scenarios.

EQUITY

The equity breakout session discussed accessibility and inclusivity across all incomes, races, ages, and abilities in relation to physical ROWs, service usability, and digital platforms; the role of policy and regulation; and measuring outcomes.

The group chose to broadly define equity as equal access for all people. In the context of the TRB Forum's focus on automated vehicles and shared mobility, there is the potential that certain groups might see little to no benefits from new mobility options but bear a disproportionate amount of the negative impacts (e.g., higher costs or increased congestion or reduced access). Additionally it is not known yet how to judge the implications of new technologies, services, and modes on a community at-large or on specific groups within communities. The group recognized the potential for unintended consequences and the importance of identifying analysis, evaluation methods and consistent tracking, and monitoring of outcomes.

Roles of public-sector agencies and private-sector providers have changed dramatically. Equity is generally an outcome of public-sector investment, ownership, or oversight rather than market forces. Some group members identified a need to newly define and affirm the role of government. A study to document and characterize the recent shifts in the role of government, as well as the relevant policy levers that exist, could help to inform public-private sector coordination, management of SAV services, and policy or regulatory approaches moving forward.

Equitable access to digital platforms also applies to usability, including persons with sight or hearing impairments that may have limitations in terms of how the vehicles communicate with them as a user. Research should consider possible SAV implications including transportation cost and travel time, the health of disparate populations, and public transit service.

STREETS AND LAND USE

This breakout group considered multimodal street design, parking impacts, electric charging, curb pick-up/drop-offs (PUDOs), connectivity, and support infrastructure.

Many state and local agencies have adopted complete streets principles, but they will need to rethink these to incorporate new technologies and, when appropriate, adopt a network rather than a corridor focus. For example, many cities are struggling with how to address electric scooters. The key consideration is how to promote safety in infrastructure design, but economic

analyses will also be needed to evaluate the market value of curb space (e.g., travel lane, parking, pick-up/drop-off) and the value of ROW elements (e.g., dedicated AV lanes, sidewalks). The roles of state and city DOTs and landowners will also need to be explored, and the successes of many access management programs may provide useful analogues. It is important to note that the transitional phase will continue as new travel modes and technologies continue to develop and evolve.

Many cities and airports have been experimenting with the design of pick-up/drop-off areas for SAVs and compiling best practices will be valuable. In addition to physical design, this review should include times of day and fee structures. This effort should build upon work underway by National Association of City Transportation Officials (NACTO) and the Institute of Transportation Engineers (ITE) should consider freight/delivery implications.

Many agencies have adopted Toward Zero Deaths initiatives, and SAVs are expected to contribute to these goals. Agencies need robust approaches to evaluate SAV safety impacts and related design and land-use treatments. Traditional methods rely on several years of crash data, but the rapid deployment of these modes and treatments make that problematic. New data sources (e.g., vehicle-to-everything, autos, roadside cameras, and onboard cameras) should be considered as well as the limitations of those data (e.g., privacy, ownership). Making data from these sources more widely available is also important, and experiences of sharing sensitive data in the medical industry may be useful. Surrogate safety assessment methods that do not rely on crash data should also be explored (e.g., conflict analysis, simulation).

SAVs (and electrification) will affect traditional funding sources for state and local DOTs (e.g., gas tax, parking revenue, enforcement fines). Alternative revenue sources (e.g., curbside fees, congestion–cordon pricing, tolls, zero-occupancy vehicle tolling) should also be explored. It is important to understand how these alternative sources influence desirable and undesirable traveler behaviors (e.g., zero-occupant vehicle cruising). In addition to offsetting losses in traditional sources, these new revenues could be used to upgrade and maintain equipment needed to support SAV services.

Many agencies are being encouraged to support the telecommunications industry small cell network efforts. A synthesis of these deployments that includes policy impacts would be useful to many public agencies. This research should also include an economic evaluation of publicly owned communication networks and vertical infrastructure (light poles and traffic signal support poles) used for mounting antennae.

Planners seek information on how to best incorporate SAVs into their planning efforts. Information on desired outcomes and system performance metrics (e.g., safety, vehicle miles traveled, congestion, productivity, environmental, economic, freight fluidity) would be very useful. Generalizable planning scenarios could be helpful in comparing and contrasting different areas and approaches. There is a need is to lessen undesirable effects, such as zero-occupancy vehicles cruising rather than parking. This research should examine leading indicators for desirable and undesirable outcomes. The rate of deployment and evolution may also warrant reconsideration of planning horizons and schedule revisions.

Traditional mode choice models have focused on the private vehicle and public transit choices. As SAVs and other technologies are deployed, new approaches to helping travelers choose a mode and methods for analyzing choices are needed. Encouraging appropriate mode choices for different trip purposes should be considered, along with the value of travel time by different modes. Designs that facilitate seamless modal transfers should be evaluated. Public support and acceptance of the different modes should be evaluated, along with concerns

including concurrent sharing. The Partners for Automated Vehicle Education coalition, recently launched by SAE International, may be helpful.

Many automated driving applications under development try to predict behavior of users of the ROWs. Some of these users are hard to predict (e.g., pedestrians, bicyclists, e-scooter users) and encouraging more uniform or predictable behavior, in part by providing dedicated spaces within the ROW for different modes, would help to make AVs safer and more efficient. These vehicles will be operating in a mixed environment for the foreseeable future and land use and design treatments that improve predictable operation will be helpful.

The use of urban air mobility (UAM) in the public ROWs is expected to increase and government agencies will need to develop policies and regulations to address UAM. These policies should consider safety, noise, and emissions. Creation of UAM routes in a region also should be considered.

Electric vehicles are expected to become more common and transportation agencies are likely to be involved in the design and deployment of the charging system. Key system considerations include: charging standard (inductive versus plug-in), the location of charging facilities, implications of shared electric fleets (including ferries), and the roles of the private and public sector. Demands on the electric grid will also need to be considered.

One potential outcome of SAVs could be reduced need for parking facilities. Methods of repurposing facilities should be explored under a range of market penetration scenarios. This should build upon efforts by the Urban Land Institute.

The Uniform Vehicle Code should be reviewed and needed changes identified.

Key Research Questions

This section includes research questions for the three breakout areas including: regulation, equity, and streets and land use.

REGULATION

What are the potential impacts of SAVs and their regulations on overall safety and public health? What are the opportunities and barriers to SAV adoption and acceptance by the public? What lessons are we learning along the way? These lessons have implications for establishing policy and regulations. In the next three years, it will be important to have objective assessment of user acceptance.

What level of government has responsibility for regulating the driving task? It is important to clarify the role of the federal government as compared to the states.

What are safety “tipping points” regarding market penetration levels of connected and automated vehicles? It is important to address different scenarios and circumstances for mixed fleets. All automated vehicles have the same safety potential, and immunity/vaccination models from the medical industry may prove to be a helpful starting point.

What are standard methodologies for state and local agencies to act on results from demonstrations and pilot projects? Agencies vary in their ability to digest and act upon data and information. A possible study focused on the United States could be modeled after the

Infrastructure Victoria report: “Advice on Automated and Zero Emissions Vehicle Infrastructure.”

EQUITY

Where are the gaps in public engagement and market research on AVs and SAVs? Most transportation users are not currently targets of private sector market research.

How do we ensure equitable access to digital platforms?

What are transportation cost and travel time implications of SAVs? In particular, what are the implications for health of disparate populations? The implications of SAVs on equity and public transit are also vital to understand, as transit is the current equity-provider within transportation.

STREETS AND LAND USE

How do complete streets need to be reconsidered at a network level for all users in light of AVs and SAVs? Research should assess the safety and economic effects, such as the value of the curb. It should also design for this SAV transitional period, drawing upon bus rapid transit and bike lane experience.

How should pick-up/drop-offs zones be managed? Waiting time and fees are two of many considerations. Best practices can look at airports as an example. Research should also build upon work by NACTO and ITE.

What are the data sources and limitations on streets and land use? Sources might include vehicle-to-infrastructure installations, automated vehicles, and municipal cameras, while limitations include privacy concerns and data ownership. Surrogate approaches to the actual data include conflicts, near crashes, and simulations. The medical industry could provide a useful model for management of sensitive personal data.

What are the impacts on pricing streets and land use on transportation funding? Electric vehicles and reduced parking requirements can lead to reduced funding, though improved management of curbsides can be an increase. Street management and funding should align with cities’ tolling, congestion pricing, and cordon efforts.

What methods should be employed to provide funds for installing, upgrading, and maintaining connected vehicle equipment? Note: deployment of small cell networks is a significant undertaking, though it is currently handled by private cellular operators.

How can we develop a synthesis of current practices as it relates to AVs and SAVs, and street and land use? Such a synthesis should evaluate policy impacts and provide an economic analysis of the U.S. DOT communication network and vertical infrastructure.

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Transformational Technologies in Transportation

Impacts on Traditional Research Processes and Programs

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TRANSPORTATION RESEARCH CIRCULAR E-C253

Transformational Technologies in Transportation

Impacts on Traditional Research Processes and Programs

Report from Workshop 3
Forum on Preparing for Automated Vehicles and Shared Mobility
May 3, 2019

Mark R. Norman
Rapporteur

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Preface

In an era of rapidly evolving transformational technologies, can our research projects and processes provide needed answers in a timely manner while still protecting the credibility of our research, and if so, how? That is the basic question that was the focus of this TRB Forum workshop and earlier discussion groups conducted by the TRB Standing Committee on the Conduct of Research.

The National Academies–TRB Forum on Preparing for Automated Vehicles and Shared Mobility was officially launched in early 2018 to facilitate evidence-based research needed to deploy these technologies in a manner and timeframe that informs policy to meet these long-term goals. The Forum has held six meetings since then, promoting discussion among its members and the public, creating white papers, developing research priority lists, and engaging in workshops dedicated to specific questions around automated vehicles and shared mobility. This paper was developed as a summary of one such workshop held for this Forum. Mark Norman authored the paper, and it was reviewed by the following Forum members: Abbas Mohaddes, Ed Seymour, Susan Shaheen, Tammy Trimble, and David Yang.

PUBLISHER'S NOTE

The views expressed in this e-circular do not necessarily represent the views of all Forum participants or members; the Transportation Research Board; or the National Academies of Sciences, Engineering, and Medicine. This e-circular has not been subjected to the formal TRB peer review process.

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A small volunteer group of Forum members and TRB staff planned and organized the mini-workshop described in this report. Members of this working group are listed below.

Name	Organization
Steven Bayless	Intelligent Transportation Society of America
Myra Blanco	Virginia Tech Transportation Institute
Hau Hagedorn	TRB Conduct of Research Committee
Katherine Kortum	Transportation Research Board
Catherine McGhee	Virginia Department of Transportation
Abbas Mohaddes (Co-lead)	Econolite/CAVita
Mark Norman (Co-lead)	Transportation Research Board
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Ed Seymour	Texas A&M Transportation Institute
Susan Shaheen	University of California, Berkeley
Susan Sillick	TRB Conduct of Research Committee
Tammy Trimble	Virginia Tech Transportation Institute
Prachi Vakharia	TRB Subcommittee on Emerging Ridesharing Solutions
David Yang	AAA Foundation for Traffic Safety

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Summary of Key Takeaways

Key takeaways from participants' discussions and panelist members' presentations at the workshop, and also from the preceding discussion groups conducted through TRB's Standing Committee on the Conduct of Research on this topic, include the following.

- Automated vehicles, shared mobility, and other transformational technologies in transportation provide a unique opportunity to make significant advances in meeting societal goals.
- Success is far from assured—we have more questions than answers. Research is the key.
- Time is short, as these technologies and deployments are advancing, and often changing, rapidly.
- The "need for speed" in the associated research depends on the issue and/or situation.
- Answering a series of questions can help researchers to determine a targeted time frame appropriate for the specific research in question.
- Options do exist to enable our research projects and processes to provide needed answers in a timely manner while still protecting the credibility of our research.
- A number of these options have been employed by others, but more models are needed.
- Collaboration among the public, private, and academic sectors is key to meeting the twin objectives of providing needed answers in a timely manner while still protecting the credibility of our research.
- There are a number of steps that TRB can take, including providing more opportunities for collaboration among the stakeholders through TRB convening activities such as this Forum, conferences, standing committees, and research panels.

Why Is This Important?

Abbas Mohaddes, Econolite/CAVita, posed the following guiding question in his opening remarks: In an era of rapidly evolving transformational technologies, can our research projects and processes provide needed answers in a timely manner while still protecting the credibility of our research, and if so, how? That is the basic question that was the focus of this TRB Forum workshop and earlier discussion groups conducted by the TRB Standing Committee on the Conduct of Research. Mohaddes' comments are as follows.

In recent years, the public has become less confident in the ability of our institutions, processes, and leaders to achieve broad societal goals. Numerous polls show that many are frustrated with continuing gridlock in Washington, D.C., and also at the state and local levels. They are tired of small scale steps being taken to address large scale problems, and have become more cynical regarding politicians' claims that they have the solutions to these problems. At the same time, voters have rebelled against revenue increases, complaining that their current tax dollars are just being wasted. Many believe that things are getting worse, longing for a time when we took bold actions to make things better.

The transportation profession is caught in this vortex. Our problems are not unique in this regard. We are operating in the same skeptical environment as other public policy issues—education, economic development, health care, immigration, safety, security, and others. Many think that bold new directions will therefore be needed to capture the public's imagination and rekindle their hopes.

For the transportation profession, there is good news. Unlike other policy issues, we have the foundations for moving in bold new directions. Policy makers and the public are enamored with the prospects of connected/automated vehicles, shared mobility, and other transformational technologies. Legislation is being considered in Washington. The U.S. Department of Transportation (USDOT) is issuing guidance on testing and deployment, and states are passing laws and regulations on when and where these technologies can be tested and operated. Numerous cities competed for USDOT Smart City grants. Every day, the media runs stories about "driverless cars." Everyone seems to be talking about these new technologies and services.

So the first step has apparently been accomplished—capturing the imagination of the public and policy makers. However, success is far from assured. Predictions of positive and negative outcomes currently cover a broad spectrum. For example, the U.S. Department of Energy (DOE) 2017 report on "The Transforming Mobility Ecosystem"[1] offers the following range of outcomes.

- A combination of automated vehicles, shared mobility systems, and electric/zero emission vehicles can reduce energy consumption and related emissions by 60% over the next 30 years.
- Conversely, a combination of automated vehicles, zero-occupancy vehicles, increased vehicle miles traveled (VMT), access for new user groups, and continued reliance on fossil fuels could increase energy consumption and related emissions by up to 200%.

The goal for the transportation profession therefore is to proactively identify and pursue policies that will push the needle to outcomes that are positive. However, these technologies and deployments are advancing, and often changing, rapidly. The recent replacement of new dockless bike services with even newer e-scooters in urban areas over a one-year period is a prime example.

There are obviously more questions than answers at this point. Providing answers through evidence-based research is therefore more important than ever.

Ensuring Quality Science

Getting It First Versus Getting It Right

Susan Shaheen, University of California, Berkeley, stressed the need for ensuring quality science. This was followed by a discussion among workshop participants regarding the trade-offs between quality and speed. The following points were made during the discussion.

We are at a key juncture. The private sector is investing billions of dollars in research to facilitate the deployment of these technologies. Just as these technologies are disrupting transportation, they may also disrupt the research processes traditionally followed by the public sector and academia.

Some have paraphrased the issue as "getting it first versus getting it right." While these are not always the same, they are also not mutually exclusive. Following traditional research processes, including research transparency and stating assumptions and limitations of the analysis, has helped to ensure quality science over many years. At the same time, research results are often not made available until after the need has passed, the policy decisions have been made, and those responsible for making policy have moved on.

During the discussion, workshop participants emphasized that the "need for speed" depends on the situation. For each research question or situation, individual participants listed the following considerations to help researchers address the question of achieving the right balance.

- What is the ultimate objective of the research?
- What is the urgency?
- What is acceptable risk?
- How much evidence will we need to move forward?
- What are the barriers?
- Can we provide transparency and balance stakeholder influence?
- Can we ensure that the research results are objective, without necessarily being neutral?

Another point made during the discussions was that traditional research processes can too often rely on one set time frame for most research projects. Answering the above questions can help researchers to determine a targeted time frame appropriate for the specific research in question. Once that is determined, the applicable research process can be designed and implemented.

Pursuing New Approaches to Our Traditional Research Processes

The typical life cycle for a research project is shown in Figure 1. The checklist that follows offers options to help research organizations and researchers in producing results that are timely while still protecting quality science. Tammy Trimble from Virginia Tech Transportation Institute presented a list generated from individuals who participated in a series of discussion groups organized by the TRB Standing Committee on the Conduct of Research. The list shown below incorporates additional suggestions from participants at the workshop.

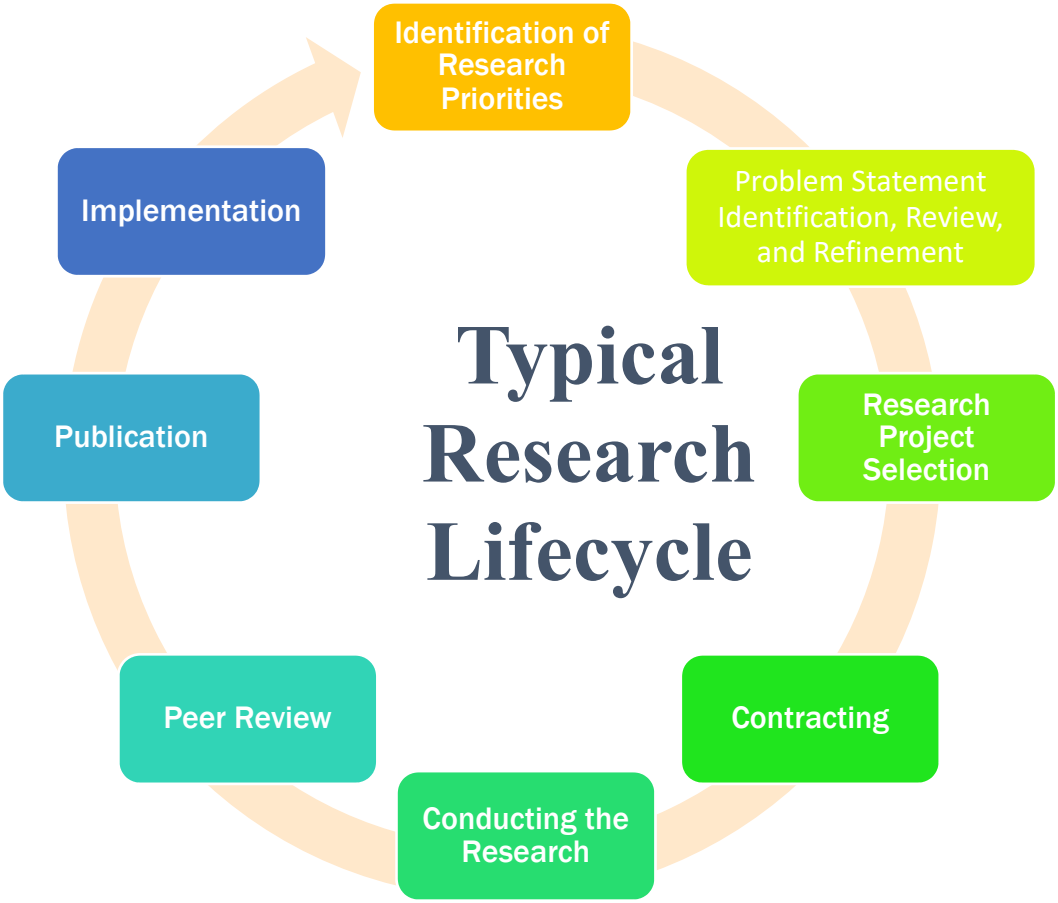

FIGURE 1 Typical research life cycle.

GENERAL RESEARCH PROGRAM MANAGEMENT

- Continuously build and nurture leadership support.
- Look for, and take advantage of, any and all opportunities to reduce administrative burdens.
- Test rapid response models used by others (e.g., National Science Foundation[2]).

IDENTIFICATION OF RESEARCH PRIORITIES

- Develop and rely on dynamic research roadmaps to establish priorities and to generate individual problem statements.
- Rely on scenario planning to consider emerging needs.
- Employ continuous calls for proposals.
- Seek approaches that will result in a process that is more continuous and more visible, e.g., a research needs dashboard.
- Seek input from stakeholders and the public to understand what is needed in the "real world."

- Prepare meta-analyses of research done on a policy topic to date, targeted to specific audiences.

PROBLEM STATEMENT IDENTIFICATION, REVIEW, AND REFINEMENT

- Pursue strategic level research—focusing more on broader research program areas rather than just on individual discrete projects.
- Align the need for more applied research (e.g., in smaller states) with desired objectives and outcomes.
- Clearly define the objective of the research at the outset of each project.
- Break research questions into smaller pieces or phases.

RESEARCH PROJECT SELECTION

- Prioritize and select individual discrete projects from broader program areas or roadmaps.
- Balance larger, complex projects with other smaller, shorter time frame projects.

CONTRACTING

- Prepare Requests-for-Proposals (RFPs) that focus more on the outcomes rather than on prescribed, specific research processes.
- Consider relying on Requests-for-Qualifications (RFQs) as opposed to RFPs.
- Prequalify contractors in defined subject areas.
- Employ indefinite delivery/indefinite quantity contracts.
- Award projects with shorter phases.

CONDUCTING THE RESEARCH

- Accomplish tasks in parallel rather than in series, and bring together at the end.
- Enhance the flexibility of the researchers and the staff to achieve the desired outcomes.
- Use interim reporting periods to determine if directional changes are needed.
- Enforce deadlines.
- Avoid scope creep.

PEER REVIEW

- Create and maintain a standing pool(s) of peer reviewers.
- Peer review phases of the research as they are completed, rather than waiting until the end of the project to review all at once.

PUBLICATION

- Release phased results of the research as they are completed.

- Release interim results and/or pre-publication findings in advance of final editing.
- Work closely with public affairs and communications experts to package the findings for specific audiences.

IMPLEMENTATION

- Include technology transfer as an integral part of the research project life cycle.
- Take advantage of scheduled field tests and demonstrations when scheduling and designing research projects.
- Use pilot projects to test "laboratory" results.
- Identify and involve a community of stakeholders and partners to deploy the results.

Fostering Collaboration Among the Public, Private, and Academic Sectors

Individual workshop panelists repeatedly stressed during the Forum workshop that collaboration among the public, private, and academic research sectors is key to meeting the twin objectives of providing needed answers in a timely manner while still protecting the credibility of our research. The potential action items that were listed along these lines by panelists include the following.

- Take steps to strengthen our research partnerships among private, public, and academia, and supplement with significant input from the end user—the public:
  - Identify common goals, such as improving safety or alleviating congestion;
  - Involve the public and stakeholders in an advisory role to help define the purpose of the research;
  - Form advisory groups and bring them together frequently;
  - Form non-traditional partnerships for collaborative research (e.g., public sector and industry);
  - Pursue collaboration through tools such as pooled fund studies and shared research roadmaps; and
  - Enlist a community of stakeholders and partners who are ready to deploy the research results.
- Use this opportunity to work with universities to attract the best and brightest into the transportation profession.
- Address the misperception on the level of "duplication" of transportation research. Note that in transportation there are often not enough resources to validate earlier research.
- Reduce competition among researchers that can result in barriers to sharing early results:
  - Encourage academics and public sector researchers to share their results as widely as possible;
  - Form collaborations with private sector stakeholders and partners early on to achieve common goals;
  - Use confidentiality agreements to facilitate the sharing of data; and

  - Pursue complementary research among and across sectors to validate and fill gaps from earlier research.
- Communicate accurate research results with the media and general public:
  - Work closely with public affairs and communications experts;
  - Package evidence-based research information targeted to specific audiences; and
  - Ensure communications experts' messages are accurate.
- Foster collaboration between state DOT research offices and other state DOT divisions:
  - Build and/or enhance relationships between the research office and other divisions to facilitate the sharing of ongoing and completed research efforts across the agency;
  - Facilitate pathways for state DOT research offices to work with other DOT divisions to identify and address emerging issues on an ongoing basis;
  - Engage divisions DOT-wide to prepare for the implementation of research results; and
  - Inspire all state DOT research offices with a sense of responsibility for policy research.

What Can TRB Do?

Hau Hagedorn, Portland State University and Chair of the TRB Conduct of Research Committee, presented a number of potential action items, which were supplemented by individual Forum workshop panelists. The resulting list of potential action items for consideration by TRB is shown below.

- Test some of the new approaches to traditional research processes listed above.
- Provide more opportunities for collaboration among the stakeholders through TRB convening activities such as this Forum, conferences, standing committees, and research panels.
- Continue conducting the research and disseminating the results of NCHRP Project 20-102, "Impacts of Connected Vehicles and Automated Vehicles on State and Local Transportation Agencies."
  - This series of research projects is employing pre-qualified research teams, a research roadmap, and pre-publication dissemination of some research results.
- Consider what options exist for pursuing a strategic research program in these areas.
  - More dedicated funding may be needed to address these issues, especially public policy issues.
- Provide a clearinghouse of information linked to a research roadmap for automated vehicles and shared mobility.
- Solicit input from the TRB Standing Committee on the Conduct of Research on additional steps that can be taken by TRB to address the issues raised above.

Appendix A
Workshop Agenda

Forum Workshop 3
Impacts on Research Processes and Programs

Friday, May 3, 2019
12:15 p.m.–1:45 p.m.

- Welcome and Introduction (Abbas Mohaddes, Econolite/CAVita)
- Transformational Technologies: Can Our Research Processes Keep Up? (Tammy Trimble, Virginia Tech Transportation Institute)
- The Value of Quality Science (Susan Shaheen, University of California, Berkeley)
- Research Best Practices: Resources Available from TRB and Conduct of Research Committee (Hau Hagedorn, Portland State University and Chair of the TRB Conduct of Research Committee)
- Presenter Q&A
- Panel Discussion
  - Panelists: Abbas Mohaddes (Moderator), Cathy McGhee (Virginia DOT), David Yang (AAA Foundation for Traffic Safety), Sue Sillick (Montana DOT, and TRB Conduct of Research Committee), Chandra Bhat (The University of Texas at Austin), Jim Sayer (University of Michigan)
- Closing and Next Steps (Abbas Mohaddes)

Appendix B
Forum Participants

TRB Forum on Preparing for Automated Vehicles and Shared Mobility
May 3, 2019

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AAA Foundation for Traffic Safety

Lawrence Yermack
Strategic Advisor
Cubic Transportation Systems Inc.

Notes

1. The Transforming Mobility Ecosystem: Enabling an Energy-Efficient Future; U.S. Department of Energy, January 2017. https://energy.gov/sites/prod/files/2017/01/f34/The%20Transforming%20Mobility%20Ecosystem%20Report.pdf.
2. National Science Foundation Grants for Rapid Response Research (RAPID). https://www.nsf.gov/pubs/policydocs/pappguide/nsf09_1/gpg_2.jsp#IID1.

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The **National Academy of Engineering** was established in 1964 under the charter of the National Academy of Sciences to bring the practices of engineering to advising the nation. Members are elected by their peers for extraordinary contributions to engineering. Dr. John L. Anderson is president.

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Learn more about the Transportation Research Board at **www.TRB.org**.

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Forum on Preparing for Automated Vehicles and Shared Mobility

Mini-Workshop on the Roles of Government and the Private Sector

July 15, 2019
Orlando, Florida

The National Academies of
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TRANSPORTATION RESEARCH CIRCULAR E-C258

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Virginia Reeder
I-95 Corridor Coalition

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Preface

The deployments of automated vehicles, shared mobility services, and other transformational transportation technologies have the potential to dramatically increase safety, reduce congestion, improve access, enhance sustainability, and spur economic development. However, success in meeting these goals is not assured, and there are significant risks that these deployments could cause unintended consequences.

The National Academies-TRB Forum on Preparing for Automated Vehicles and Shared Mobility was officially launched in early 2018 to facilitate evidence-based research needed to deploy these technologies in a manner and timeframe that informs policy to meet these long-term goals. This e-circular summarizes a workshop held by the Forum to discuss the roles of government and the public sector as these technologies are advanced.

Virginia Reeder of the I-95 Corridor Coalition and Scott Schmidt of the Alliance for Automobile Manufacturers authored the paper, and it was reviewed by Jim Mahugh, Washington State DOT; David Zipper, German Marshall Fund; Raj Ponnaluri, Florida State DOT; Daniel Sperling, University of California Davis; and Katherine Kortum and Mark Norman, Transportation Research Board.

ACKNOWLEDGMENTS

A small volunteer group of Forum members and TRB staff planned and organized the mini-workshop described in this report. Members of this group were:

- Patricia Hendren, I-95 Corridor Coalition (cochair)
- Scott Schmidt, Alliance of Automobile Manufacturers (cochair)
- Katherine Kortum, TRB
- Mark Norman, TRB
- Virginia Reeder, I-95 Corridor Coalition

Contents

Introduction

In order to better inform all forum members and generate discussion on the strategic crosscutting issues of deployments of automated vehicles (AVs) and shared mobility (SM) services, members are holding a series of "mini-workshops" in 2019. These mini-workshops focus on answering three main questions:

1. Why the subject area is of critical importance;
2. What the current state of play is; and
3. What the future might hold.

The Potential Impacts on Roles of Different Levels of Government and Private-Sector Mini-Workshop occurred on July 15, 2019, in Orlando, Florida. This workshop summary includes key takeaways, panelist remarks, summaries of breakout group discussions, panelists' reactions to these discussions, and a set of key takeaways.

Workshop Format and Agenda

This mini-workshop explored the potential impacts on roles of different levels of government and the private sector. It was designed with four objectives in mind:

1. Explore what the roles of local, state, and federal and private sector should be and could be.
2. Explore what the different agencies need from each other in order to play that role.
3. Encourage new ways of thinking about how this could all work.
4. Provide participants with something concrete they can take back to their own roles.

The mini-workshop opened with a panel of three speakers with different perspectives, each providing insight toward how their roles might shift.

- David Zipper, German Marshall Fund, provided perspectives on SM and AVs, mobility as a service (MAAS), and local-level government roles.
- Raj Ponnaluri, Florida Department of Transportation (DOT) offered his perspective from the state government level, particularly related to data.
- Scott Schmidt, Auto Alliance, represented the auto manufacturers' perspective.

After the panel remarks, participants broke into five breakout groups, each assigned to a stakeholder group:

1. City–local,
2. Transportation network companies (TNCs),
3. Transit,
4. State government, and
5. Original equipment manufacturers (OEMs).

Following these conversations, each breakout group shared highlights from their conversations, and then panel members then reacted to these summaries.

Summary of Panelist Presentations

Presentations from the meeting are available online at http://www.trb.org/trbavsmforum/July2019TRBAVSMForumMeeting.aspx.

DAVID ZIPPER
German Marshall Fund

David Zipper kicked off the panel portion of the workshop with his presentation titled "MAAS, Urban Mobility Data, and AVs." He emphasized that we should all assume that the future of urban mobility will be shared and that users will want seamless experiences. This reality brings up a number of questions related to roles of agencies. Who is selling what in the marketplace? Who owns and has access to the data? How will AVs will fit into this landscape?

Uber sells transit tickets in Denver on their platform. While there is a benefit to TNCs as they begin to do this, there are going to be headaches for travelers. Will the public have to manage many apps in order to access all of the options? We should consider other alternatives; one to look to is Whim, the all-in-one multimodal transportation app in Finland, where the government has passed legislation to require providers to show all of the options available. Is this a role we would like our government to take? If so, what level of government is appropriate?

Regarding data, the ride-hail industry is the first mode to be a truly shared model, but those providers are resistant to sharing data. With the next modes (i.e., e-scooters), cities are requiring that the companies provide data. About 40 cities are using the Mobility Data Specification, developed by the City of Los Angeles. This specification requires that mobility companies share data in real time. The goal is to try to limit chaos on the roadways as AVs begin to show up, but many questions remain about how this will all unfold. AV OEMs are pushing for smooth data sharing. As all relevant players sort out their roles and responsibilities, data sharing will inevitably be a critical piece.

In response to a participant question, Zipper discussed the fact that there is huge potential in the area of courier service and delivery, although it does not get much attention. It represents a real opportunity to get some of the larger trucks off urban streets in particular. There has not been much analysis done in this area compared to the amount of analysis about passenger traffic, but it would be a great research project.

RAJ PONNALURI
Florida Department of Transportation

Raj Ponnaluri presented next on the topic of tackling data challenges. He began by stating that although everyone is focused on data, we still often do not know what data sets are coming out of new CV and AV projects. As we explore the opportunities and understand the roles of OEMs, agencies, and others, partnerships with third parties will be crucial. However, it will be just as important to understand the outcomes of those partnerships.

It is incumbent on all agencies to be aware of the different perspectives of the stakeholders. For example, operations and maintenance data are key for local agencies, and states

need to support local partners in that. Private companies are looking for real-world test beds and the data they get from these pilot opportunities are perhaps their most critical output. States need to understand that these start-ups and their investors are assuming a great deal of risk and also need to be sensitive to what they require to be able to assume that risk.

Florida DOT has developed an enterprisewide information technology strategy to manage its data sharing; this strategy is termed as the Reliable, Organized, Accurate Data Sharing (ROADS) initiative. ROADS provides many benefits, though a V2X data platform (including vehicle-to-infrastructure and vehicle-to-vehicle) will be required to leverage data emerging from the CV and AV projects. One great challenge is that there are no established public methods on data sharing, and we need micro-level and real-time data now. However, the sheer amount of data is a barrier. Conducting return-on-investment analyses will be critical for all agencies as we determine how to allocate resources, how to share data, and what to do with the new information we are able to access.

SCOTT SCHMIDT
Auto Alliance

Scott Schmidt rounded out the panel from the perspective of auto manufacturers with a presentation titled “Infrastructure Considerations to Accelerate Deployment of Highly Automated Vehicles.” He began by emphasizing that all infrastructure benefits (lane markings, signage, etc.) that need to be upgraded for AVs will also benefit human drivers today.

Given the current level of variability in road system infrastructure, vehicle manufacturers are working to develop automated driving system (ADS) -operated vehicles that can accommodate a wide range of potential road infrastructure conditions. However, ADS developers face substantial challenges in developing systems that operate on highly variable and complex road systems, especially in construction zones. Where road infrastructure is inadequate or not reliably maintained, ADS-operated vehicle manufacturers will likely limit the operational design domain (ODD) of their vehicles and or geo-fence difficult roads–intersections to avoid them. OEMs would like to have several features of the roadway infrastructure standardized and maintained to a level that is appropriate for connected and automated vehicle (CAV) use.

In addition, the focus will remain on designing “infrastructure independent” technology, which will lead to more complicated and costly systems and likely inhibit deployment. Schmidt also explained the steps that public agencies can take across all infrastructure categories (e.g., lane markings, traffic signals and signs, construction zones, intersection crosswalks, and speed bumps) to facilitate a “hands-on” approach that will help accelerate development and deployment of AVs.

Summary of Breakout Sessions

Following the panel session, participants were randomly assigned to one of five breakout groups. Once the group assembled, the groups were assigned a role from which they would consider AV- and SM-related policy questions: OEM, state government, TNC, city or local government, and transit agency. From the perspective of this assigned role (and not the one they normally take in their professional capacity), participants spent 1 h discussing and answering the following four questions:

1. From the perspective of [your group] why would you want to support AV and SM?
2. Infrastructure. What is [your group]'s relationship to the infrastructure needed (user, owner, operator)? What is [your group]'s role today in ensuring infrastructure supports AVs? How will this need to change as the adoption of AVs increases? Does this role change if the AVs are part of a SM service?
3. Data. What is [your group]'s relationship to data in AV and SM (consumer, creator, owner)? What is [your group]'s role today in ensuring the data supports AV and SM? How will this need to change as the adoption of AV and SM increases?
4. Testing. What is [your group]'s relationship to testing new AV and SM technology? What is [your group]'s role today in ensuring that testing supports progress in AV and SM? How will this need to change as the adoption of AV and SM increases?

Following these questions, groups identified what they need from their fellow partners (e.g., the other groups represented) and any barriers they saw to playing the role(s) they identified.

At the conclusion of the hour, all workshop participants reconvened and a reporter from each group provided a summary of their group's conversation.

OEM GROUP

Enhanced safety and market competitiveness were key reasons why OEMs would want to pursue AV technology and SM. Given demographic shifts (aging population) and the fact that many younger adults want mobility but do not want to drive, this group felt that new OEM business models emphasizing higher levels of automation would be needed to sustain corporate viability and growth.

OEMs and ADS developers will need to provide guidance on what the most-critical aspects of infrastructure are to support deployment. In addition, standardization of infrastructure was important as well as development of specialized (AV-specific) infrastructure in limited geographic zones to support initial deployments of L4 use cases.

There are many categories of data that need to be considered. For example, AVs will need to access critical infrastructure information such as work zones, etc. Vehicles themselves will likely need to provide operations data to jurisdictions to support management of SM and road usage, and they will need to record safety data related to pre- and post-crash conditions. OEMs will also have the responsibility to ensure the cybersecurity of any vehicle-related data and transmissions.

Both virtual and physical on-road testing are essential to the safe development and deployment of AV technology. With respect to on-road testing, OEMs will need authorization from road jurisdictions that may require legislation and regulation. Part of that legislation–regulation would likely include definitions and limits on liability.

OEMs also seek consistency of regulatory requirements between states and other local jurisdictions. Some participants felt that the development of more coordinated test sites would also help accelerate development and deployment.

The OEM group also identified the following barriers to the role they foresee playing: money or political will–risk aversion; overly burdensome regulations; public perception; and competition between states and cities.

STATE GROUP

The state group reported that their reasons for supporting AV and SM fall within three categories: resource allocation, advancing agency goals (e.g., safety, mobility, economic development, equity, environment—which vary by context), and ensuring consistency across boundaries. Their needs from their partners covered the range of close working relationships through coalitions and other arrangements, data, plans, and a readiness to move forward. In many cases, states lead the way for local jurisdictions, and states generally own most of the infrastructure.

The group organized their thinking around infrastructure into four critical categories: physical, communication, contingency response communications system, and new standards. For data, they explored the roles of the consumer, creator, owner, and partner. As with other groups, they determined that data must be in an open format the still protects privacy. Ideally, states and local agencies would share their progress toward these data standards and formats to avoid starting from scratch with each new deployment. For testing, the group emphasized the need for consistency and for the state to be aware of all projects going on. A theme of this group was that the public sector should play the role of steward of the private sector as AVs become reality.

TNC GROUP

The TNC group supported AV and SM to achieve leveraging of research and investment, accessibility, issues with labor markets, safety, profit, and good stewardship of mobility. They discussed that there are both positive and negative outcomes regarding land use changes. The group also saw these new trends as an opportunity to work in partnership with the regulators.

Regarding infrastructure, many TNCs do not want to wait for the infrastructure, but as the AV and SM systems get bigger, there will be a need for that. It will be critical for TNCs to work in cooperation and collaboration with the infrastructure owners.

With respect to data, standards are critical and this group would look to the public sector for development of those. However, there is a balance to be found with government and how much it “stands in the way” or “gets out of the way.” The TNCs will be viewing data from the utility standpoint.

The greatest barriers this group identified are not-in-my-backyard thinking; lack of data standardization; new or different partnerships and collaboration; a higher demand than what

technology can provide; true equity and access; funding; vehicle communications; and how to incorporate these new models into long-range planning.

CITY–LOCAL GOVERNMENT GROUP

This group identified a range of reasons for wanting to be invested in AV and SM, including safety, equity, access, and economic development. The group recognized that the elected officials leading these entities would be looking for some early wins and wanting to show how these investments would be able to benefit the community.

Cities and local agencies will look to the state and federal governments for leadership and guidance in data standards and collection, including for legislation that protects the data from discovery in court. Some expressed a preference for the state and federal governments to consider an opt in–opt out policy approach for data sharing that provides the flexibility of joining.

A local government has a clear role as an infrastructure owner–operator but also in the realm of providing or leasing fiber. Nonetheless, strong asset management is not occurring at most city and local levels. As questions about what to invest in and how to maintain new types of infrastructure emerge, they will need some clear guidance from partners to facilitate these practices and decisions and to develop a sustainable funding plan to build and maintain CAV-related infrastructure. The conversation about data with the public will be critical as privacy and cybersecurity questions arise.

TRANSIT GROUP

The transit group is interested in AV and SM to address first mile–last mile needs, labor costs, and service improvements for all users. Transit's role within the infrastructure realm includes maintaining right-of-way (ROW); potentially working to create car-free zones; facilitating connected infrastructure; procuring new vehicles; and creating modal connection points at curbs.

This group has an inherent interest in sharing data and looks forward to working with partners on that. They raised questions about the need to keep the public interest in mind when managing data and whether a public agency can be the aggregator of all AV and SM data. The transit group looks to testing as a way to enhance service further (e.g., bus rapid transit, reducing parking).

The transit group will need to collaborate with partners to achieve dedicated ROWs and to find ways to share limited infrastructure. Elected officials will need to be involved to force data sharing. This group stated that while transit agencies often have a hard time "letting go" of what they do but they will have to give up some control in order to achieve the desired goals. This may include rethinking ways for buses to pick up and let off passengers.

PANEL REACTIONS TO BREAKOUT GROUP PRESENTATIONS

Individual panelists then shared their thoughts about the discussions presented by the breakout groups.

- For entities with a role in planning:
  - AVs need to be planned for—not just considered in the operational context, but how to model these travel behaviors is challenging. Transit and freight will be the first level of deployment, so those entities need to be involved in the planning.
  - As we look ahead and plan, we need to remember that land use changes over time. An area that might be rural today may quickly become suburban or even urban. We should be thinking about AVs when planning new development.
  - Representatives from France attended and reported on their "Great Rendezvous on the Robomobile Life" in June 2019. This event is an open forum for questions and debates on all of the changes that robomobility could involve. (Robomobility is the French term for "pervasive driverless mobility of persons and goods.") The event is designed to inform the long-term choices of both public and private players, both in France and internationally. Comparing French and U.S. priorities indicates that as the United States builds out, U.S. priorities may change and land use planning may become a higher priority.
- For entities with a role in regulatory efforts:
  - We need to achieve a regulatory balance. A lack of guidelines will not serve the community well. As one example, SAE is developing on-road testing standards that can be used as state and city requirements.
  - If we are to provide a seamless user experience across all modes, the states or federal government are going to have to get involved and help determine what minimum levels of data sharing is needed and how it should be accomplished.
  - The competition among states and cities could pose a risk; if standards get too relaxed to try to draw in pilot testers, some participants felt that there could be safety concerns.
- And finally:
  - As evidence accumulates that ride sharing is increasing congestion (but with increased vehicle-miles traveled per trip, and a reduction in transit use), the TNCs need to work with partners to alleviate these impacts.
  - Return-on-investment studies and benefit–cost analyses will be key to helping elected officials and other leaders see the value in moving forward with investment.
  - Collaboration is happening in many places for states (e.g., American Association of State Highway and Transportation Officials, Transportation Research Board, I-95 Corridor Coalition), but we also need to create places for local governments and other agencies to collaborate.
  - AVs will not be the only players in future transportation systems. Micromobility, TNCs, transit, and traditional automobiles will all play a part as well.

Key Takeaways

Based on discussions of individual forum members and attendees, key takeaways from the workshop included the following.

Current roles will pave the way, but partnerships and relationships will need to change.

It is inevitable that the new technology associated with AVs and SM will impact our transportation network, options, behaviors, and needs. While many traditional roles may not shift drastically (e.g., infrastructure operator, transit service provider), each party will need to listen and collaborate with a new set of partners to ensure that we realize the benefits, work through the challenges, and solve the inevitable issues.

The key is to acknowledge what we do not know.

There has been a great deal of hype about the advent of AVs and SM. Pieces of the envisioned future already exist, but large questions remain about the technology, implementation, policies, and the many expected outcomes and impacts. It is incumbent on all stakeholders to acknowledge openly that the path forward is not clear, and the actions of different partners can affect the way things unfold. This shared understanding will allow for the most comprehensive and creative solutions.

Everyone wants guidelines, frameworks, etc.

With all of these unknowns, each entity is looking for guidelines and frameworks that establish key roles and responsibilities as well as consistent yet flexible regulatory approaches within which to move forward with technology development, policy adoption, and new responsibilities. Understandably, those who have traditionally provided this structure are hesitant to adopt practices in the face of an unknown future and with the concern that too much regulation could hinder innovation. In addition, most states have indicated a preference for an open format that still protects data privacy, and the structure of such a system is not yet clear.

Consistency and standardization are critical, but it is unclear who should establish that.

There may need to be a few new seats at the table with a slightly different set of perspectives in order to find that balance between a set path and room for playing in the sand box.

Vehicle manufacturers will continue to push agencies to improve existing traffic control devices.

Where road infrastructure is inadequate or not reliably maintained, ADS-operated vehicle manufacturers may limit the ODD of their vehicles or geofence difficult roads–intersections in order to avoid them.

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TRB Forum on Preparing for Automated Vehicles and Shared Mobility

Mini-Workshop on the Economic Implications of Automated Vehicles and Shared Mobility

July 14, 2019
Orlando, Florida

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TRB Forum on Preparing for Automated Vehicles and Shared Mobility

Mini-Workshop on the Economic Implications of Automated Vehicles and Shared Mobility

King W. Gee
American Association of State Highway and Transportation Officials

Art Guzzetti
American Public Transportation Association

Katherine Kortum
Transportation Research Board

July 14, 2019
Orlando, Florida

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TRB Forum on Preparing for Automated Vehicles and Shared Mobility
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Preface

The deployments of automated vehicles, shared mobility services, and other transformational transportation technologies have the potential to dramatically increase safety, reduce congestion, improve access, enhance sustainability, and spur economic development. However, success in meeting these goals is not assured, and there are significant risks that these deployments could cause unintended consequences.

The National Academies–TRB Forum on Preparing for Automated Vehicles and Shared Mobility was officially launched in early 2018 to facilitate evidence-based research needed to deploy these technologies in a manner and timeframe that informs policy to meet these long-term goals. This E-Circular summarizes a workshop held by the Forum to discuss the roles of government and the public sector as these technologies are advanced.

King W. Gee of the American Association of State Highway and Transportation Officials (AASHTO), Art Guzzetti of the American Public Transportation Association (APTA), and Katherine Kortum of the Transportation Research Board authored the paper.

ACKNOWLEDGMENTS

A small volunteer group of Forum members and TRB staff planned and organized the mini-workshop described in this report. Members of this group were:

- King W. Gee, AASHTO
- Art Guzzetti, APTA
- Katherine Kortum, TRB
- Mark Norman, TRB

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Introduction

In order to better inform all Forum participants and generate discussion on the strategic crosscutting issues of deployments of automated vehicles (AV) and shared mobility (SM) services, participants held a series of "mini-workshops" in 2019. These mini-workshops focused on answering three main questions:

1. Why is the subject area of critical importance?
2. What is the current state of play?
3. What might the future hold?

The Economic Impacts of Automated Vehicles and Shared Mobility Mini-Workshop occurred on July 14, 2019, in Orlando, Florida. This workshop summary includes panelists' remarks, summaries of breakout group discussions, panelists' reactions to these discussions, and a set of key takeaways. This e-circular, while brief, is intended to complete the series of five e-circulars resulting from the five workshops.

Workshop Format and Agenda

The workshop's objective was to consider what research is still needed on the economic implications of automated vehicles and shared mobility that would inform actions to maximize benefits and mitigate disbenefits. This research would then also inform funding and financing options.

The workshop contained two presentations, each of which was followed by a breakout session. Workshop leaders randomly divided participants into three breakout groups to discuss their reactions to and feedback on the presentations.

Overall, the workshop leaders asked the participants to keep the following questions in mind as they thought through needed research:

1. Which research questions are of immediate importance, versus those dependent on deployment phase or technology development?
2. Who should be sponsoring or underwriting such research?
3. Who are the key audiences for the results of such research?

Summary of Panelist Presentations

ECONOMIC IMPACT AT THE SYSTEMS LEVEL

Dick Mudge of Compass Transportation provided an opening statement, giving his perspectives of the systems-level economic impact analyses needed to advance automated vehicles and shared mobility (AV&SM). He pointed out that the impacts of AVs are hard to forecast and will be nonlinear. In the past, forecasts about transformational changes missed the mark, and often by a wide margin. In general, these inaccurate forecasts underestimated the impacts and provided very little economic analysis. Decisions about what actions to take were made on a "common-sense" basis. Despite this past experience, clear funding and a business case for decisions is important, both in AVs and in all transformational decision-making processes.

After Mudge's presentation, Forum members broke into three groups. Some of the key highlights of the breakout discussions included the following areas of needed research:

- Testing and validating key assumptions in macroeconomic studies.
- How technical feasibility and business models are applied in specific scenarios under different environments (politics, demographics, density).
- User acceptance and public perception challenges (overcoming skepticism and negative publicity).
- What economic and safety benefits are available at different levels of market penetration?
- Economic factor differences for goods movement via AV&SM versus that of personal mobility.
- Economy impacts when good transportation options are provided to the mobility disadvantaged.
- Governance and policy levers for AV&SM on larger policy issues (e.g., environment, congestion, jobs, access to health care, sprawl and land use, equity, sustainability, security).
- Economic impacts on labor and markets.
- Shared vocabulary and common frames-of-reference, Mobility-as-a-Service, ancillary services.
- How might early adopters such as freight, transit, and taxi help lead the way to broader adoption?

SPECIFIC ECONOMIC IMPACT ANALYSIS AREAS

During this presentation, the group considered the application or topic-specific economic impact analyses needed to facilitate or support deployment of AV&SM. Cathy McGhee, Virginia Transportation Research Center, presented her perspectives. She reviewed the media attention focused on the potential of AV&SM along with the downsides. Job losses may or may not be significant, but fear of them is a limiting factor. There is also potential for increased vehicle miles traveled and unknown impacts to the auto manufacturing industry, as it is not yet clear how

demand for vehicles will change in an era of highly automated vehicles coupled with shared mobility. Transportation revenues may also shift.

McGhee highlighted some of the research needs she sees. She posed the following questions:

- Many of the economic analyses are based on modeling, but how confident are we in modeling assumptions regarding traveler behavior?
- What industries will be most impacted by AV&SM and how can job losses be mitigated?
- Finally, how can states best prepare for changes in both travel patterns and transportation revenues?

After breaking out into the same three groups, Forum participants developed the following key issues about priority needs:

- Applicability of AV&SM in different scenarios, and different phases and levels of automation in "critical mass" contexts (e.g., a major demo in a metro area).
- Culture change and vehicle sharing attitudes under specific scenarios, regional differences, and sociodemographic factors, and what implications does this have for outcomes.
- Monetary—pricing tools to address VMT/PMT, parking, curb space access.
- Transaction cost factors for mobility.
- One payment impact on use and access.
- How and when can AV&SM complement traditional public transportation?
- What is the right role of government and transit agencies to assure equity, and would a clearer AV&SM policy framework foster better outcomes?
- Should there be consistent ODDs for AV suppliers?
- Would CV development accelerate the achievement of full automation (level 5)?
- Implications for effective disaster response in a shared AV world (e.g., in mass evacuations).
- What are the challenges and opportunities of AV&SM in rural areas?
- How can we clearly assess the negative impacts of AV&SM and how should we mitigate such consequences?
- How might early adopters such as freight, transit, and taxi help lead the way to broader adoption?
- Penetration levels—develop an understanding of economic benefits that come with different levels of AV market penetration. What might we expect to see at 10% market penetration? At 20%? At 50%? The analyses should look at the impact of market penetration relative to specific benefits such as safety and efficiency.
- How does AV&SM rise and/or fall when tested in the context of current policy issues and possible solutions, such as carbon taxes, congestion fees, job access, sprawl levels, driver shortages, and environmental and financial sustainability?

Presentations from the meeting are available online at http://www.trb.org/trbavsmforum/July2019TRBAVSMForumMeeting.aspx.

Key Takeaways

During the workshop, Forum participants discussed a number of key takeaways from the discussion. They are as follows.

- The economic impacts of transformational changes are difficult to forecast.
- Economic forecasts of previous transformational changes have missed outcomes, and often by a wide margin.
- The economic impacts have usually been underestimated, and as a result, decisions have been made on a "common-sense" basis, with relatively little reliance on economic analyses.
- In addition, the economic impacts have usually been nonlinear.

A clear funding and business case will be important for the success of AVs and shared mobility. Neither the funding nor the business case has yet been clearly articulated.

Research is needed in the following areas:

- Efficacy of key assumptions
- Modeling for specific scenarios
- Impacts of user acceptance
- What economic and safety benefits accrue at different levels of market penetration
- Economic impacts when good options are provided to the transportation disadvantaged
- Relationships between economic impacts and impacts on other policy issues
- Environment, congestion, sprawl, equity, sustainability
- Jobs
- Transit
- Impacts of pricing tools
- VMT, parking, curb space access
- Transaction cost factors
- One payment systems
- Mobility-as-a-Service

Next Steps

At the workshop, Forum participants also discussed the next steps for research on automated vehicles and shared mobility, which include the following.

- Refining and sifting of the research areas, and vetting by the Forum participants
- Collaboration and coordination of research sponsorship
- Engaging policy makers on the available research results
- Development of policies and infrastructure that accelerate achievement of AV&SM benefits
- Taking actions that mitigate negative impacts

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DIRECTORY OF INFORMATION RESOURCES

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TRB staff continues to keep this list updated, and the most current version is posted on the Forum's website (https://trb.org/AVSMForum). Forum participants and others are encouraged to bring similar resources to the attention of the TRB staff.

The fifteen new resources that have been added since the Forum's last meeting in October 2019 are shown below.

Contents

SCENARIOS FOR AUTOMATED VEHICLES AND SHARED MOBILITY

- Autonomous Vehicle Implementation Predictions: Implications for Transport Planning; Victoria Transport Policy Institute, February 2020: https://www.vtpi.org/avip.pdf
    - Explores the impacts of autonomous vehicles (AVs) and their implications on planning issues. Investigates how quickly AVs are likely to develop and be deployed; their likely benefits and costs; and how they are likely to affect travel demands and planning decisions.
- Zero Emission Vehicles: Forecasting Fleet Scenarios and their Emissions Implications, NCHRP Web-Only Document 274, Transportation Research Board, February 2020: http://www.trb.org/main/blurbs/180232.aspx
    - Analyzes a set of scenarios of infrastructure development, policy changes, and cost parameters, with a suite of 49 simulations across those scenarios conducted to assess their impact on nationwide zero emission vehicle (ZEV) adoption and the corresponding levels of exhaust emissions. The model used in the scenarios analysis is a consumer choice model that estimates future sales, populations, and fuel consumption of advanced technology vehicles (ATVs), including ZEVs. A PowerPoint presentation also accompanies the document.
- The Effect of Automated Vehicles on Toll Roads; Fitch Ratings, February 2020; https://www.fitchratings.com/site/re/10107648
    - Predicts the effects of automated vehicles on toll roads. Observations and predictions include: Full autonomy will be transformative, overall VMT expected to increase, however, other factors could combine to decrease VMT, monopolistic systems are best positioned, managed lanes are most vulnerable, and timing of AV use is still uncertain. Due to uncertainties, Fitch has not taken rating actions or changed outlooks on toll road issuers due to risks from AVs.
- Understanding Surveys of Public Sentiment Regarding Automated Vehicles; U.S. Department of Transportation, November 2019, https://rosap.ntl.bts.gov/view/dot/43628
    - Explores the public's outlook on automated vehicles, focusing specifically on attitudes regarding safety, trust, and willingness to try, as well as the factors that influence those opinions. Compiles the results of numerous surveys and studies conducted over the past four years and tracks consumer attitudes over time, against the backdrop of newsworthy events in the development, testing, and early deployment of automated vehicles. Also presents an overview of research on the factors that affect consumer technology adoption, particularly in the context of innovative technologies, and identifies implications of this research for future assessments of the public's interest in automated vehicle.
- Insights Into Future Mobility; MIT Energy Initiative, November 2019; http://energy.mit.edu/wp-content/uploads/2019/11/Insights-into-Future-Mobility.pdf
    - Uses a scenario-based approach to explore some of the major factors that will affect the evolution of personal mobility leading up to 2050 and beyond. The five main areas of inquiry include: impact of climate change policies, outlook for vehicle ownership and travel, characteristics of alternative vehicle powertrains and fuels, infrastructure considerations for charging and fueling, and the future of personal mobility in urban areas - with a focus on the potentially disruptive role of autonomous vehicles and ride-hailing services.

- Impacts of Automated Vehicles and Shared Mobility on the Future Roles of the Public and Private Sectors; Virginia Reeder, Scott Schmidt, and Katherine Kortum; November 2019: http://onlinepubs.trb.org/onlinepubs/circulars/ec258.pdf
    - Summarizes the July 15, 2019 workshop on the topic conducted by the National Academies/TRB Forum on Preparing for Automated Vehicles and Shared Mobility. Key takeaways included: Current roles will pave the way, but partnerships and relationships will need to change; One key is to acknowledge what we do not know; Everyone wants guidelines, frameworks; Consistency and standardization are critical, but it is unclear who should establish these; Vehicle manufacturers will continue to push agencies to improve existing traffic control devices.
- An Update on the Outlook for Automated Vehicle Systems: Society of Actuaries, Richard R. Mudge and Alain Kornhauser; October 2019: https://www.soa.org/globalassets/assets/files/resources/research-report/2019/automated-vehicle-update.pdf
    - Summarizes major trends and trigger points, including those for policy, technology, and vehicles. The report also analyzes recent major events, including: slower deployment - with a few exceptions, Waymo moves forward, trucks, safety record - and the need for more data, implications of Tesla insurance package, company mergers, Uber and Lyft IPOs, regulations, local opposition to TNCs, AVs and the mobility impaired. Conclusions include, “"Reality has caught up with the hype/romance of the popular press concerning the future of automated driving. Disappearing is the vision of connected swarms of driverless personal cars flowing effortlessly down our arterials and freeways. The buying public, however, is beginning to absorb the driver-assisted technologies that not only deliver safety, comfort and convenience, but also serve to embolden the traditional consumer-oriented business model. This, in turn, has helped accelerate private investment and technology partnerships that involve almost every automobile manufacturer."

GUIDANCE FOR STATE, AND LOCAL AGENCIES

- Foreseeing the Impact of Transformational Technologies on Land Use and Transportation; Transportation Research Board, National Cooperative Highway Research Program's NCHRP Research Report 924, February 2020; http://www.trb.org/main/blurbs/179645.aspx
    - Reviews the characteristics of new transportation-related technologies and their applications in the transportation sector and explores a wide variety of potential impacts on areas such as travel and land use and planning projects.Examples of transformational technologies include wireless telecommunications, shared vehicles, connected vehicles, fully autonomous vehicles, alternative-fuel vehicles, smart cities and communities, big data analytics, internet-of-things, as well as UAVs or drones, 3-D printing, and more. Concludes that public agencies face significant challenges continuing to perform their governmental functions in the face of the private sector’s prodigious output of these new technologies. Agencies need to rethink how they develop their policies and plans—and they need to obtain new expertise.
- Prioritizing Public Value in the Changing Mobility Landscape: Harvard University Ash Center for Democratic Governance and Innovation, January 2020: https://ash.harvard.edu/files/ash/files/ash_mobility_goldsmith_gardner_final_.pdf

  - Looks at the values and goals cities affect with policies concerning connected mobility, and how to create a new framework that aligns with these objectives. First, the authors identify the transformative changes affecting cities and mobility. Second, they discuss in more detail the guiding values and goals that cities have around mobility with examples of these values in practice. Makes the case that cities must use specific public values lenses when planning and evaluating all the different facets of mobility. Transportation has entered a new phase, and the authors believe that cities should move forward with values- and community-driven policies that frame changing mobility as an opportunity to amend and improve previous transportation policies.
- Considerations for Evaluating Automated Transit Bus Programs: U.S. Federal Transit Administration, prepared by the John A. Volpe National Transportation Systems Center, December 2019: https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/146801/considerations-evaluating-automated-transit-bus-programs-fta-repor-no0149.pdf
  - Assists transit stakeholders with designing and implementing evaluations of automated transit-bus programs. In designing evaluations, transit agencies and other stakeholders should identify program goals and audiences affected by the technology; develop a logic model that maps project inputs, activities, and outcomes; choose an appropriate evaluation design; and collect and analyze data on key performance indicators related to their program goals.
- Transformational Technologies in Transportation: Impacts on Traditional Research Processes and Programs: TRB Transportation Research E-Circular 253, Mark Norman (rapporteur), October 2019: http://onlinepubs.trb.org/onlinepubs/circulars/ec253.pdf
  - Addresses the basic question - In an era of rapidly evolving transformational technologies, can our research projects and processes provide needed answers in a timely manner while still protecting the credibility of the research, and if so, how? Includes a list of questions that can help researchers to determine a targeted time frame appropriate for the specific research in question. Lists options that exist to enable research projects and processes to provide needed answers in a timely manner while still protecting the credibility of the research.

FEDERAL AGENCY NOTICES, GUIDANCE, AND INFORMATION

- Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0; U.S. Department of Transportation, January 2020, https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/360956/ensuringamericanleadershipav4.pdf
  - Establishes U.S. Government principles that consist of three core interests, each of which is comprised of several sub-areas. Unifies efforts in automated vehicles across 38 Federal departments, independent agencies, commissions, and Executive Offices of The President, providing high-level guidance to federal agencies, innovators, and all stakeholders on the U.S.

SAFETY & SECURITY

- No new resources added under this category

ROLE OF SHARED MOBILITY

- Transportation Network Companies (TNCs): Impacts to Airport Revenues and Operations: Airport Cooperative Research Program, Transportation Research Board, December 2019; http://www.trb.org/main/blurbs/180077.aspx
    - ACRP Research Report 215 is designed to help airport operators develop and implement practical approaches to managing TNCs within the context of commercial ground transportation policies and programs. The report presents best practices that have proven to be effective tools that airport operators can use to manage TNC operations and develop sustainable revenue models. It particularly is designed to help airport operators evaluate the tradeoffs among customer service, revenue generation, current operations, and long-term facility planning.
- Taxonomy & Classification of Powered Micromobility Vehicles: SAE International, November 2019; https://www.sae.org/news/press-room/2019/11/sae-international-publishes-industry%E2%80%99s-first-standard-for-classification-and-definition-of-powered-micromobility-vehicles
    - Provides clarity and organization around the nomenclature of these vehicles. The standard provides a criteria for “powered micromobility vehicles” and a classification system that defines six types of powered micromobility vehicles by physical attributes—including powered bicycles, standing and seated scooters, self-balancing and non-self-balancing boards, and skates—with descriptors for curb weight, vehicle width, top speed and power source.
- E-Hail Regulation in Global Cities: Rudin Center for Transportation, New York University, November, 2019; https://wagner.nyu.edu/files/faculty/publications/RUDIN_EHAIL_REPORT.pdf
    - Describes current and future regulatory strategies for e-hail services in 13 international cities. Helps cities learn from each other's regulatory approaches to leverage the power of shared information. Also seeks to offer ways for e-hail services to adapt their business models to meet increasing government regulation.

e-Group Community Postings
October 2019 – February 2020

- Is Congress Making Progress on an AV Bill?
- NHTSA Gives OK to Nuro's Driverless Delivery Vehicles
- Impact of Transformational Technologies on Land Use and Transportation
- The Impact of AVs on Planning
- Have Cities Lost Control of the Urban Tech Revolution?
- FCC Votes to Move Forward on 5.9 GHz Reallocation Plan
- Forecasting EV Fleet Scenarios
- The Effect of AVs on Toll Roads
- Top Seven Mobility Trends for 2020
- Global Guide to AV Laws and Regulation
- Understanding Public Sentiment Regarding AVs
- Data Sharing Guidance for Public Transit Agencies
- U.S. DOT: Ensuring American Leadership in AV Technologies
- Tipping Point for AVs?
- How Locals Need To Prepare for the Future of V2V/V2I
- NAE - Why Everyone Has It Wrong About the Ethics of AVs
- Friday Fourm: Prioritizing Public Value in the Changing Mobility Landscape
- Optimizing the Lateral Wandering of AVs
- FTA Issues Guidance for Evaluating Automated Transit Bus Programs
- Forum Friday: Forum Session Addresses Existential Questions
- Secretary Chao Announces Initiatives at TRB Annual Meeting Chair's Luncheon
- U.S. DOT Blog - Preparing for the Future with AV 4.0
- AVs & Shared Mobility Sessions at TRB Annual Meeting
- U.S. DOT Releases AV 4.0 Guidance
- U.S. DOT Releases "Inclusive Design Challenge" Request for Information (RFI)
- Rethinking Micromobility to Ensure It Works for All
- Potential Impacts of AVs on Transit and Parking Systems
- Impacts of TNCs to Airport Revenues and Operations
- Insights Into Future Mobility
- TRB Forum to Focus on Preparing for Future Scenarios
- AVs and Shared Mobility - Impacts on the Roles of the Government and the Private Sector
- Managing Transportation Systems in a Fast Changing World
- Considerations of Current and Emerging TMC Data (FHWA)
- Canadian National Institute for the Blind releases final report of AV Study

- TRB Releases Overview of Scores of Annual Meeting Sessions on AVs & Shared Mobility
- Testimony from Senate Committee Hearing on Safety of AVs
- Guidelines for Regulating Shared Micromobility (NACTO)
- Friday Forum:SAE Publishes Standard for Classification and Definition of Powered Micromobility Vehicles
- US. DOE Seeks Input for Innovation Council
- NTSB, Senators Call for Stronger Regulation of AVs
- FCC Chair Announces Intent to Reallocate 5.9 ghz Spectrum
- Common Naming for Advanced Driver Assist Technology Pushed by AAA, Partners
- TRB Forum Session at 2020 TRB Annual Meeting
- Regulating e-Hail Companies in Global Cities
- Developing Standards for How AVs Will Interact
- The Race for Automated Trucks is On
- Issues in Autonomous Vehicle Testing and Deployment
- TRB Cooperative Research Programs: Update on Status of CAV Research Projects
- RFP Issued to Update Research Roadmap for NCHRP 20-102
- The Changing Context for V2I (Thought Piece)
- Lawsuit Challenging NYC's Cap on Ride-Hail Drivers is Dismissed
- Impacts on Traditional Research Processes and Programs
- Society of Actuaries Updates Outlook for AVs
- Report - Smart Cities, Dumb Infrastructure
- Secretary Chao Announces New 'Mobility And Inclusion' Programs
- AV Bill - Status Update
- Advanced Technologies Credited With Reducing Fatalities in 2018
- AVs Could Worsen Congestion - Adelaide Test Model
- Transportation Electrification - States Rev Up
- Creating the Right Urban Infrastructure for Shared, Seamless Autonomy - McKinsey Roundtable

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TRANSPORTATION RESEARCH BOARD

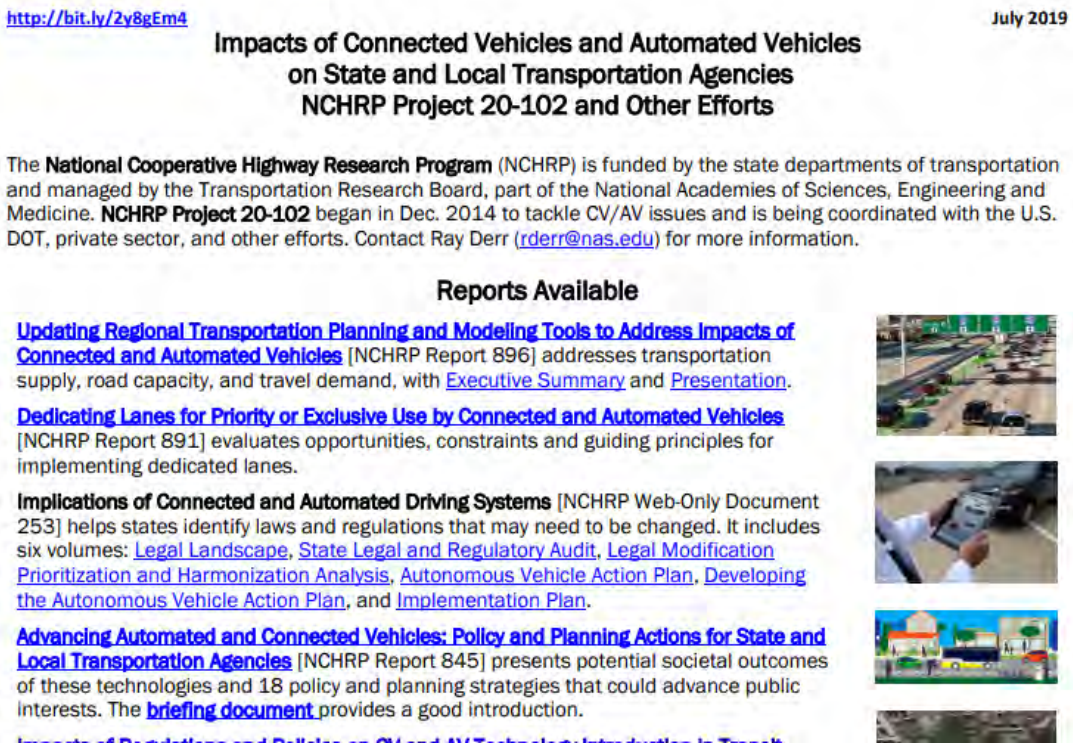
Update on Cooperative Research Programs

Ray Derr, Project Manager
Transportation Research Board
National Cooperative Highway Research Program

February 25, 2020

Impacts of CVs and AVs on State and Local Transp. Agencies [NCHRP 20-102]

- Summary of TRB Research at http://bit.ly/2y8gEm4
- Next selection meeting at Automated Vehicle Symposium, July 27-30, San Diego



http://bit.ly/2y8gEm4 July 2019

Impacts of Connected Vehicles and Automated Vehicles on State and Local Transportation Agencies NCHRP Project 20-102 and Other Efforts

The **National Cooperative Highway Research Program** (NCHRP) is funded by the state departments of transportation and managed by the Transportation Research Board, part of the National Academies of Sciences, Engineering and Medicine. **NCHRP Project 20-102** began in Dec. 2014 to tackle CV/AV issues and is being coordinated with the U.S. DOT, private sector, and other efforts. Contact Ray Derr (rderr@nas.edu) for more information.

Reports Available

Updating Regional Transportation Planning and Modeling Tools to Address Impacts of Connected and Automated Vehicles [NCHRP Report 896] addresses transportation supply, road capacity, and travel demand, with Executive Summary and Presentation.

Dedicating Lanes for Priority or Exclusive Use by Connected and Automated Vehicles [NCHRP Report 891] evaluates opportunities, constraints and guiding principles for implementing dedicated lanes.

Implications of Connected and Automated Driving Systems [NCHRP Web-Only Document 253] helps states identify laws and regulations that may need to be changed. It includes six volumes: Legal Landscape, State Legal and Regulatory Audit, Legal Modification Prioritization and Harmonization Analysis, Autonomous Vehicle Action Plan, Developing the Autonomous Vehicle Action Plan, and Implementation Plan.

Advancing Automated and Connected Vehicles: Policy and Planning Actions for State and Local Transportation Agencies [NCHRP Report 845] presents potential societal outcomes of these technologies and 18 policy and planning strategies that could advance public interests. The **briefing document** provides a good introduction.

Foreseeing the Impact of Transformational Tech. on Land Use and Transportation [NCHRP Report 924]

- Guidance for transportation investment and land use decisions on technologies that
  - Replace the need to travel
  - Facilitate travel
  - Increase flexibility in travel
  - Improve government services
  - Improve the delivery of transportation services
  - Improve the delivery of parking
  - Improve logistics

Credit: fastcodesign.com

Connected Roadway Classification System Development [NCHRP TBD]

- Three Infrastructure Approaches
  - Talking to the Road
  - Seeing the Road
  - Simplifying the Road
- Four Classification Levels
  - In Need of Upgrade
  - Meets Best Practice
  - Meets Emerging Markets (1-5 years)
  - Meets Next Decade Market

Credit: nacto.org

Updated Research Roadmap for NCHRP 20-102 (NCHRP 20-102(13)B)
January 10, 2020 Meeting

	CAT Coalition	TRB Forum	Private Sector	US DOT	States/Local Agencies	TRB CRPs
What is underway						
Goals						
Audience						
Strengths						
Weaknesses						
Opportunities						
Threats						

Summary coming soon outlining priorities for 20-102; catalog of recommended projects in April

State-of-the-Art Review of CAT Systems [NCHRP 20-124(128)]

Document and disseminate lessons learned from CAT system deployments that state and local DOT leadership can apply to decisions affecting their agency

Schedule

- Jun 2019, Las Vegas
- Oct 2019, ITS World Congress Singapore
- Dec 2019, Arizona
- Jan 2020, Session 1647, Tuesday 6-7:30 PM
- Apr 2020, Florida
- Jun 2020, Germany & Netherlands
- Aug 2020, Ohio & Pennsylvania
- Oct 2020, ITS World Congress, Los Angeles

Panel

Tracy Larkin-Thomason, NV
Carlos Braceras, UT
Tom Byron, FL
Shanté Hastings, DE
Randy Iwasaki, Contra Costa Co.
Julie Lorenz, KS
Patrick McKenna, MO
Russell McMurray, GA
Roger Millar, WA
Jennifer Toth, Maricopa Co.
John Corbin, FHWA
Gummada Murthy, AASHTO