NCHRP 20-113A

Planning Document for Transformational Technologies Affecting Transportation

Final Report

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by

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The initial task in this effort (Project 20-113A) supported the TRB Partners in Research Symposium: Transformational Technologies that was held on October 31-November 1, 2016 in Detroit, Michigan. This report documents that symposium and was prepared by Peter Sweatman and Abbas Mohaddes of CAVita, LLC. The work was guided by a technical working group and managed by Ray Derr, NCHRP Senior Program Officer.

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EXECUTIVE SUMMARY

New technologies have the potential to transform transportation as we know it. Public agencies are being challenged to facilitate technology deployment to meet public policy objectives. These objectives include improved safety, reduced congestion, enhanced sustainability and economic development. Research is needed to assist the public and private sectors in deploying these technologies in a manner and timeframe that can maximize the probability of successfully meeting these policy objectives.

Relevant technologies include connected and automated vehicles (CAV), shared mobility (SM), alternative-fuel vehicles, NextGen, air and space innovation, Big Data, cybersecurity, Internet-of-Things (IoT) and 3D printing. Paths for deployment of these technologies include personal mobility services, smart infrastructure, freight supply chains, Smart Cities and Communities, data networks and unmanned aerial systems (UAS).

The TRB Partners in Research Symposium: Transformational Technologies was convened by TRB, in partnership with NCHRP and the Michigan Department of Transportation (MDOT), and held on October 31 and November 1, 2016. This report summarizes the highlights and findings of the interactive symposium. Participants discussed partnering to move faster and bridge the gap between technology development and public policy. Highly automated vehicles – a central topic - are transformational. Shared mobility (SM) – a hot topic at the symposium - is causing a reset in city living. Smart Cities and Communities thinking provides an exciting technology platform provided we can anticipate impacts. The rate of change is inexorable, and the private and public sectors need to rethink their dialog, with the help of academia.

The symposium revealed a concerning level of uncertainty surrounding the central topics, discouraging public-private collaboration and preventing timely policy development. TRB has the opportunity to play a new role in reducing uncertainty by bringing together public-private-academic partnerships for accelerated research and policy advice. TRB's expertise is needed to systematize a long list of research questions and to implement a research process more suited to this time of rapid change. The new process must create a higher level of public-private trust and willingness to share private data from real technology users of public infrastructure – often termed *model deployments*. TRB's process of curation should also extend to replication of deployments, aggregation of data, development of policy advice based on data and metrics, and greater use of transportation data science.

In addition to its currently-expanding activities in transformational technologies, TRB should consider steps to address the central issues raised so clearly at the symposium. Those steps fit the medium of the National Academies Roundtable. Based on the biggest issues raised by industry-government-academic participants, and reinforced throughout the two days of discussion, the following three research roundtables are most likely to garner trilateral support and have the most beneficial impact:

I. Cooperative National Research Planning in Transformational Technologies

   There is an urgent need for a widely-shared and continuously updated national roadmap for automated and connected vehicle research.

II. Precursory Policy Analysis in Transformational Technologies

There is an urgent need for scenario planning, impact analysis and economic analysis of shared automation.

III. Living Laboratories Network and Data Pipeline

To accelerate research in automated mobility and create data access, aggregation, sharing, and joint analytics.

The launch of these roundtables should be planned as a group. While entities (companies, agencies and universities) may wish to join a specific roundtable, major sponsors may be interested in supporting all three as they represent a very large collective step forward, with no other known avenue for such a strongly-supported initiative. In addition, six high-priority research projects developed through breakout discussions have been recommended for early initiation to directly support the creation of roundtables.

1 INTRODUCTION

New technologies have the potential to transform transportation as we know it. Public agencies are being challenged to facilitate technology deployment to meet public policy objectives. These objectives include improved safety, reduced congestion, enhanced sustainability and economic development. Research is needed to assist the public and private sectors in deploying these technologies in a manner and timeframe that can maximize the probability of successfully meeting these policy objectives.

Technologies under immediate consideration include connected and automated vehicles (CAV), shared mobility (SM), alternative-fuel vehicles, NextGen, air and space innovation, Big Data, cybersecurity, Internet-of-Things (IoT) and 3D printing. Paths for deployment of these technologies include personal mobility services, smart infrastructure, freight supply chains, Smart Cities and Communities, data networks and unmanned aerial systems (UAS).

Traditional automotive companies are being disrupted by technology companies, and a host of new companies are entering the transportation sector, dealing with services as well as technology development. Markets for the subject technologies depend on actions by government agencies at all levels, timely policy development and greater understanding and collaboration between the private and public sectors. There is great scope for the National Academies, academic and research institutions, standards bodies and industry and professional associations to assist with necessary policy development, accelerated demonstration and deployment, and research.

The TRB Partners in Research Symposium: Transformational Technologies was convened by the Transportation Research Board (TRB) in partnership with the National Cooperative Highway Research Program (NCHRP) and the Michigan Department of Transportation (MDOT); the symposium agenda is included in Appendix A. On October 31 and November 1, 2016 over 100 representatives of industry, government and academia came together at the Westin Detroit Metropolitan Airport to increase mutual understanding of policy development challenges and underpinning research needs. This report summarizes the highlights of the symposium and recommends steps to greater collaboration in deployment, research and policy development.

The symposium was built upon a considerable body of existing TRB activity in the introduction of innovative technologies in transportation, including the Transformational Technology Task Force of the Executive Committee and NCHRP's activities in connected and automated vehicle (CAV) policy development and transformational technologies. As part of the TRB Executive Committee's effort, the key transformational technologies were reviewed and potential approaches for TRB to increase its contribution were considered[1] (1), including the use of industry-government-academic roundtables and more targeted research methods.

The goal of the symposium was to create a *research roadmap* and *government-industry partnerships* to address *public policy objectives*, by addressing the following questions:

[1] Mohaddes, A. & Sweatman, P. (2016) Transformational technologies in transportation. TRB Circular E-C208, May 2016.

- What are the most critical research needs for positive policy outcomes from deployment of transformational technologies?
- Which are best addressed through public/private/university partnerships?
- Given the rapidly changing terrain, can partnerships keep research needs current?
- What form may these partnerships take, and what role can TRB and others take in facilitating such partnerships?

The symposium was planned by a TRB-NCHRP Organizing Committee, with guidance from NCHRP Panel 20-113, Research Roadmap for Transformational Technologies, and representatives of TRB's extensive research committee structure. The symposium was structured to allow for the perspectives of both policy development and technology commercialization to be heard: what do policy makers need from industry? – and, what does industry need from policy makers? The participants were well balanced between government, industry and academia, as well as regions across the country. Entities new to the transportation sector were included, as well as the more established industries, and modalities adjacent to the road-based ground transportation community – such as rail, air, supply chain, warehousing, and real estate – were represented as well as the disciplines of data science, alternative energy, travel behavior, urban science and artificial intelligence. The principal public sector incumbents in highway transportation – state departments of transportation – and their private sector counterparts were well represented.

This report provides a concise summary of the symposium proceedings and outcomes of the breakouts and review panels, and it includes CAVita's recommendations for next steps in establishing roundtables based on the symposium discussions. These recommendations include:

- Steps to close the gap between technology availability and policy development;
- Research questions and a responsive research program;
- Roundtable topics, activities and membership profile; and
- High-priority research outlines.

2 SYMPOSIUM HIGHLIGHTS

2.1 Plenary Sessions

The opening sessions challenged participants to think about partnering to move faster and bridge the gap between technology development – and desire for deployment and market development – and public policy. The following points were made during the plenary session presentations and discussions.

There is a risk that lack of informed action by policy-makers will stifle innovation and cause significant societal benefits to be missed. Is it possible for technology to respond more to public policy needs and be a catalyst for substantial partnerships?

Highly automated vehicles are transformational. The rate of change is unpredictable, and both private and public sectors need to be prepared to rethink everything they are doing. This is a particular challenge for the public sector that is in many ways removed from the process of technology development and the growing service economy. The government has a responsibility to make investments that reduce risk and to educate consumers. The current National Highway Traffic Safety Administration (NHTSA) engagement with the auto industry and guidelines for highly-automated vehicles (HAV's) are a good example of policy collaboration in an environment of disruptive technology. From the public perspective, it is necessary to accelerate, adapt, understand and maximize societal goals.

Several streams of innovation are coming together in personal mobility. When we combine shared, electric, and automated vehicles we may be looking at a sharp decline in private vehicle ownership in cities. Equally important is innovation in the supply chain for goods, where national competitiveness is at stake and a large element of the national economy and workforce is in play. Similar forces for reinvention are evident in other modes, such as rail and air.

2.1.1 Shared Mobility

Technology is enabling a rapid rollout of shared mobility (SM) and the field is changing rapidly, while data, analysis and information is scarce. There is an urgent need to develop an understanding of the impact of SM on current transportation systems. New fields of data science are being applied to public urban transit, creating an on-demand multi-modal transport system along with prescriptive analytics.

2.1.2 Highly-Automated Vehicles

We have a very long way to go with the introduction of highly-automated vehicles, and there will be a protracted period of "mixed operations" where such vehicles co-exist with a traditional combination of road users. Important factors in the rate of penetration of automation include social acceptance, availability of trustworthy products, and the creation of field operational tests for learning and validation. For highly-automated vehicles (HAV's), federally-funded field operational tests (FOT's) for AV integration are needed.

Among highway agencies, simple support for road trials does not necessarily constitute policy. We need a dynamic 10-year roadmap detailing the required systems and sub-systems. Multiple "concepts of operations" are needed to represent the diverse road transportation applications that

can be automated, to be deployed in living laboratories. Technology convergences – such as connected and automated vehicle technologies - are important and a roadmap for CAV (and adjacent technological innovation) is urgently needed.

2.1.3 Public-Private Partnerships

Public-private partnerships are not always well understood but are essential to technology deployment. Government roles are evolving from the regulator, to the partner, and perhaps facilitator. All partners need to be guided by the mission. Research is not only a good catalyst for collaboration, but it is also needed to support metrics for the alignment of partners. Transportation has both a powerful business impact as well as a decisive social impact through its impact on household expenditure (of both money and time).

We will see tremendous convergence of technologies and platforms, with a mix of technology, policy, consumer needs and business models. By way of example, there may be a role for "municipal vehicles". There needs to be a strong value proposition, clear to all parties. The private sector is looking for demonstrable efficiency of investment and reduced time to market through acceleration. Companies are looking for the necessary partnerships to develop viable business models for services using connected and automated vehicles.

The expansion of connected vehicle pilots to new locations and use cases is a positive step, but extrapolating from a pilot to nationwide practice remains extremely difficult. The scaling problems are mainly in procurement, and there is no common process – or "platform". There is a need for broader constituencies, outreach and education.

Aviation safety is a good example of a successful public-private partnership. Today, the integration of unmanned aerial systems into the airspace system is a major challenge, and contains the same difficult public-private issue we see with automated ground vehicles: the mix of manned and unmanned systems.

2.1.4 Energy and Environmental Impacts

With respect to energy consumption and greenhouse gas (GHG) emissions, it is not clear whether CAV's and mobility on demand (MOD) represent an improvement or a degradation. From a user's perspective, technologies such as shared ride services, connected transit and CAV's increase the complexity of decision making in mobility. There is a need for "mobility decision science" to support informed investment decisions. The R&D opportunity space is still emerging and expanding.

2.1.5 Trend of Presentations and Discussion

The rapporteurs highlighted certain trends in the contributions from participants:

- Policy is clearly lagging technology in some areas; it is easy to get policy initiatives wrong, and sometimes involves "picking winners and losers", and it can be challenging to motivate policy makers to move faster due to uncertainty; there is a need to educate policy makers, provide clarity on policy goals through data understanding and develop a "policy roadmap";

- This requires a rethinking of the role and process of research: involving more players, nimble, built around deployments, and *accelerated*;
- On the one hand, automation offers high hopes to improve safety, reduce congestion, reduce energy use, support shared mobility and multi-modal integration, improve social mobility, improve access and reduce costs; however, there is great uncertainty about connected and automated vehicle effects on vehicle miles of travel (VMT), the time frame for introduction of highly automated vehicles, effects on vehicle ownership and use, and effects on land use; there is also uncertainty about technological reliability, robustness of technology to external conditions, fail safe pathways, human-computer interaction and cybersecurity; this makes a strong case for testing through model deployments and multiple use cases; and this represents a non-traditional approach to research;
- Public/private/university partnership deployments represent a useful research paradigm, with an important role for TRB as a convener and non-partisan broker; both technology and policy research is needed, and best employed in tandem; and
- There are many specific research topics, including data sharing, assessment of technology and business model impacts, integration of systems, cyber-security, and technology reliability.

2.2 Breakout Sessions

Each breakout session focused on research needs, and the highlights are summarized in the following paragraphs. In many cases, research was discussed in terms of unanswered questions.

2.2.1 Shared Mobility (P1)

Shared mobility has the potential to create shared automated vehicles (SAV's), a powerful answer to many societal issues. However, there are too many unanswered questions, and the field of shared mobility has a limited "playbook" for research:

- What are the impacts of MOD on the transportation system?
- How to address social inclusion and the "digital and income divide"?
- What are the safety impacts of ridesourcing and transportation network companies (TNC's)?
- How to quantify the impact of shared mobility on public transit and the economy?
- How to incorporate the wide spectrum of shared mobility services into regional planning tools?

2.2.2 The Supply Chain (P2)

The supply chain provides the context for essential improvements in both the demand and supply of freight, and it is rapidly evolving. Technologies, including automation, are of vital interest throughout the supply chain, including on-road operations. The path to efficient public sector investment is not clear. Research questions include:

- To develop a public sector, multimodal decision support system for freight connectivity optimization, focusing on freight corridors, bottlenecks and data protocols?

- What is the critical path to "Level 4" automation of freight vehicles? How to understand public acceptance or resistance?
- What are the workforce implications of automated freight mobility?
- What are the effects of 3D printing?

2.2.3 Smart Cities and Communities (P3, P4)

Smart cities depend on data, and the integration of transportation data with other types of data. Project development and procurement are key issues. There is a clear case for highly-automated vehicle (HAV) test beds; however, questions remain concerning the role and impact of ridesourcing/TNC's. One of the most pervasive issues is changes in parking and impacts on land use. Research questions include:

- What are the impacts of ridesourcing/TNC's on the transportation system of cities and other communities?
- What are the most significant land use implications affecting real estate, zoning and development?
- What will parking look like, and how will parking policy need to change?
- What standards need to be developed, and how soon?
- How do ridesourcing/TNC's affect adherence to the Americans With Disabilities (ADA) Act?
- How do traffic apps affect driver choices and behavior?
- How can we best document impacts of deployment on equity?
- Syntheses are needed on procurement of best practices and municipal/local data uses by companies and third parties.
- What are the implications of changing public-private roles? Will state DOT's and regional/local agencies need to change their business models and contract out?
- What are the scenarios for economic implications? How would revenue be redistributed with lower household transportation costs and less local taxes and charges?
- Scenario and use case research is needed for long-term impacts.

2.2.4 Airspace Innovation (P5)

Air space innovation faces a major challenge in the automation of both the flight deck and air traffic control and management in a safe way with an appropriate transition path. Unmanned aerial systems (UAS) have significant transportation applications, along with many other fields. Research questions include:

- How should UAS be used for traffic monitoring and accident detection? What are the best practices?
- Need for surveys of local concerns about drones.
- Need for a curriculum for training UAS operators.
- Many human-machine issues relating to automation.

2.2.5 Light Vehicle Automation and Connectivity (T1)

Light vehicle automation and connectivity represents the single most powerful technology discussed, but it suffers from the lack of a national research roadmap for CAV, and a large number of unanswered questions. Many of the questions raised relate to data access, sharing and

handling. It is understood that other important questions relate to reliability, security, privacy, legal and liability, applicable road rules, and "mixed operations". The discussion revealed a need for a more concerted research approach with a much broader catchment of expertise, deeper access to HAV developer data, and the immediacy of deployments and field operational tests. Research questions raised include:

- What are the data and use cases that are available and relevant?
- How should data be standardized/anonymized so that it can be shared?
- How should data be maintained through its life cycle, from generation to use to storage?
- What are the appropriate data sets to expect from sensors?
- What are the metrics for software reliability?
- How do you judge whether algorithms are performing well?
- How do you define privacy?
- What data should be preserved through a catastrophic event so you know what happened?
- How much data should be made public? and
- What are appropriate safety metrics for highly automated vehicles?

2.2.6 Heavy Vehicle Automation and Connectivity (T2)

Heavy vehicle automation and connectivity needs research to identify a wide range of impacts affecting parties with disparate interests. Users are interested in safety and sustainability, public agencies are interested in shifts in the workforce, and private companies are interested in costs and market share. Policy development needs to have a strong awareness of policies that nurture, enable, hamper, or are neutral. Technology is moving so rapidly that a regular dialog is needed, and innovative forums need to be developed with much broader representation than in the past. We should not lose sight of the strong implications of freight mobility technology for international competitiveness. The use of automated trucks in older urban settings needs strong consideration. Pilot deployments and research studies are needed to address these issues in a practical and timely manner. Research questions raised include:

- How can the public sector best use the private sector provider's data?
- How can the public gain from sharing their data?
- What are the different impacts of disruptive technology on large, small and individual operators?
- How do tougher emission standards influence deployment?
- What are the changes in risk exposure for insurance companies?
- What is the impact of automation on road construction and maintenance?

2.2.7 Infrastructure Implications of Automation and Connectivity (T3)

The breakout on infrastructure implications of automation and connectivity called for a new form of agility in research so that the public sector can keep up with the private sector. This should be "fast-succeed/fast-fail", quick-pivot type of research that is also low-risk, low-cost and easy to engage. Research issues raised include:

- Support for changes in the Manual on Uniform Traffic Control Devices (MUTCD) and operational guidance;
- What information do consumers want from vehicle-to-infrastructure (V2I) systems?

- Establishing a framework where data from connected vehicle (CV) pilots and Smart Cities and Communities initiatives can be aggregated to provide guidance on policy;
- Policy primer for state and local decision makers; and
- Focus on all infrastructure needs, including multimodal transportation and utilities distribution, within a Smart Cities and Communities context.

2.2.8 Big Data and Networks (T4)

Big data and networks raise the need for transportation data science development in tandem with "living laboratories". This requires federated data management and fusion, data science best practices for transportation, standardized datasets and a "data analytics pipeline". Private-public-university data sharing is necessary, including collaboration at the design stage. Cybersecurity challenges need to be addressed: transportation systems should not be treated in isolation and should use diversity as a guard against security breaches. Research issues raised include:

- Can cities build-in additional incentives for private data sharing?
- Why is there resistance to use of the cloud?
- Should security be designed top-down or bottom-up?
- Is redundancy a better way to ensure resilience and strength?
- What is the best way to develop security best practices and communicate to agencies and stakeholders?

2.2.9 Alternative Fuel Vehicles (T5)

The breakout on alternative fuel vehicles noted that all "alt-fuel" vehicles are under consideration, including electric, hybrid, hydrogen, bio-fuels, E85 and CNG/LNG. The market will see an influx of new alt-fuel vehicles and households will entertain the duality of one fossil fuel vehicle and one electric vehicle (EV). EV's have the advantage of regulated pricing of electricity. Federally-funded alt-fuel corridors will be developed. Research questions raised include:

- Should we create a synthesis report on the state of the art?
- Can we develop case studies or scenarios where alternative fuel development paths can be analyzed?
- What are the benefits to cities and communities of alt-fuel vehicles?
- What are the impacts on supply chains and freight movement?
- How can public-private partnerships impact the development of alt-fuel infrastructure?

3 PRINCIPLES FOR ACCELERATED RESEARCH AND COLLABORATION

While each breakout session created its own research ideas (as summarized in Section 2), certain general principles for accelerated research and collaboration emerged across the breakout sessions, as follows.

3.1 New Research Roles and Responsibilities

- TRB implementing a process for accelerated research: researchers need to be more responsive to policy needs; projects need rapid-response review and the ability to change direction and discontinue unproductive avenues.
- High-trust data curation and analytics: TRB can play a specific role in "leveling the playing field" for the disclosure of privately-held data and ensuring that research projects informing policy avoid structural biases.
- Helping agencies keep pace with technology: researchers can help more specifically with the development of best practices, planning tools, scenario development and broader consideration of the ramifications of technologies (eg. the labor impacts of automation and 3D printing).

3.2 Emerging Research Fields Requiring New Methodologies

- Gaining a structured, quantitative understanding of shared mobility as a transportation pathway: it is challenging to quantify the societal and economic impacts of shared mobility services and their impacts on commonly-held transportation system metrics (such as auto ownership and VMT).
- Impact analysis of technology deployments on public roads – going beyond current concepts of model deployments, field operational tests, and including scenario analysis and simulation: it is extremely challenging to initiate deployments in fresh locations, reflecting new use cases with inexperienced proponents and partners.
- Defining the role of data science in transportation: "living labs" provide big data opportunities; how does transportation fit into a larger definition of "urban science" and data analytics that would include the topic of energy? could a USDOT data commons be established?

3.3 National Research Plan for AV's

- The symposium identified numerous questions surrounding HAV's; while NHTSA has made a good start on HAV policy guidance, that policy is focused on vehicle safety; TRB would be an appropriate body to develop and maintain a national CAV research plan that encompasses all societal impacts, modes, paths to deployment, and key adjacencies such as shared mobility, data science, Smart Cities and Communities and alternative energy.

3.4 Public Sector Investment in Freight Mobility

- The supply chain is a key plank of national competitiveness; there is a need for a multimodal decision support system for public sector investment in freight connectivity,

with a focus on freight corridors and bottlenecks and protocols for data sharing and management.

3.5 Challenges and Opportunities with Smart Cities

- Creation of incentives for sharing of private data: can Smart Cities and Communities create incentives for data sharing? Best practices are needed for federated data management and fusion.
- What is the impact of ridesourcing/TNC's on cities and communities? Ridesourcing and ridesplitting represents an important deployment path for technologies, but the impact of these services on the economic and social wellbeing of cities and communities has not been systematized, nor quantified.
- Changes in parking and land use: the combined impact of HAV's and ridesourcing is potentially "game-changing"; scenario analysis is needed to understand the impact of these technologies on revenue generation and the economics of a city.

3.6 Convening of Partnerships

- What is the appropriate model for a project involving industry, government and academia? What role can TRB play to equalize the playing field and act as an intermediary for pooling resources and solving gaps and misunderstandings?
- Collaborative data analysis: use of data from data-intensive vehicles including HAV's; shared use of data sets between key universities and approved parties.
- Role and value of TRB roundtables: model deployments are an important catalyst for roundtable activity; how to conduct collaborative research is an important part of a roundtable; model deployments will create research topics that support consensus. ***See Appendix B for a description of TRB Roundtables.***

4 RESEARCH PRIORITIES AND NEXT STEPS

4.1 Closing the Technology-Policy Gap

The symposium was notable for bringing to light a vast array of questions, covering scenarios, consumer acceptance, technology, infrastructure, investment, standards, institutional relationships and the role of research. The provision of answers to these questions is the biggest barrier to accelerated, socially-beneficial deployment of technology in transportation. Policy makers will not be able to move forward without greater clarity, and the private sector needs more certainty in making the necessary investments. And, the very public-private dialog needed to accelerate progress is impeded by pervasive uncertainty.

A clear model for closing the technology-policy gap emerged at the symposium, involving the following steps:

- Formulation of **questions** of public-private significance to be addressed;
- Planning and conduct of commonly-held **research** to address these questions in the most timely manner; and
- Provision of **answers** in the form of policy advice and dynamic policy roadmaps.

4.1.1 Questions of Public-Private Significance

The questions raised at the symposium may not represent a complete list, but the breakouts were sufficiently intensive to identify several classes of issues of critical importance. There was a strong desire to discuss questions and perceived barriers that government and industry representatives could come together on. The examples given are drawn from questions raised in sessions and breakouts.

- **Questions that need to be answered to create and mobilize the needed public-private partnerships**; examples include:
    - What are the best near-term scenarios?
    - How reliable and robust are AV's?
    - How socially acceptable are AV's?
    - What are the social and economic implications of ridesourcing/TNC's?
    - What incentives may be created for sharing of private data?
- **Questions that speak to a dynamic 10-year shared vision of mobility transformation**; examples include:
    - What are the real, or ultimate, needs of users?
    - What is the ideal scenario(s) with fully-evolved deployment of technology?
    - Is there a path to Level 4 automation for large freight vehicles?
    - What is the future of public transit?
    - Are CAV's and ridesourcing/TNC's better or worse for energy and GHG under various deployment scenarios?
- **Questions pertaining to several deployment paths (eg light vehicle, heavy vehicle, public transit) carried out in stages**; examples include:
    - What is efficient industry investment?
    - How can time to market be accelerated?

- What are the business models?
- How will data be curated and shared?
- What are the best models for public-private partnerships?
- What is the national roadmap for CAV research?

4.1.2 Planning and Conduct of Commonly-Held Research

The symposium discussion often touched on circumstances creating the need for a new approach to research that would involve:

- Much faster results, presented in simpler formats (as compared to the traditional research review and publication process);
- Continuous review and the ability to "pivot" - redirect or discontinue; and
- Translation of results into policy roadmaps and policy advice tailored to relevant levels of government;

In addition to researchers, TRB can play an active role in leveling the public-private arena, avoiding structural bias, dealing with misunderstandings, ensuring fair treatment of assets such as data (including protection of proprietary data), using public infrastructure for research, and packaging results as policy advice.

Three distinct types of research were frequently discussed at the symposium:

- Pilots and deployments that collect data from real users and public infrastructure, representing scenarios of commercial and societal interest ("model deployments", or "living laboratories");
- Investigations aimed at increasing the understanding among public, private and academic partners, or facilitating real-world deployments reflecting a range of use cases ("research investigations"); and
- Studies aimed at extracting more powerful and reliable information from existing and prospective data sources, increasing the effectiveness of "living labs", and helping build norms of urban transportation data science ("scientific studies").

Many participants viewed *deployments* as the core of the needed research program, and the main catalysts for TRB's expanded role with transformational technology. The *research investigations* and *scientific studies* would help ensure that maximum value is obtained from deployments.

4.1.3 Public Policy Roadmaps and Advice

Researchers need to be involved in translating research findings into practical policy guidance. Data from deployments and Smart Cities and Communities initiatives needs to be aggregated to develop policy advice.

4.2 Formulation of Roundtables

TRB roundtables – operated under the auspices of the National Academies of Sciences, Engineering, and Medicine - have the potential to plan and activate solutions to many of the issues raised at the symposium. The "strawman" roundtables proposed here reflect the biggest issues raised by participants and will provide TRB with the necessary focus and leadership in

transformational technology research. In addition to its individual focus, each of three primary roundtables is described briefly in terms of potential activities, research programs and membership. Potential topics for additional roundtables are also included.

4.2.1 Roundtable I: Cooperative National Research Planning in Transformational Technologies

Focus: A curated collaboration of national stakeholders, industry, government and academia to discuss a national plan for shared, connected, and automated vehicle research and deployment; the plan should encompass all societal impacts, modes, paths to deployment, and key adjacencies such as shared mobility, data science, Smart Cities and Communities and alternative energy; it should be updated in a nimble manner. The scope of this roundtable would also include research: to advance, accelerate and update the plan; to increase mutual understanding of automated mobility by private and public entities; and to support education and outreach.

Discussions to include:

- Formulation and systematization of a comprehensive list of research questions, including input from all major national stakeholders;
- Tailored convening and collaboration process appropriate for a national plan;
- Inclusion of cybersecurity, privacy, workforce, access and equity, land use and the issues of energy and environment;
- Consideration of consumer acceptance of the key technologies;
- Development of a dynamic 10-year vision of mobility changes;
- Identification of steps to deployment of this vision; and
- Development of scenario analyses and case studies that support the vision and deployment.

Research projects to include:

- Compilation of research methods and results;
- Identification of needs for fundamental scientific research advances to provide enabling technologies for higher levels of automation;
- Forecasting, simulation modeling, before-and-after analysis, focus groups, cost-benefit analysis and interviews as required;
- Research design for collaborative projects involving industry, government and academia;
- Development of scenarios (or use cases) for deployment of connected, automated, shared and electric vehicles; and
- Liaison with other roundtables.

Membership to include:

- Universities;
- Industry associations and their professional constituencies;
- Government agencies (federal, state and local levels);
- Private companies (including traditional and non-traditional players);
- Relevant TRB committees;

- Standards organizations; and
- Consumer organizations.

4.2.2 Roundtable II: Precursory Policy Analysis in Transformational Technologies

Focus: A forum for direct engagement of researchers with policy makers and industry for the purpose of early development of policy responses to likely technology scenarios; this process will be informed by early access to research results, impact analysis and economic analysis.

Discussions to include:

- Consideration of likely and alternative technology scenarios for all modes;
- Analysis of a wide range of impacts, including personal mobility, equity, safety, supply chain, environment, energy, workforce, financial and economic;
- Specific policy circles for federal, state, regional, and local agencies;
- Formation of academic panels to assist policy makers and develop policy guidance and decision tools; and
- Development of a dynamic policy roadmap based on longer-term technology scenarios.

Research projects to include:

- Interpretation of research findings;
- Metrics, tools and related data management;
- Best practices and scenario planning;
- Cost effectiveness analysis; and
- Impact analysis, including economic, GDP and labor indicators, as well as impacts on public transportation.

Membership to include:

- Universities;
- Government agencies (federal, state, regional and city/local levels);
- Industry associations and their professional constituencies;
- Private companies (including traditional and non-traditional players);
- Policy advisory bodies and companies; and
- TRB committees.

4.2.3 Roundtable III: Living Laboratories Network and Data Pipeline

Focus: A working discussion among universities, companies and government agencies to assist the formation of mission-critical pilots and deployments, including joint analysis of aggregated data.

Discussions to include:

- Definition of the public-private playing field for data sharing and collaborative research;
- Development of trust mechanisms and common understandings, including protection of privacy, proprietary data, and intellectual property;

- Ensuring unbiased research designs and data analyses;
- Process for peer review of living laboratories;
- Consideration of a transportation data commons;
- Joint access to existing databases and proposed databases;
- Joint access to data flowing from highly-automated vehicles (HAV's); and
- Scientific contributions to smart cities data integration and urban science.

Research projects to include:

- Metrics, tools and data management, including standardization of data;
- Best practices for field operational tests (FOT's), pilots and model deployments;
- Guidelines for early deployments on public roads;
- Standardization of data sets;
- Data mining, data fusion, predictive models, prescriptive models, interventions and simulations;
- Testing of prototypes and pre-production systems;
- User acceptance and behavior;
- Robustness and reliability of highly-automated technologies;
- Cybersecurity and privacy of automated and connected technologies;
- The path to Level 4 automation for large and heavy freight vehicles;
- Crash investigation, incident analysis and safety performance for automated vehicles; and
- Interaction of automated vehicles with other vehicles and road users.

Membership to include:

- Universities;
- Government agencies (federal, state, regional and city levels);
- Industry associations and their professional constituencies;
- Private companies (including traditional and non-traditional players);
- Companies throughout the broader CAV ecosystem (including ridesourcing/TNC's, tech, traffic control, ITS, IT, and insurance);
- Standards organizations; and
- TRB committees.

4.2.4 Potential Topics for Additional Roundtables

Based on the contributions of symposium participants, the following topics should also be considered for roundtable development:

- User acceptance and deployment of CAV technologies, including V2I;
- Risk management during the transitional period of increasing automation (including the human interactions with automation);
- Resilience and cybersecurity of connected and automated systems;
- The role of ridesourcing/TNC's), as well as other shared mobility modes such as carsharing, bikesharing and microtransit;

- Combined impacts of highly-automated vehicles (HAV's), shared mobility and electrification on parking and land use in cities;
- Research protocols and methods for studying shared mobility (SM);
- Public sector investment in the supply chain;
- Economic impacts of transformational technologies;
- Environmental impacts of transformational technologies; and
- Corridors for alternative-fuel vehicles.

4.3 Recommended Approach to Collaborative Accelerated Research

The symposium revealed that TRB can play an important role in closing the gap between technology and policy development, in the field of transformational technology deployment. Three key elements need to be considered:

- Unanswered questions that are impeding policy development and investment in technology;
- A collaborative, accelerated and dynamic research program addressing these questions; and
- Timely translation of research into policy advice.

What is the status of these elements post-symposium?

The large number and wide range of questions raised in a structured manner suggests that we have a reasonably complete list, and a representative list. The questions clearly show three underlying desires on the part of participants:

- To clear the way for more productive public-private partnerships;
- To share perspectives on the "fully-deployed" future and, insofar as practical, create a shared vision of that future; and
- To facilitate manageable steps toward that vision to be taken in an open and collaborative manner.

Going forward, these desires should guide the formulation of research needs and questions to be addressed.

With regard to the research program, participants were of the strong opinion that traditional research methods and outputs are not adequate in this rapidly-moving field. An accelerated program should be developed using three types of research described in 4.1.2, and termed *model deployments, research investigations and scientific studies*. Part of the needed acceleration derives from the collaborative environment in which research is conducted, as well as planning and interventions on the front end, and research review and translation of results to policy.

4.3.1 TRB Roundtables

Roundtables are recommended as the primary means for identifying and prioritizing the necessary research and considering policy responses and initiatives. The three "strawman"

roundtables described in 4.2 constitute a vital role for TRB, and all emerged as among the most prominent issues at the symposium. They are:

Roundtable I: Cooperative National Research Planning in Transformational Technologies

Roundtable II: Precursory Policy Analysis in Transformational Technologies

Roundtable III: Living Laboratories Network and Data Pipeline.

The launch of these roundtables should be planned as a group, although Roundtable I may receive priority. While entities may wish to join a specific roundtable, major sponsors may be interested in supporting all three as they represent a very large collective step forward, with no other known avenue for such a strongly-supported initiative. Opportunities for members need to be carefully structured because additional sponsors will be needed for specific research projects within roundtables. Entities should also be given the opportunity to support other potential roundtables listed in 4.2.

4.3.2 Priority Research Projects

Symposium participants were asked to nominate critical research needs for positive policy outcomes, especially those suitable for industry-government-academic collaboration. The following topics are considered to be the most immediately relevant and able to support the launch of the roundtables.

4.3.2.1 Development of Scenarios for Deployment of Connected, Automated and Shared Vehicles

What are the forces driving the convergence of connectivity, automation and the sharing economy? What is the range of use cases that will benefit from such convergence? What are the barriers and impacts of such a convergence and use cases? Who are the main drivers of such deployment, and what are the needs of each in terms of accelerating progress?

Comment: This research investigation is entry-level in terms of better understanding the building blocks of automation for personal mobility (and goods movement), establishing collaborative relationships, and contributing to the national CAV research roadmap. Early relevance as an enabler of Roundtable I.

4.3.2.2 Public Sector Support for the Supply Chain

How can technology contribute to connectivity in the supply chain? How can we best describe a multimodal decision support system for infrastructure investment and operational decisions, with a focus on freight corridors and bottlenecks, and protocols for data sharing and management?

Comment: This research investigation represents entry-level understanding of the potential contribution of CAV to the optimization of the supply chain. Early relevance as an enabler of Roundtables I & III.

4.3.2.3 Impact of MOD on the Transportation System

How will MOD in all of its ramifications affect the transportation system? How adequate are current transportation metrics and descriptors to describe this transition? Research to include: vehicles mile traveled and induced demand & public transit, GHG, auto-ownership, occupancy, temporal and spatial scale, built environment, and examination of the impact on land use and parking.

Comment: This research investigation is entry-level in terms of establishing collaborative relationships, solid foundations for other research efforts and creating early policy impact. Early relevance as an enabler of Roundtable II.

4.3.2.4 Impact of Transformational Technologies on Land Uses

Emerging technologies have already transformed the last mile of retail and altered the demand for and characteristics of "brick and mortar" stores and distribution center buildings. The proposed research would focus on three-to-five technologies, such as highly automated vehicles, MOD and 3D printing (3DP) and identify the range of potential impacts on land uses. Potential changes in site selection and demand for retail, office, distribution, housing, parking and production would also be identified, along with considerations for communities. The research will consider a range of settings, including urban, suburban and rural.

Comment: This research investigation represents entry-level impact analysis and translation of findings to policy guidance. Early relevance as an enabler of Roundtable II.

4.3.2.5 Framework for CV Pilot and Smart Cities and Communities Data Analytics for Policy Guidance

Establishing a framework where data from CV pilots and smart cities/communities initiatives can be aggregated to provide guidance on policy. What lessons have been learned from the curation of model deployment and FOT data? How may such data be used to support changes to operational guidance (e.g., the MUTCD)? What does the data tell us about what users expect from CV and V2I? How could such data support a policy primer for state and local decision makers? What additional data should be collected in deployments?

Comment: This research investigation represents entry-level collaborative data analysis and translation of findings to policy guidance. Early relevance as an enabler of Roundtable III.

4.3.2.6 Framework for Data Curation and Standardized Data Sets

Establishing a framework for data streams emanating from highly-automated vehicles and living labs in CAV and smart cities/communities. How can such data be combined

with static and dynamic data sources used in transportation? How can the diverse data sets of industry and government at the municipal, state and federal levels be combined? How can proprietary data be protected?

Comment: This scientific study supports entry-level collaborative database development. Early relevance as an enabler of Roundtable III.

5 GLOSSARY

3DP	3D printing
ADA	Americans With Disabilities Act
AV	automated vehicle
CAV	connected and automated vehicles
CNG	compressed natural gas
CV	connected vehicle
E85	85 % ethanol
EV	electric vehicle
FOT	field operational test
GDP	gross domestic product
GHG	greenhouse gas
HAV	highly-automated vehicle
IoT	Internet-of-Things
IT	information technology
ITS	Intelligent Transportation Systems
LNG	liquefied natural gas
MDOT	Michigan Department of Transportation
MOD	mobility on demand
MUTCD	Manual on Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
SAV	shared automated vehicle
SM	shared mobility
TNC	transportation network company
TRB	Transportation Research Board (of the National Academies of Science, Engineering and Medicine)
UAS	unmanned aerial systems
USDOT	U.S. Department of Transportation
V2I	vehicle-to-infrastructure
VMT	vehicle miles of travel

Appendix A: PARTNERS IN RESEARCH SYMPOSIUM PROGRAM

Monday, October 31, 2016

Jane Lappin, Master of Ceremonies: Director of Public Policy and Government Affairs, Toyota Research Institute

8:30– 8:50 a.m. **Welcome and Symposium Objectives**

- **Neil Pedersen**: Executive Director, Transportation Research Board of the National Academies of Sciences, Engineering and Medicine (TRB)
- **Kirk Steudle**: Director, Michigan Department of Transportation (MDOT), and Member and Past Chair of TRB Executive Committee

8:50 – 10:00 a.m. **Keynote Addresses: Transformational Technologies: Speed and Grace**

Kirk Steudle, Moderator: Executive Director, MDOT

- **Emily Castor**: Director of Transportation Policy, Lyft
- **Geoffrey Kasselman**: Executive Managing Director, National Industrial Practice, Newmark Grubb Knight Frank
- **Ken Leonard**: Director, ITS Joint Program Office, USDOT
- **Chan Lieu**: Senior Legislative Advisor, Venable LLC
- **Dean Wise**: Vice President, Network Strategy, Burlington Northern Santa Fe Railway

10:00 – 10:30 a.m. **Coffee break**

10:30 – 11:45 a.m. **Panel: Technology and Policy Driving Mobility**

Susan Shaheen, Moderator: Co-Director, Transportation & Sustainability Research Center, University of California, Berkeley

- **Pascal Van Hentenryck**: Seth Bonder Collegiate Professor, University of Michigan
- **Jane Lappin**: Toyota Research Institute
- **King Gee**: Director of Engineering and Technical Services, American Association of State Highway Transportation Officials
- **Abbas Mohaddes and Peter Sweatman**: Principals, CAVita

11:45 a.m. – 12:30 p.m. **Panel: The Art of the Possible in Public-Private Collaboration**

Jane Lappin, Moderator: Toyota Research Institute

- **Justin Holmes**: Director of Corporate Communications and Public Policy, Zipcar
- **Eric Johnson**: Lockheed Martin Associate Professor of Avionics Integration, Georgia Institute of Technology
- **Trish Plonski**: Senior Vice President Business Development, Strategy and M&A, Xerox Services

12:30 – 1:45 p.m. **Lunch**

- **Reuben Sarkar**: Deputy Assistant Secretary for Transportation, U.S. Department of Energy

1:45 – 4:15 p.m. **POLICY BREAKOUT SESSIONS**

Personal and Shared Mobility (Breakout P1)

Moderators
- **Susan Shaheen**: Co-Director, Transportation & Sustainability Research Center, University of California, Berkeley
- **Larry Yermack**: Strategic Advisor, Cubic

Commentators
- **Art Guzzetti**: Vice President of Policy, American Public Transportation Association
- **Paige Tsai**: Policy and Insights, Uber
- **Richard Wallace**: Director of Transportation Systems Analysis, Center for Automotive Research

Freight Mobility and Evolving Supply Chains (Breakout P2)

Moderator
- **Anne Strauss-Wieder**: Director, Freight Planning, North Jersey Transportation Planning Authority (NJTPA)

Commentator
- **Dean Wise**: Vice President of Network Strategy, BNSF Railway

Smart Cities I: Mobility & Access (Breakout P3)

Moderator
- **Joanna Pinkerton**: Co-Director, Honda/OSU Partnership, Ohio State University

Commentator
- **Rob Bertini**: Director, Center for Urban Transportation Research, USF

Smart Cities II: Entrepreneurship & Economic Development (Breakout P4)

Moderators
- **Regina Hopper**: President & CEO, Intelligent Transportation Society of America
- **Wes Guckert**: National Product Council, Urban Land Institute

Air and Space Innovation (Breakout P5)

Moderator
- **Yu Zhang**: Associate Professor, Department of Civil and Environmental Engineering, University of South Florida

Commentators
- **Chris Brinton**: President, Mosaic ATM
- **Eric Johnson**: Professor, Georgia Tech
- **Parimal Kopardekar**: Principal Investigator NASA NextGen
- **Joseph Post**: Deputy Director, NAS Systems Engineering and Integration, FAA

4:15 – 4:45 p.m. **Break**

4:45 – 5:45 p.m. **Plenary reporting by moderators**

5:45 – 7:15 p.m. **Reception**

Tuesday, November 1, 2016

Jeffrey Paniati, Master of Ceremonies: Executive Director, Institute of Transportation Engineers

8:00 – 8:30 a.m. **Rapporteurs - The Story So Far**

- **Chris Hendrickson**: Hamerschlag University Professor of Engineering Emeritus, Carnegie Mellon University
- **Shelley Row**: President and CEO, Shelley Row Associates

8:30 – 11:00 a.m. **TECHNOLOGY BREAKOUT SESSIONS**

Automation & Connectivity I: Light Duty Vehicles (Breakout T1)

Moderator	**Frank Sgambati**: Director of Marketing & Product Innovation, Robert Bosch LLC
Commentators	**Emily Frascaroli**: Ford Motor Company
	Timothy Johnson: National Highway Traffic Safety Administration

Automation & Connectivity II: Heavy Duty Vehicles (Freight & Transit) (Breakout T2)

Moderator	**Steve Shladover**: Program Manager, Mobility, California Partners for Advanced Transportation Technology
Commentators	**Anne Strauss-Wieder**: NJTPA
	Sabrina Sussman: Senior Policy Advisor, Federal Affairs Office, Bill de Blasio, New York Mayor
	Allan Rutter: Division Head, Freight Mobility Division, Texas A&M Transportation Institute

Automation & Connectivity III: Infrastructure (Breakout T3)

Moderators	**Ananth Prasad**: Vice President, HNTB
	Katherine Turnbull: Executive Associate Director, Texas A&M Transportation Institute
Commentator	**Bob Arnold**: Acting Associate Administrator, Office of Operations, FHWA

Big Data and Networks (Breakout T4)

Moderator	**Al Hero**: R. Jamison and Betty Williams Professor of Electrical Engineering and Computer Science, University of Michigan
Commentator	**James Pol**: Technical Director, Safety Research and Development, FHWA
	Doug Couto: Senior Fellow, Center for Digital Government
	Carol Flannagan: Research Associate Professor, University of Michigan
	Pascal Van Hentenryck: University of Michigan

Alternative Fuel Vehicles and Infrastructure (Breakout T5)

Moderator	**Scott Belcher**: CEO, Telecommunications Industry Association
Commentator	**Reuben Sarkar**: U.S. Department of Energy

11:30 a.m. – 12:15 p.m. **Plenary reporting by moderators**

12:15 – 12:30 p.m. **What's Next?**

- **Kirk Steudle**: Executive Director, MDOT
- **Mark Norman**: Director of Program Development & Strategic Initiatives, TRB

12:30 p.m. Adjourn

Appendix B: TRB ROUNDTABLES

Conducted under the auspices of the National Academies of Sciences, Engineering, and Medicine; TRB Roundtables are designed to bring together leaders in government and industry, scientists and other experts from academia, practitioners, representatives of public interest groups, and consumers.

Each TRB Roundtable will offer an independent venue, in which individuals of goodwill from diverse perspectives can gain shared understanding and fresh insights during open dialogue on important, complex, and diverse policy. Roundtables will illuminate issues that need to be resolved, and opportunities for further work can be expected to develop from their meetings and publications.

A typical TRB Roundtable will:

- Include an average of 35 individuals, including a representative from each Roundtable sponsoring organization from the public or private sector, non-profits, and academia; supplemented by other experts in the field;
- Be organized around one or more issues from which the participating parties will benefit from an ongoing dialogue;
- Determine its own agendas;
- Often use authored papers to inform its discussions;
- Partner with TRB standing committees to foster workshops or conferences;
- Be offered opportunities to raise issues to be addressed as part of consensus policy studies program conducted by the National Academies and TRB; and
- May foster "innovation collaboratives" to engage participants with similar interests and responsibilities in cooperative activities to further advance aspects of each roundtable or forum's statement of task.

The power of TRB Roundtables at the National Academies stems from the ability of the Roundtable members to choose topics of common interest and then facilitate discussions of these issues among members and experts in a neutral setting that builds trust and promotes problem-solving.

TRB expects to create Roundtables to address some of the most critical transportation issues, including those associated with transformational technologies, resilience, and transportation and public health.

Organizations from the public and private sector, non-profits, and academia may propose the creation of new TRB Roundtables, contribute as TRB Roundtable sponsors, and participate in Roundtable activities. Funding levels for each category may vary, and can depend on an organization's ability to pay, existing contributions to TRB, the degree of alignment between a sponsor's mission and the mission of the roundtable, and/or the size and level of activity of the Roundtable. All sponsors, regardless of the amount of funding they contribute, as well as invited non-sponsors, will be considered equal contributors to the discussions and the work of the Roundtable.

Those interested in sponsoring and participating in TRB Roundtables, and/or in proposing issues for new TRB Roundtables, should contact Mark Norman; Director, TRB Program Development & Strategic Initiatives; email: mnorman@nas.edu.