Connected and Autonomous Vehicles in Society: An Agenda for Social and Policy Research

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Executive Summary

On May 18-19, 2018, a workshop was held at Michigan State University: "Autonomous Vehicles in Society: Building a Research Agenda." The workshop produced an agenda for social, economic, and policy research on connected and autonomous vehicles and infrastructure to support that research.

Connected and autonomous vehicles (CAVs) vary widely in their levels of connectivity and autonomy, and they are always part of a larger transportation system which is in turn embedded within broader social, political, and economic contexts. Each CAV system will be deployed in a particular local/regional context. A deployment can range from pilot tests to fully operational transportation systems. We can think of these deployments as a stream of sociotechnical experiments, each in a unique context constituted by different objectives, technology, geography, economics, ownership, legal institutions, etc. **How can we learn and generalize from these CAV deployments?**

IMPLICATIONS FOR SOCIAL SCIENCE AND POLICY RESEARCH

- **Start now.** CAVs are on the roads. Industry and society need relevant, expedient research.
- **Need for speed.** Rapidly changing technology affects research design, execution, and reporting. Research on CAV deployments must be conducted and disseminated quickly, ahead of mass deployments.
- **Data access.** There is a strong argument for requiring data access and reporting as a condition of licensure for CAVs to improve public learning and competent policy formation.
- **Comparing and generalizing from cases.** Each CAV deployment should be treated as a case to be studied. Researchers should do comparative analyses between cases and generalize across cases where possible.
- **Convergence.** The need for convergent research teams is clear, because research on CAV deployments cuts across traditional disciplinary boundaries. For the reasons we outline here, social scientists should be engaged at all stages of CAV deployment -- design, implementation, monitoring, and analysis.

RESEARCH INFRASTRUCTURE INVESTMENTS ARE NEEDED TO SUPPORT:

- Platform model for convergence and collaboration.
- Data availability and standardization.
- Rapid dissemination of results.
- Research coordination between industry, government and academia.

Introduction

Connected and autonomous vehicles (CAVs) are starting to be deployed on public roads. CAV technology is an example of a broader phenomenon: "Intelligent, interactive, and highly networked machines--with which people increasingly share their autonomy and agency--are a growing part of the landscape, particularly in regards to work" (NSF, DCL 17-065). It remains to be seen how quickly CAVs will be deployed (when, where, in what form), but now is the time to begin studying them.

History shows that revolutionary changes in transportation systems can have far reaching social, economic, legal, and ethical implications. CAVs are intended to address the social need of *mobility*, with intersecting problems such as congestion, safety, air quality, land use, and energy use. The potential for social upheaval is substantial. This white paper suggests a CAV research agenda that considers potential social developments in conjunction with potential technological developments.

Background

The meeting at MSU was the first in a series of workshops sponsored by the NSF Research Coordination Network on *Work in the Age of Intelligent Machines* (NSF IIS-1745463). It was co-sponsored by the MSU Center for Business and Social Analytics, in cooperation with the Institute for Public Policy and Social Research and the School of Planning, Design and Construction. We brought together participants from diverse perspectives to identify research themes of mutual interest to industry, government and academia.

Convergence in CAV/mobility research

Mobility is a societal need that exemplifies the need for *convergence* research. The National Science Foundation identifies the following two primary characteristics of convergence research:[i]

- ***Research driven by a specific and compelling problem.*** Convergence Research is generally inspired by the need to address a specific challenge or opportunity, whether it arises from deep scientific questions or pressing societal needs.
- ***Deep integration across disciplines.*** As experts from different disciplines pursue common research challenges, their knowledge, theories, methods, data, research communities, and languages become increasingly intermingled or integrated. New frameworks, paradigms, or even disciplines can form sustained interactions across multiple communities.

The convergence paradigm "brings together intellectually-diverse researchers to d*evelop effective ways of communicating across disciplines by adopting common frameworks and a new scientific language*, which may, in turn, afford solving the problem that engendered the collaboration, developing novel ways of framing research questions, and opening new research vistas." (Ibid.)

The MSU workshop included participants from diverse backgrounds and interests, including industry, law, geography, sociology, engineering, urban design, business, computer science, anthropology, and science and technology studies. Whenever possible, research on CAV/mobility should include similarly diverse teams.

Terms used in this white paper

- *Connected and autonomous vehicle (CAV)*. An individual vehicle with at least some capability for communication and autonomous action.
- *CAV system.* The set of technology deployed by a manufacturer so that a specific CAV can operate. This set might include, for example, other CAVs or proprietary infrastructure.
- *CAV deployment.* The whole picture of a site-specific implementation of CAVs. These could be quite small and controlled (e.g., an airport tram system) or large and complex (e.g., mobility-as-a-service for the city of Chicago). CAV deployments include an operating design domain (ODD), and may also require infrastructure investments and rule-setting from both public and private sources.
- *Trips and mobility.* Social research on CAVs requires moving away from familiar categories like "cars and trucks" and thinking in terms of *trips* and *mobility*. *Trips* are the basic unit of demand for *mobility*. People make trips to work, trips to school, trips to the doctor, etc. Different kinds of trips and different kinds of passengers (e.g., youth, elderly, disabled) require different kinds of vehicles. Differing mobility service designs will set limits on what kinds of passengers and trips can be accommodated. When we focus on *mobility*, rather than vehicles, it directs our attention to the social, geographic, and economic aspects of transportation: Who or what needs to move? From where to where? At what cost?

Applications of CAVs

"Connected and autonomous vehicles" refers to a large and expanding set of possible transportation systems. Each CAV operates in an ecosystem that includes other vehicles, social norms, navigational infrastructure (e.g., GPS), traffic signs and signals, and charging and maintenance stations, as well as a web of economic and legal relationships concerning ownership, licensure, liability, and insurance.

Systems in context. Each CAV deployment will occur in a unique combination of local geographic, economic, social, cultural, legal, and technical factors. The metaphorical *island* in the title of the recent KPMG report, *Islands of Autonomy*[ii], is particularly apt. Further, each deployment will take place at a moment in time before and after other deployments that may influence design choices and public perceptions about the current deployment.

It is helpful to identify dimensions that characterize the variety of CAV deployments and applications.

- **Levels of autonomy.** The degree of vehicle "autonomy" can be conceptualized on a spectrum from fully human control to fully machine control[iii] . This report focuses on vehicles at the high end of the spectrum that would operate with little or no human intervention.
- **Levels of connectivity.** Different methods for mapping and navigation involve different levels of connectivity (a) between vehicles and (b) between vehicles and infrastructure such as traffic signals. Connectivity can allow vehicles to share information about congestion and traffic obstructions, report their anticipated time to arrival, etc.
- **Specialized infrastructure.** Different vehicle designs will require specific kinds of infrastructure to enable a functional CAV deployment[iv] . In addition to physical roads, CAVs might require specialized fuel stations, maintenance, and vehicle storage facilities. Depending on how they are designed, CAVs are likely to require digital infrastructure, such as GPS, up-to-date mapping (to navigate and avoid congestion), traffic signals, road markers, and more.

- **Land, Sea, Air.** Land-based CAV systems involving passenger vehicles and trucks are getting a lot of attention, but autonomous navigation (autopilot) has been used in sea and air applications for decades, as well as specialized ground vehicles for such environments as mining and docks. *We focus here on land-based passenger systems*, but the space of possibilities is much larger.
- **Applications.** Passenger mobility in urban areas is only one of several major applications (operating design domains) for CAVs. Long distance trucking and freight transport is another application that is expected to be viable soon.[v] Materials handling and logistics within warehouse and production facilities are viable now.[vi] More specialized application niches are being investigated, from grocery delivery[vii] to logging.[viii]

CAV technology is changing rapidly

Economic competition is spurring rapid advances in the technologies contributing to CAVs. These technologies include sensors, connectivity, interfaces, on-board computation, and software for mapping, scene interpretation, decision making, planning, data management, and more. These advances have been driven by intense competition between industry vendors, suppliers, universities, OEMs (original equipment manufacturers, or traditional car companies) and nation-states. Small startups are innovating across the board, and large, non-traditional competitors, such as Apple, Cisco, Google, Nvidia, and Uber, have been investing in the technology as well. There is a general assertion from CAV innovators that the public's inherent interest in increased safety and/or efficiency also drives CAV development.

Steering the future

Predictions about the impact of CAVs often imply a sense of inevitability as in: "Autonomous vehicles will transform our cities."[ix] While it seems likely that CAVs will generate significant changes, the location, time scale, and specific nature of those changes are difficult to predict. ***One important message from the MSU workshop is that public policy, law, and insurance, in conjunction with economics, industry structure, and public preferences, will shape the trajectory of CAV-based mobility systems.***

Simply put, the future is not inevitable. The specific scenarios for CAV utilization that unfold in specific locations will be strongly influenced by legal and policy choices, which should be informed by the needs of local populations. For example, will autonomous vehicles blend freely with regular traffic, or will they be segregated into separate lanes? Well informed policy decisions depend on gaining knowledge and experience from the early deployments that are beginning to take place now and from the people affected by them. Towards that end, both industry and society need relevant, expedient research.

The need for research on CAVs & society

System design is social design

Currently, most research attention is focused on the technical issues required to make CAV systems feasible. These technical issues, such as navigation, sensing, and steering, present fascinating research challenges. ***However, a critical point that emerged from the MSU workshop is the extent to which technical aspects of vehicle design and system design have societal implications.***

For example, because CAVs depend on coordination with infrastructure, there may be geographic boundaries within which certain kinds of mobility services might be cheap and convenient. Outside the boundary, they might not. These service boundaries seem likely to reinforce social divisions (urban/suburban, urban/rural, poor/economically stable), especially if the relative cost of owning, operating, and insuring conventional vehicles goes up.

CAV deployments are *designed*, including the vehicles, the digital infrastructure, the physical roadways, and the applicable systems of law, ownership, liability, and insurance. Design choices inherently involve trade-offs among competing values and stakeholders. CAVs optimized for one application may be unsuitable for another. As a result, technical design choices place boundaries on the kinds of trips and kinds of users that can be served.

CAVs are social machines

While it may seem strange to say so, CAVs are being designed to engage in social behavior: to sense and respond to their surroundings, to share information (e.g., about obstructions and congestion), and to cooperate with other vehicles (e.g., speed harmonization). CAVs can interact with each other, with passengers, with infrastructure, and with pedestrians, cyclists, and other objects in their environment. These social capabilities are needed for CAVs to maintain situational awareness of contextual factors around the vehicle in order to navigate safely. ***The social norms that develop around CAVs as social actors will be a critical factor in the design of CAV technology and the success of CAV deployments.***

Public policy and social justice

Because mobility touches every aspect of social life, CAV deployments will inevitably engage issues of access (Who can ride? Where can they go?), economics (Who pays? Who benefits?), and governance (Who is in control?). While CAV advocates predict social benefits[x], there is a realistic possibility that CAV deployments will reinforce social division by creating systems of mobility that are accessible to some and not to others. ***Participants at the MSU workshop emphasized that communities of every size need to proactively address the question: What do we want our communities and our society to look like?***

We return to this theme in more detail below, but the key point is that CAVs will have social consequences. Policy makers should find out how people would like to experience their cities and neighborhoods (see also: Jane Jacobs' work on urban neighborhoods[xi]). There are questions surrounding whether Americans want CAV technology to dominate their neighborhoods and how much influence policy-makers can and should exercise.

There was consensus that vendors of CAV technology should not be allowed to shape a vision of our future and demand that the public adopt it. Proposed CAV deployments should be seen in the context of alternatives. For example, the door-to-door lifestyle potentially offered by CAV systems conflicts with more active mobility choices such as walking and cycling. Policy makers are likely to feel caught in a dilemma between promoting technology and innovation and promoting public welfare and transparency. Convergence research that tracks public reactions to deployment proposals, and then to actual deployments, will aid both technology development and the public welfare.

The future is here, but it is unevenly distributed

From a social science perspective, a basic problem in conducting research on CAV deployments is that they are, for the most part, still in the future. We are trying to understand phenomena that have not yet happened. Fortunately, each new deployment of a CAV system provides an opportunity for learning that can help inform the design of future deployments. Because these innovations are unevenly distributed in time and space, we can study "the future" by looking at current CAV deployments. International comparisons may be especially interesting, since different national contexts are at different stages of readiness for CAV deployments.[xii]

CAV deployments challenge researchers

There are additional factors that make CAVs a challenging subject, particularly for social science research:

Continuous change. Because the technology is changing rapidly, rigorous comparisons over time will be difficult at best. This difficulty is compounded by the fact that CAV deployments are dynamic systems, with feedback between social, economic, and technical factors. Plus, like any transportation system, they are subject to daily, weekly, and seasonal variations.

Variety of cases. Each CAV deployment presents researchers with a unique case.[xiii] There is tremendous variety in these cases (passenger/freight, land/sea/air, different nations -- plus a host of technical and contextual factors). The number of cases is small compared the number of variables, so conventional statistical inference is likely to be difficult. Configurational methods like Qualitative Comparative Analysis (QCA) may be more fruitful.

Path dependence. Like other large scale technological changes, we anticipate a path dependent trajectory of innovation. Due to the highly contextualized nature of CAV deployments, each will have its own path, with its own unique dynamics, its own tipping points (e.g., critical mass of ridership), and its own tendency to get locked in to a particular configuration. For example, car manufacturers are now making critical decisions about whether (or how) vehicles will communicate with each other. Infrastructure manufacturers have not yet created universal standards for how vehicles will communicate with their surroundings. Filtering applicable lessons from these complex unique cases will require deep cooperation between disciplines.[xiv]

Research Themes

Participants at the MSU Workshop were asked to consider several research themes and then propose research questions, including data requirements and potential users of the research. These themes and questions reflect the interests and priorities of the participants, so they should be regarded as illustrative. They demonstrate how seemingly technical issues (e.g., cyber security) interact with issues ranging from urban design to social justice -- with the day-to-day lives of everyday people.

1. PUBLIC PERCEPTIONS

Autonomous vehicles have been in use for years in theme parks and as airport trams. In these settings, the lack of a driver is taken for granted. Likewise, the widespread availability of driver-assist safety features, such as blind spot detection and adaptive cruise control, is introducing the public to benefits of advanced sensors and automation in passenger vehicles. At the same time, accidents and fatalities with CAV systems can be very salient and may negatively influence public perceptions.

Survey research to date has been severely lacking. Better methodologies are needed to control for the public's lack of knowledge and understanding of CAVs. ***High quality research is starting to appear,***[xv] ***but this area is ripe for up-to-date empirical research.***

This leads us to ask, what are the perceptions of various population groups toward autonomous vehicles? What do members of the public think CAVs are like, can be like, or should be like? How do these perceptions change over time? What are the sources of those perceptions? To what extent do people have personal experience with specific CAV systems, and to what extent are their perceptions based on other experiences? Depending on the specific CAV systems in question, different segments of the public may be relevant, including persons with disabilities, age groups (seniors, youth), occupational groups (e.g. trucking), cultural and ethnic groups, socioeconomic status groups, or geographic groups (urban, rural, suburban). These discrete groups provide a clear opportunity for rapid prototyping of research avenues, research methods, and applicability of sociological results to technological development.

In addition to perceptions, it is critical to understand how people interact with CAVs and how CAVs interact with other actors in their environment. As mentioned above, CAVs are social machines that sense and respond to their environment. ***There is a need for ethnographic data on interaction patterns involving CAVs (how they form and how they change over time).***

2. DEMAND FOR MOBILITY AND PATTERNS OF MOBILITY

While mobility services are often cited as mechanism to reduce congestion in urban areas, that outcome is by no means guaranteed. If the cost (monetary, time, risk) of mobility is reduced, economic theory suggests that demand should increase. Also, congestion is influenced by the pattern of mobility, not just the aggregate number of passenger miles travelled. In general, the effects of CAV technology are contingent on design and policy choices that will be unique to each deployment. For example:

- **First order effect: substitution.** If CAVs become sufficiently inexpensive and convenient, they will substitute for other modes of transportation. This substitution can occur at the level of single trips or at the level of vehicle ownership. Economies of scale in mobility services could produce price points where substitution is attractive, quickly tipping to the new systems. But the old systems will still be in place, with their own users, creating a transitional period where CAVs coexist with current transportation systems (see theme 6, below).
- **Second order effect: increased demand.** Rather than staying home, people may ride more often if a mobility service is sufficiently inexpensive and convenient. Increased demand is especially likely among populations whose mobility is currently limited, such as the elderly, disabled persons,

the urban poor, or youths, if they perceive the technology is safe. This induced demand can be expected to add significant congestion to already overcrowded urban transportation systems. Consider the problem of 10,000 people arriving or leaving at the same time for a sporting event or a concert. How will drop-off and pick-up be organized?

- **Third order effects: difficult to predict.** CAVs may have third-order effects that are even more difficult to predict. For example, point to point traffic could deplete some forms of commerce because people no longer walk by stores on the way to the subway or bus. By contrast, some businesses far from transportation hubs may benefit. Sprawl may proliferate because time and distance are discounted as individuals are no longer required to perform the dynamic driving task and so can perform productive work or be entertained.

In each CAV deployment, we have an opportunity to understand and hopefully anticipate first, second, and third order effects on overall demand for mobility in general and the patterns of mobility in particular. These effects will influence other short term and long term outcomes, including employment and social/economic geography.

3. CYBER SECURITY AND PRIVACY

Some of the greatest potential benefits from CAVs result from connectedness (e.g., speed harmonization, situational awareness, and the potential to learn collectively from incidents). Connected vehicles are, by definition, integrated into a web of communicative relationships. This integration raises questions about security, privacy, and information access. Who should have legitimate access to vehicles and their data? How can illegitimate access be prevented? Controlling access is complicated by the need for connectivity. Security and privacy involve a range of risk/benefit trade-offs and lead to some challenging questions.

- **How small can the radius of situational awareness be for road vehicles?** A CAV needs to have adequate situational awareness of specific contextual factors occurring within some specified area around the vehicle in order to successfully navigate. A logical goal is to minimize the size of this zone, which would maximize privacy and minimize incoming security risks. How large a zone is needed for an individual CAV to make good decisions? Zone size will likely vary depending on the situation and different geographic conditions (e.g., urban/rural). It would also vary with speed and driving conditions. For example, conditions such as road closure, construction, and special events might require a much larger radius (2-5 miles).

- **How does a vehicle establish trust in vehicle-to-vehicle communications?** How many communicating CAVs need to be in the area of communication to create information reliability? When one CAV is faulty, how many others does a visiting CAV need to "hear" to figure out what is true? How many other CAVs does a local CAV, with deep local knowledge, need? Do established local vehicles deserve more trust than others? Should government-to-vehicle communications be one way, or both ways? Under what circumstances? How should special CAVs (such as garbage trucks and buses) be treated?

- **Under what conditions should CAV data be used for surveillance?** CAVs are capable of recording a great deal of what goes on inside them and around them. Cameras and sensors on CAVs support navigation and passenger interactions. Even with current technology, the data collected is an obvious source of information for surveillance.[xvi] This capability presents challenges in terms of policy and public awareness.

Research on cyber-security and privacy would directly benefit both technology development and the development of fair and pertinent regulations, incentivizing industry/government cooperation.

4. WORK, EMPLOYMENT AND INDUSTRY STRUCTURE

Historically, changes in technology are accompanied by shifts in occupations. Employment is mediated by changes in industrial structure, as well. The innovation associated with CAV technology is likely to involve "creative destruction."[xvii] Old systems of production and employment will fail, but new ones will emerge.

The employment effects of automation continue to be a major source of concern in America. The OECD predicts that "over 2 million drivers across the US and Europe could be directly displaced by 2030" by autonomous trucking.[xviii] Even in industries like trucking, where autonomous technology directly substitutes for certain portions of a human driver's tasks, the effects on employment are likely to be variable and difficult to predict. Research at MSU predicts that AV technology will support, not replace, truck drivers.[xix]

Industries like automotive manufacturing and sales are predicted to suffer a significant decline in established categories, especially for the traditional passenger sedan: "We estimate a precipitous decline—from 5.4 million units sold in the U.S. today to just 2.1 million units by 2030, impacting the equivalent of more than 10 assembly plants and forcing many current players to exit this vehicle class."[xx] Similar impacts might be expected for automobile-related industries such as automobile maintenance and repair, auto insurance, or parking lots. ***At this point, the magnitude and timing of such impacts is speculative. Research is needed to document how specific CAV deployments actually influence shifts in employment and industry structure.***

5. SMART CITIES AND URBAN DESIGN

Participants at the MSU Workshop focused special attention on cities and urban design. Questions in this arena naturally involve policy. There are a wide range of topics in which CAV systems intersect with the traditional concerns of city planning and urban design. Across all of these topics, policy makers need research on how to design policies that improve urban living.

- **Demographics.** Demographic trends influence the social/economic geography that creates demand for mobility. Different regions will have different profiles.
- **Infrastructure.** Existing infrastructure may be adequate for some CAV systems, but not for others. As existing roads and other transportation infrastructure becomes obsolete, what new investments will be required? These public investment choices will interact with other investment priorities.
- **Priorities.** Cities need to consider obsolescence and renewal. Planners need to understand how CAV systems fit into national priorities in planning cities, such as the complete streets concept.[xxi] Where would CAVs fit into the master plan – will these vehicles make streets more or less socially connected?
- **Finance.** How can CAV deployments be financed? Governments will have to offset losses in how current roads are financed (e.g., gas tax revenues are decreasing as more electric vehicles are introduced).
- **Governance.** Governments, from towns to nations, will need data to monitor activities and make decisions. They will need to request or require information connected with the planning, design, and licensing activities of CAVs.

- **Resilience.** While a highly integrated web of CAV systems may be highly efficient in theory, what happens when it breaks down? Planners need to build resilience into transportation systems and into master plans as a whole. We need to create networks capable of self-recovery.

6. CO-EXISTENCE PERIOD

Some mix of CAVs and traditional transportation systems is likely to persist for decades to come. Systems need to be designed to accommodate this variety. ***This may be the most challenging and unpredictable aspect of this topic because the co-existence period will influence the degree to which society is willing to accept CAVs.***

One can also consider transitional periods from the point of view of individual vehicles, at very short time scales. At intermediate levels of vehicle autonomy, human drivers share control with automated systems. This is already an area of intensive research. In aviation, automated piloting and collision avoidance systems are common. Modern "driver assist" technology can apply brakes and help with steering. ***We are already living in a blended world, so there are existing opportunities to study these transitional situations.***

7. SOCIAL JUSTICE

Policy questions in urban planning are often closely connected with issues of social justice. The history of technology shows that new and disruptive technologies can be used to reshape power relations and exclude participation by some groups, most recently exemplified by access to the internet and net neutrality. Participants at the MSU workshop suggested the idea of *mobility justice* and argued for an approach that uses value sensitive design to "design in" the social values deemed important. They identified two aspects of social justice that seemed particularly salient: anticipatory justice and affirmative access.

- **Anticipatory Justice:** How will people and places be affected by CAVs? Who is likely to benefit/lose? How is equity defined in mobility? Social norms can be used as a basis for defining justice. Researchers can gain insights from public engagement, interviews, social media, and qualitative/quantitative data. This aspect of social justice connects to the research theme on public perceptions.
- **Affirmative Access:** What policies are needed to promote equitable access? What ideals drive mobility justice? Are there classes of the public that deserve affirmative access, and how should those classes be defined? CAV access policies can draw from past policies that promoted access to energy, food, health services, transportation, etc., but mobility justice might also require defining new groups who need assistance.

8. SOCIOMOBILITY

If we think of CAVs as social actors, it is natural to investigate their interaction patterns with other social actors (e.g., pedestrians, cyclists, traffic signals, and other vehicles). By *interaction pattern*, we mean a time-ordered sequence of behavior by a set of social actors in a situation. We introduce the term *sociomobility* to highlight the idea that mobility can be analyzed as patterns of interactions among social actors. *Sociomobility* is intended to evoke related terms, such as *sociotechnical* and *sociomaterial*, that emphasize the social aspect of technology. Research on interaction patterns may facilitate a number of related themes:

- **Disciplinary convergence.** Interaction patterns provide a point of contact between computer science and social science. There is a strong foundation in microsociology and social psychology upon which we can build.[xxii]
- **Sensor interpretation.** Interaction patterns provide a frame of reference for sensor interpretation and should be relevant to situational awareness and safety.
- **Comparison of CAV deployments.** Interaction patterns provide a basis for comparing CAV deployments and evaluating their change over time.

Recommendations

The research themes outlined here are suggestive of the broad range of ways that social science research can work with industry and policy makers to inform the design and deployment of CAVs. CAVs are on the roads now. ***The critical message from the MSU workshop is that we should immediately start to conduct research and invest in infrastructure to support this research. While the future is difficult to predict, we should prepare for the scenario where CAVs become a central part of our transportation systems for decades to come.***

Start now

An initial round of funding should be made available to support studies of early deployments. These studies could vary widely in size, but could include multi-disciplinary teams and labor-intensive data collection (e.g., ethnographic fieldwork), so budgets could exceed $1 million/year for large projects. Studies should emphasize convergence research and should involve industry and government collaboration. Studies should address multiple themes in a given setting and comparative studies across settings, as appropriate. The program that administers the funding should require participation in annual workshops to facilitate learning across studies. Funded projects should also support infrastructure investments, as discussed in the following sections. A reasonable budget for an initial program would be $18 million (to support 6-8 projects @ $750K - $1M/year x 3 years).

Platform model for convergence and collaboration

To maximize the cumulative value of this work, infrastructure is needed to accelerate the research process from data collection to dissemination of results. Individual studies are required, but learning will be maximized by comparison of CAV deployments and tracking over time. Towards this end, we envision a platform model with shared storage and governance mechanisms that would provide appropriate access to diverse stakeholders, including industry, government, academia, and the public. Data and results may be generated and used in many different ways, only some of which we can anticipate now. In the following sections, we suggest some key areas and objectives for initial investment. Over time, incentives for participation can be adjusted so that the platform is self-sustaining.

Data availability and standardization

Many different sources of data are potentially useful to analyze CAVs and CAV deployments in context.

- **Data standards:** There is an immediate need for industry and government authorities to consider and commit to data standards that will be useful for both technology and policy development. These data standards can be expected to shift over time; rapid prototyping practices (from business/management) will be necessary to seek and confirm which data standards are useful.
- **Availability and sharing:** The public has inherent safety and financial stakes in how CAV systems and CAV deployments develop and are implemented because they will be an increasing part of the public infrastructure. It is therefore reasonable for lawmakers or Executive Branch organizations to consider requiring certain data sharing from industry, CAV systems or deployments, or researchers, and/or to allow use of such shared data.
- **Data for education:** Data should be made available for students, educators and other interested parties.
- **Confidentiality:** Members of the public and non-public industry entities have a reasonable expectation of privacy and confidentiality. Rules and standards regarding privacy and confidentiality of databases, data used for research, and data transferred in the normal operation of CAV systems should be considered.
- **Standards for infrastructure, connectivity and data.** Competing vendors regard operational data as proprietary. Furthermore, vendors are likely to offer competing standards and protocols (think VHS vs. Betamax), which may limit connectivity and/or transparency. However, cooperation and standardization can be expected to increase efficiency in both deployments and governance.
- **Continuous survey of relevant populations.** Due to the rapidly changing nature of both the technology and the context of CAV deployments, new and recent information will be continuously needed.

Increase rapid dissemination of results

CAVs are a very fast-moving phenomenon. New CAV deployments are happening at an increasingly rapid pace. Unfortunately, peer-reviewed journal publications can take years. How can high quality research be disseminated on a much shorter time scale?

- Industry partners could introduce useful processes when they are part of a research project. Rapid iterative prototyping and continuous quality control are both standards that promote rapid, but firmly data-grounded, development in systems, products, or processes.
- Convergence research may require non-standard channels for dissemination, since it may not fit traditional disciplinary expectations. A technical report series or specialized journal might be more appropriate.

Opportunities for research coordination

- To improve quality and comparability of results across studies, a national series of cross-disciplinary workshops could be established.

- International studies may make particularly powerful and interesting basis for comparison, since different national contexts are at different stages of readiness for CAV deployments.[xxiii]
- Governmental bodies with pertinent powers can prioritize regulating and/or funding big-picture studies that individual entities are less likely to implement.
- Social science research about attitudes toward and impacts of CAVs will produce data. Standards for metadata and data access would encourage meta-analysis across multiple studies on different CAV systems for more generalizable findings.
- Coordination with industry groups should be encouraged. Industry partnerships are already forming to explore social implications; for example, the **Partnership for Transportation Innovation and Opportunity**[xxiv] includes American Trucking Associations, Daimler, FedEx Corp., Ford Motor Co., Lyft, Toyota Motor North America, Uber, and Waymo.

Endnotes

i https://www.nsf.gov/od/oia/convergence/index.jsp

ii https://assets.kpmg.com/content/dam/kpmg/za/pdf/2017/11/islands-of-autonomy-web.pdf

iii See SAE J3016 for detailed definitions: https://www.sae.org/standards/content/j3016_201806/. The SAE categories have been adopted by NHTSA, as well.

iv National Academy of Sciences is funding a project for standardized classification system for connected roadways http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4224

v https://www.itf-oecd.org/sites/default/files/docs/managing-transition-driverless-road-freight-transport.pdf

vi https://www.technologyreview.com/s/608197/before-they-hit-the-road-driverless-vehicles-will-take-over-warehouses/

vii https://www.cnbc.com/2018/06/27/kroger-to-soon-begin-driverless-grocery-delivery.html

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ix https://www.law360.com/articles/958973/how-autonomous-vehicles-will-transform-our-cities

x https://futurism.com/images/7-benefits-of-driverless-cars/

xi Jane Jacobs was a pioneering voice in urban planning who advocated for the identity and preservation of urban neighborhoods https://en.wikipedia.org/wiki/Jane_Jacobs.

xii https://assets.kpmg.com/content/dam/kpmg/xx/pdf/2018/01/avri.pdf

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