



Transformational Technologies in Transportation: State of the Activities

DETAILS

86 pages | 8.5 x 11 | PAPERBACK

ISBN 978-0-309-44774-4 | DOI 10.17226/23599

AUTHORS

Abbas Mohaddes and Peter Sweatman; Technical Activities Division; Transportation Research Board; National Academies of Sciences, Engineering, and Medicine

BUY THIS BOOK

FIND RELATED TITLES

Visit the National Academies Press at NAP.edu and login or register to get:

- Access to free PDF downloads of thousands of scientific reports
- 10% off the price of print titles
- Email or social media notifications of new titles related to your interests
- Special offers and discounts



Distribution, posting, or copying of this PDF is strictly prohibited without written permission of the National Academies Press. (Request Permission) Unless otherwise indicated, all materials in this PDF are copyrighted by the National Academy of Sciences.

TRANSPORTATION RESEARCH
CIRCULAR

Number E-C208

May 2016

**Transformational
Technologies
in Transportation**

State of the Activities

TRANSPORTATION RESEARCH BOARD

TRANSPORTATION RESEARCH BOARD 2016 EXECUTIVE COMMITTEE OFFICERS

Chair: James M. Crites, Executive Vice President of Operations, Dallas–Fort Worth International Airport, Texas

Vice Chair: Paul Trombino III, Director, Iowa Department of Transportation, Ames

Division Chair for NRC Oversight: Susan Hanson, Distinguished University Professor Emerita, School of Geography, Clark University, Worcester, Massachusetts

Executive Director: Neil J. Pedersen, Transportation Research Board

TRANSPORTATION RESEARCH BOARD 2016–2017 TECHNICAL ACTIVITIES COUNCIL

Chair: Daniel S. Turner, Emeritus Professor of Civil Engineering, University of Alabama, Tuscaloosa

Technical Activities Director: Ann M. Brach, Transportation Research Board

Peter M. Briglia, Jr., Consultant, Seattle, Washington, *Operations and Preservation Group Chair*

Mary Ellen Eagan, President and CEO, Harris Miller Miller and Hanson, Inc., Burlington, Massachusetts, *Aviation Group Chair*

Anne Goodchild, Associate Professor, University of Washington, Seattle, *Freight Systems Group Chair*

David Harkey, Director, Highway Safety Research Center, University of North Carolina, Chapel Hill, *Safety and Systems Users Group Chair*

Dennis Hinebaugh, Director, National Bus Rapid Transit Institute, University of South Florida Center for Urban Transportation Research, Tampa, *Public Transportation Group Chair*

Bevan Kirley, Research Associate, Highway Safety Research Center, University of North Carolina, Chapel Hill, *Young Members Council Chair*

D. Stephen Lane, Associate Principal Research Scientist, Virginia Center for Transportation Innovation and Research, *Design and Construction Group Chair*

Hyun-A C. Park, President, Spy Pond Partners, LLC, Arlington, Massachusetts, *Policy and Organization Group Chair*

Harold R. (Skip) Paul, Director, Louisiana Transportation Research Center, Louisiana Department of Transportation and Development, Baton Rouge, *State DOT Representative*

Ram M. Pendyala, Frederick R. Dickerson Chair and Professor of Transportation, Georgia Institute of Technology, *Planning and Environment Group Chair*

Stephen M. Popkin, Director, Safety Management and Human Factors, Office of the Assistant Secretary of Transportation for Research and Technology, Volpe National Transportation Systems Center, Cambridge, Massachusetts, *Rail Group Chair*

Robert Shea, Senior Deputy Chief Counsel, Pennsylvania Department of Transportation, *Legal Resources Group Chair*

Eric Shen, Director, Southern California Gateway Office, Maritime Administration, Long Beach, California, *Marine Group Chair*

TRANSPORTATION RESEARCH CIRCULAR E-C208

Transformational Technologies in Transportation

State of the Activities

Abbas Mohaddes and Peter Sweatman
CAVita

Task Force on Transformational Technologies in Transportation
Executive Committee
Transportation Research Board

May 2016

Transportation Research Board
500 Fifth Street NW
Washington, D.C.
www.TRB.org

TRANSPORTATION RESEARCH CIRCULAR E-C208
ISSN 0097-8515

The **Transportation Research Board** is one of seven programs of the National Academies of Sciences, Engineering, and Medicine. The mission of the Transportation Research Board is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal.

The **Transportation Research Board** is distributing this E-Circular to make the information contained herein available for use by individual practitioners in state and local transportation agencies, researchers in academic institutions, and other members of the transportation research community. The information in this circular was taken directly from the submission of the authors. This document is not a report of the National Academies of Sciences, Engineering, and Medicine.

**Executive Committee Task Force on
Transformational Technologies in Transportation**
Kirk Steudle, *Chair*

Jon Eisenberg
Chris Hendrickson
Roger Huff
Jane Lappin
Timothy Schmidt
Steven Shladover
Katherine Turnbull
Gregory Winfree
Dean Wise

Transportation Research Board
Mark R. Norman, *Director, Program Development & Strategic Initiatives*

Cover photo: Don Pettit, National Aeronautics and Space Administration

Transportation Research Board
500 Fifth Street NW
Washington, DC
www.TRB.org

Lea Camarda, Production Editor; Jennifer Correro, Proofreading and Layout

Contents

1. Executive Summary	1
2. Introduction	7
3. Key Transformational Technologies	8
3.1 Connected and Automated Vehicles	8
3.1.1 Introduction	8
3.1.2 Technology Description and Trends: The Connected Vehicle Stream	10
3.1.3 Technology Description and Trends: The Automated Vehicle Stream	11
3.1.4 The Impact of Transportation Shared-Use Services	12
3.1.5 Key Connected and Automated Vehicle Applications and Deployments	13
3.1.6 Key Groups of Players in Connected and Automated Vehicles	14
3.1.7 The Evolution of Connected and Automated Vehicles	16
3.1.8 Key Organizations and Players	18
3.1.9 Business Models	18
3.1.10 Key Efforts in Convening and Publicizing	19
3.1.11 Adjacent Technologies and Interconnected Matters	20
3.2 Unmanned Aerial Systems	21
3.2.1 Introduction	21
3.2.2 Technologies and Application	24
3.2.2.1 Technological Challenges	26
3.2.2.2 Center of Excellence	27
3.2.3 Key Activities and Entities	28
3.2.4 Privacy and Civil Liberties Considerations	29
3.2.5 National Security Issues	30
3.2.6 Business Opportunities	31
3.2.6.1 Section 333	31
3.2.6.2 Pathfinders	31
3.2.7 Media Coverage and Attention	32
3.3 Internet of Things	34
3.3.1 Introduction	34
3.3.2 Technology, Trends, and Application	35
3.3.3 Key Activities and Entities	38
3.3.3.1 Large-Scale Deployments	38
3.3.3.2 The Market for Internet of Things	39
3.3.4 Smart Cities	41
3.3.4.1 Overview	41
3.3.4.2 Technology Description and Trends	42
3.3.4.3 Key Applications and Deployments	42
3.3.4.4 Business Models	44
3.3.4.5 Key Efforts in Convening and Publicizing	44
3.3.4.6 Adjacent Technologies and Interconnected Matters	45
3.3.5 Key Organizations and Players	46
3.3.6 Security, Risks, and Opportunities	46

3.4 Cybersecurity.....	48
3.4.1 Overview.....	48
3.4.2 Technology Description and Trends.....	49
3.4.3 Key Organizations and Players.....	50
3.4.4 Key Applications and Deployments.....	50
3.4.5 Key Efforts in Convening and Publicizing.....	52
3.4.6 Business Models.....	52
3.4.7 Adjacent Technologies and Interconnected Matters.....	54
4. Potential Transformational Technologies.....	55
4.1 Next-Generation Air Transportation System: NextGen.....	55
4.1.1 Overview.....	55
4.1.2 Technology Description and Application.....	57
4.1.3 Business Models.....	59
4.1.4 Key Organizations and Players.....	60
4.1.5 Efforts in Convening and Publicizing.....	60
4.1.6 Adjacent Technologies and Interconnected Matters.....	60
4.2 3-D Printing.....	63
4.2.1 Overview.....	63
4.2.2 Technology Description and Trends.....	64
4.2.3 Key Organizations and Players.....	66
4.2.4 Key Applications and Deployments.....	67
4.2.5 Business Models.....	67
4.2.6 Key Efforts in Convening and Publicizing.....	68
4.2.7 Adjacent Technologies and Interconnected Matters.....	68
4.3 Big Data.....	69
4.3.1 Overview.....	69
4.3.2 Technology Description, Trends, and Application.....	71
4.3.3 Business Models.....	73
4.3.4 Key Organizations and Players.....	76
4.3.5 Efforts in Convening and Publicizing.....	76
4.3.6 Adjacent Technologies and Interconnected Matters.....	77

1

Executive Summary

This technical memorandum provides the review and findings of state of the activities conducted by CAVita relative to the transformational technologies identified by TRB. This study was prepared for and peer-reviewed by the TRB Executive Committee’s Task Force on Transformational Technologies.

The current state of the selected topic is considered to be represented by the nature of key technologies and their state of development; the key players involved; methods used to demonstrate the technologies to a national audience; methods used to publicize the technologies and convene their proponents and stakeholders; the economic significance of technologies and associated business models; and the possibilities for wider impact through synergies with other key technologies or other adjacent matters.

A key building block for TRB’s new value proposition is to sufficiently describe all of these topics—the key disruptive technologies of vital interest to a broader cohort of TRB stakeholders and collaborators. A consistent set of considerations has therefore been adopted and applied to each topic.

Given the very wide range of topics, this overview draws extensively on Internet research, adopting a high-level approach to attribution of sources. In certain areas the authors have relied on their own knowledge of specific topics, but also of the broad sweep of the national dialogue on transportation.

The activities that this effort will be helping to design will play an important part in the sustainable, leading-edge positioning of TRB in the national (and perhaps international) dialogue on transformational technologies in transportation.

The topics are all technological but include elements of service provision, business models, and broader impacts, including community value and societal impacts. Even when the report refers to “technologies,” this means systems—often with multiple layers of base technologies. The hot topics are fundamentally technological. Some of the topics, including smart cities and cybersecurity, might be termed megatrends, and have global meaning.

The first topic under consideration is connected and automated vehicles (CAVs). CAVs have the potential to transform a large portion of the U.S. ground transportation system, from the private and public to the urban and rural. The topic of CAVs also interacts strongly with most of the other transformational topics identified by TRB. To this end, it is believed the prospective stakeholders and constituencies are broad and that there exists an ecosystem which, in addition to the CAV community, includes the Internet of Things (IoT), big data, unmanned aerial systems (UASs), smart cities, and the other TRB hot topics listed above. These topics are recognized as being in various current levels of traction but TRB is interested in significant correlations and interrelationships going forward.

In the review of CAVs, the key players are considered in the following eight broad categories, each with many industry segments and multiple levels of government, academic, and research activity:

1. Policy development;
2. Vehicles;
3. Infrastructure;

4. Personal technology (tech);
5. Communications, computation, and big data;
6. Insurance, standards, and security;
7. Mobility services; and
8. Convening, deployment, and evaluation.

Mobility services, vehicles, and personal technology (tech) are thought to represent the most important nexus for automated vehicles. All eight constituencies are of interest because they may assist TRB in developing a sustainable set of convening activities, somewhat resilient to inevitable disruptions in the hot topics.

The CAV sector is likely to be influenced by at least some of the additional key topics in this study: smart cities, big data, IoT, cybersecurity, and the shared-use economy. If we consider mobility services, disruptive start-up companies like Uber have excelled in providing consumer-oriented ride services accessed and paid for through personal devices. The success of these companies, along with other sharing models like car sharing and ride sharing, has led the long-established automakers to move into the world of mobility services. Recent examples from GM include a major investment in Lyft and the launch of the car-sharing service Maven.

UASs could provide relief for urban areas, reducing congestion caused by conventional ground-based package delivery operations. Currently payloads are limited but a network of UASs could support first and last-mile logistics networks.

The FAA is taking the leadership role in United States, preparing a roadmap to illustrate the significant undertaking it is to build the basis for the National Airspace System (NAS) to transition from UAS accommodation to UAS integration.

FAA Administrator Michael Huerta addressed the Aero Club in Washington, D.C., on October 21, 2015:

Perhaps one of the greatest evolutions in our thinking is occurring today. After 112 years of focusing on carrying humans safely aloft, we face a different kind of challenge. It has become apparent to all of us that we are at the dawn of a time when unmanned aircraft are playing a growing role in world aviation.

Somebody called the birth of the unmanned aircraft industry the Wright Brothers moment of our time. Maybe so. Maybe not. But, there's no question that innovation in this new segment is taking place at the speed of imagination.

The approach taken by FAA in developing a roadmap for UAS integration, along with national research capabilities, provides interesting parallels, and contrasts with national CAV activities.

In review of the IoT, experts estimate that the IoT will consist of almost 50 billion objects by 2020. "I think the Internet of Things is the next driver of tech growth," said LogMeIn president Bill Wagner. "It's a trillion-plus-dollar market opportunity."

British entrepreneur Kevin Ashton first coined the term in 1999. Typically, IoT is expected to offer advanced connectivity of devices, systems, and services that goes beyond machine-to-machine communications (M2M) and covers a variety of protocols, domains, and applications. The interconnection of these embedded devices (including smart objects), is expected to help usher in automation in many fields, while also enabling advanced applications like a Smart Grid, and expanding to the areas such as smart cities.

Marc Benioff, Chairman and Chief Executive Officer, Salesforce.com, USA, said, “The Internet of Things is ground zero for a new phase of global transformation powered by technology innovation, generating significant economic opportunities and reshaping industries.”

In September 2015, President Obama launched a new Smart Cities initiative. This initiative packages a number of programs to foster research, increase activity across federal departments, and kick-start industry–university collaborations and deployment. The package is indicative of the significant attention to smart cities opportunities now being developed in cities across the United States.

Highlights of this announcement include the following:

- More than \$35 million in new grants and more than \$10 million in proposed investments to build a research infrastructure for Smart Cities by the National Science Foundation (NSF) and National Institute of Standards and Technology.
- Nearly \$70 million in new spending and more than \$45 million in proposed investments to unlock new solutions in safety, energy, climate preparedness, transportation, health and more, by the U.S. Department of Homeland Security, U.S. Department of Transportation (DOT), U.S. Department of Energy, U.S. Department of Commerce, and the Environmental Protection Agency.
- More than 20 cities participating in major new multicity collaborations that will help city leaders effectively collaborate with universities and industry.

An important part of the smart cities movement is based on making data that is routinely acquired by public agencies available to entrepreneurs who then create new business models and start-ups based on the use of data that was until now unavailable. Cities like San Francisco and New York were instrumental in setting the pace. Within the past 10 years, many cities (and states and regions) have appointed chief technology officers and this has accelerated the trend to more data, and new types of data, in cities.

As one looks at the correlations among the various transformational technologies, the observation can be made that they have a profound impact on how research and development (R&D) is conducted in the private sector. In particular, because test and evaluation is often in the open environment (field tests–pilot deployments as opposed to laboratories) in the transportation industry, the validity, effectiveness, and commercial success of technologies tend to be expedited.

Very recently, Transportation Secretary Anthony Foxx announced a \$50 million Smart Cities Challenge to consolidate data-driven ideas to make transportation safer, easier, and more reliable. It is likely that CAV technologies will play a major role in competing smart cities concepts.

McKinsey Global Institute noted: “We view technology both in terms of potential economic impact and capacity to disrupt, because we believe these effects go hand-in-hand and because both are of critical importance to leaders.” As the early 20th-century economist Joseph Schumpeter observed, the most significant advances in economies are often accompanied by a process of “creative destruction,” which shifts profit pools, rearranges industry structures, and replaces incumbent businesses. This process is often driven by technological innovation in the hands of entrepreneurs. Schumpeter describes how the Illinois Central Railroad’s high-speed freight service enabled the growth of cities yet disrupted established agricultural businesses.

According to the FAA’s *Destination 2025* (2011):

NextGen is series of inter-linked programs, systems, and policies that implement advanced technologies and capabilities to dramatically change the way the current aviation system is operated. NextGen is satellite-based and relies on a network to share information and digital communication so all users of the system are aware of other users' precise locations.

NextGen was born on the 100th anniversary of the Wright brothers' flight when Congress and President George W. Bush in 2003 established an interagency office to “manage work related to the Next Generation Air Transportation System.”

NextGen's foundation creates new potential, making it possible for different NextGen components to come together and provide new functions.

Many of the NextGen stakeholders correspond with those for UAS. Not surprisingly, several stakeholders overlap with those in other transformational technology areas such as big data and IoT. These are important elements as the prospective constituencies are analyzed in correlation with the convening strategies.

A recent report from the Atlantic Council predicts that 3-D printing “has the potential to be as disruptive as the personal computer and the Internet.” It is variously estimated that the Internet impacts the worldwide economy at \$3 to \$6 trillion per year. All of the flow-on disruptive economic effects of 3-D printing cannot be foreseen, but there seems little doubt that we are dealing with a mega-disruptive technology.

Crowdfunding is currently being sought for the URBEE 2, a car being prototyped by Kor Ecologic using 3-D printing. It is expected to weigh some 1,200 lb, comprising about 40 pieces of thermoplastic. Its production will require far less material than a traditional car. It will need almost no labor and time to assemble. Its designers can employ unorthodox shapes and materials to maximize efficiency.

Big data is a broad term for data sets so large or complex that traditional data processing applications are inadequate. Accuracy in big data may lead to more confident decision making. And better decisions can mean greater operational efficiency, cost reduction, and reduced risk.

You can't manage what you don't measure.

There is much wisdom in that saying, which has been attributed to both W. Edwards Deming and Peter Drucker, and it explains why the recent explosion of digital data is so important. Simply put, because of big data, managers can measure, and hence know, radically more about their businesses, and directly translate that knowledge into improved decision making and performance.

In traffic management we have seen it in performance measurement and management. Agencies such as the California DOT (Caltrans) currently utilize significant amounts of data that they collect in real time through various sensors and vehicle probes. Applying analytics, results are actionable information that can be used for decision making and sharing with travelers. Another example is the traveler information–511 systems that many states enjoy where big data is analyzed and shared with travelers.



Several state DOTs are developing a performance measurement dashboard to quickly review system parameters and performance metrics in real time. As such systems evolve, a variety of data could be included such as infrastructure data, systems data, calculated data, environmental, weather, and geographic information systems (GIS).

A significant correlation exists among the TRB hot topics and big data. This is likely to be an important cross-sectional platform.

Cybersecurity is a worldwide, high-profile mega-trend impacting national security, global political, policy development and business dealings and every industrial sector in the United States. The integrity and security of all software, data, and operating systems in both the public and private sectors is a matter of intense media interest on a daily basis. Exposure to hacking, release of private information, and cybercrime is a major preoccupation for virtually every government, company, and individual.

The cybersecurity industry has become highly entrepreneurial and is characterized by a race to expose and audit vulnerabilities, educate company leadership, develop Internet protocol and populate a high-tech workforce. New positions and divisions are being created in companies and government agencies of all stripes, for example, the rise of the digital risk officer.

It is important to recognize that the very developments that are revolutionizing transportation—including connectivity, automation, instant access to mobility services and integration of personal devices—are acting to multiply vulnerabilities. Serious attention to cybersecurity best practices in transportation is in the early stages, and will need to evolve and keep pace with the technological reinvention of transportation.

Companies providing protection against cyber attacks tend to see the biggest threats for connected systems and mobile systems. This trend highlights transportation as a critical sector for cybersecurity R&D and deployment.

The key players in cybersecurity tend not to be directly involved in transportation. However, the advent of CAV brings in new companies who do engage with key cybersecurity players.

There appears to be a significant correlation between the hot topics at various levels including technology, players involved, business models, and challenges. Further, the propensity for convening and national dialogue is growing in these areas, and many organizations are including such adjacent topics to attract participants.

Transportation is seen as a common field of play for many of the organizations and industry players, and there exists an opportunity for TRB to lead in this arena, convening in a sustainable fashion.

This report has a broad transportation focus and does not set out to distinguish between transportation and transportation research. It was found that the hot technologies tend to represent very large market potential, and so the emphasis is on how to deploy, overcome barriers and create complex partnerships in many cases. R&D is of course part of these processes, and all of the hot technologies are, or have been, R&D-intensive. It was also found that research organizations play a distinct, and perhaps relatively new role in helping to develop the larger systems needed to realize the full potential of the technologies. This was seen occurring in CAVs, UASs, and smart cities. It was also seen that the cross-cutting technologies of cybersecurity and big data need help in translating complex solutions to end users.

At a high level, the hot topics can be characterized as follows:

- Connected–automated vehicles (CAVs) are a potential national ground transportation solution with high market, consumer, and societal significance; the realization of CAVs full potential will require sustained cooperation among many stakeholders.
- Shared-use services is a generational service economy concept that has extreme disruptive power in transportation and has a natural affinity with CAVs. It has a very high market potential, consumer, and societal significance.
- Unmanned aerial systems (UASs) are a national operations and mobility solution with significant market and consumer potential; the realization of UASs' full potential will require government action and consumer acceptance.
- IoT is a technological megatrend that will underpin many smart products and services.
- Cybersecurity is an essential, high-value process technology that underpins many fields of system operations and consumer services.
- Smart cities is a technological mega-trend that bundles related technologies including big data and IoT.
- NextGen is a new-generation national system for the control of aviation operations. It is led and operated by government and enables high market and societal value. The need for and wide use of the system is not at issue.
- 3-D printing is a highly disruptive technology in manufacturing, logistics, and transportation. It has extremely high market value and flow-on effects, including the enterprises of IP, research and standards.
- Big data is an information technology that enables other transformational technologies, and game-changing advances in multiple fields of operation (including transportation).

Considering the potential status of the hot topics from a transportation perspective, the following comments are offered, subject to further analysis:

- CAV. Including shared use services; there is an extremely natural connection here: automation and shared services have a mutually disruptive effect.
- UASs. NextGen is a natural corollary; the national integration task has an interesting parallel with CAV.
- IoT (including smart cities); the CAV topic interacts strongly, as does cybersecurity.

The following topics have potential to be transformational technologies:

- NextGen: natural parallel with unmanned aerial vehicles (UAVs);
- 3-D printing: already relates with CAV;
- Big data: represents the most cross-cutting technological mega-trend; and
- Cybersecurity: relates very strongly on multiple fronts: CAV, IoT, and UAS.

Introduction

This TRB e-circular represents Stage 1 of CAVita's work on transformation technologies as a new value proposition for TRB. This study was prepared for and peer reviewed by the TRB Executive Committee's Task Force on Transformational Technologies, but was not subjected to the formal TRB peer-review process. No language should be construed as consensus findings or recommendations of the authors; TRB; or the National Academies of Science, Engineering, and Medicine. Furthermore, the views expressed in this e-circular are those of the attributed authors and do not necessarily represent the views of TRB or the National Academies of Sciences, Engineering, and Medicine.

Stage 1 focuses on the current state of a number of key topics identified by the TRB Executive Committee Task Force on Transformational Technologies, supported by a staff team that includes all of the TRB Divisions. The current state of the selected topics is considered to be represented by the nature of key technologies and their state of development; the key players involved; methods used to demonstrate the technologies to a national audience; methods used to publicize the technologies and convene their proponents and stakeholders; the economic significance of technologies and associated business models; and the possibilities for wider impact through synergies with other key technologies or other adjacent matters.

The key topics are considered in two groups: those currently considered by the Task Force to be truly transformational and those that have the potential to be transformational.

A key building block for TRB's new value proposition is to fully describe all of these topics—the key disruptive technologies of vital interest to a broader cohort of TRB stakeholders and collaborators.

It is intended that this description will lead to a subject matter architecture that can be put in motion by an innovative set of TRB activities, with a long-term view. These activities will be designed to create new value to a broadened set of constituencies.

The activities will play an important part in the sustainable, leading-edge positioning of TRB in the national dialogue on transformational technologies in transportation.

Key Transformational Technologies

TRB has identified a number of transformational technology hot topics and immediate attention is focused on the following:

- CAVs, including shared use services;
- UASs (drones);
- IoT (including smart cities); and
- Cybersecurity.

In addition, the following technologies that have potential to be transformational technologies include the following:

- NextGen,
- 3-D printing, and
- Big data.

The topics are all technological, but include elements of service provision, business models, and broader impacts, including community value and societal impacts. Even when we speak of technologies, we mean systems, often with multiple layers of base technologies. The hot topics are fundamentally technological. Some of the topics, including smart cities and cybersecurity, might be termed mega-trends and have global meaning.

Among the topics under consideration: first is CAVs. CAVs have the potential to transform a large portion of the U.S. ground transportation system: private and public, urban, and rural. The topic of CAV also interacts strongly with most of the other transformational topics identified by TRB. To this end, the spectrum of prospective stakeholders and constituencies is broad and there exists an ecosystem which in addition to the CAV community includes IoT, big data, UASs, smart cities, and others as identified above. The sometimes disparate topics are in various current levels of traction, but TRB is interested in significant correlations and interrelationships going forward.

Given the exceedingly wide range of topics, the authors have drawn extensively on Internet research and have adopted a high-level approach to attribution of sources. In certain areas the authors have relied on their own knowledge of specific topics, but also of the broad sweep of the national dialogue on transportation.

3.1 CONNECTED AND AUTOMATED VEHICLES

3.1.1 Introduction

The term connected vehicles (CVs) refers to both connecting vehicles and infrastructure, and to connection among all ground vehicle players: cars, freight trucks, buses, motorcycles, bicycles, and pedestrians. Also included are other modes such as bus rapid transit, heavy rail, and light rail. Connected refers to licensed wireless regimes dedicated short-range communication

(DSRC), the newer cellular technologies (together these regimes are often referred to as V2X), satellite, Internet, and all forms of telematics.

The term automated vehicles refers to various levels of replacement of human control (3), with a more limited range of ground vehicle players: cars, freight trucks, and buses. However, the definition also includes new configurations of these base vehicle units such as platoons (4).

The terms automated and autonomous are often used interchangeably. However, autonomous (5) usually means a vehicle that relies entirely on its own onboard sensors for situation awareness in the roadway, and therefore for exercising vehicle control functions. Automated vehicles may cover a very wide range of automated driving features, often falling well short of fully automated capabilities. For example, adaptive cruise control would be one example of a low-level automated performance feature.

The terms connected and automated are often used together from the perspective that they are among the most exciting, or far-reaching, technologies currently being talked about in transportation. When we hear about CAVs, we may have a sense that the two technologies are closely related or even interdependent. In fact they are currently separate technologies.

The connected part of connected and automated generally refers to a V2X-enabled capability that creates machine awareness of the trajectories of equipped vehicles in the immediate vicinity. This machine awareness applies to vehicles as well as specific features of the infrastructure, such as intersections and curves. Such machine awareness may be used to identify safety risks, but also to condense or smooth traffic flow. These applications of the technology require warnings or notifications for drivers, in order for the driver to make the required vehicle corrections.

Connected only becomes highly effective when the density of equipped vehicles in the traffic stream increases to a certain point. So the rate of deployment of V2X technology in vehicles and infrastructure is a key issue. This requires consideration of original equipment fitment in both vehicles and infrastructure, as well as the use of the aftermarket for vehicles and potentially for infrastructure as well.

The automated part of connected and automated refers to any substantial form of active control on the part of the vehicle rather than the driver. Automated vehicle features have to some extent evolved from a class of advanced driver assist systems (ADAS) (6). It is also interesting to think about the concept of automated intersections in the sense that traffic controls automatically respond to the vehicles going through the intersection.

So how and when do connected and automated come together? Currently, most would agree that connectivity would be highly beneficial to automated vehicles. However, there is much to play out here: first in terms of what specific benefit is provided when automated vehicles of various stripes become connected; and second in terms of the rate at which connectivity becomes available, and where it is available within the network.

It is clear that the topic of CAVs is high stakes, and yet many complexities and convergences will be encountered along the way. The manner in which these technologies actually work, and the extent to which they support each other, will only be seen in a protracted public-private-consumer interaction that will probably evolve over a decade or two.

Definitions and perceptions of these technologies will remain highly fluid. In the first wave of this TRB activity, connected and automate” will be considered separate technologies, with an eye to the evolution of each. We also need to be prepared for the convergence of these two streams.

3.1.2 Technology Description and Trends: The Connected Vehicle Stream

CVs (and infrastructure) rely on wireless communication regimes. The selected wireless regime provides a platform upon which a rich variety of applications may be placed and operated. The requirements of the application—its purpose and scope—largely determine the necessary capabilities of the assigned wireless communication method.

In the United States, CVs have been developed primarily for the purpose of deploying safety applications. While safety applications may cover a wide field in terms of specificity for avoiding crashes, the adopted wireless method must accommodate the most demanding applications.

The platform development that was largely funded by the U.S. DOT uses DSRC (7), a form of Wi-Fi that currently uses part of a 75-MHz slice of licensed spectrum at 5.9 GHz. The signal reliability and short latency of this wireless regime are suitable for highly specific safety applications like forward collision warning, electronic brake light assist, or left turn assist. It is possible that future versions of cellular technology, such as 5G, will have adequate technical performance—similar to DSRC—and it would be beneficial if they were considered.

The DSRC platform is used to send basic safety messages (BSMs) that contain vehicle position, speed, and heading, as a minimum. BSMs are sent 10 times per second and are received by equipped vehicles and infrastructure equipment in the immediate vicinity.

The technologies hosted by the vehicle include the DSRC platform, application software, and driver interfaces. Connections to the vehicle's controller area network data bus are preferred and widen the range of information that may be transmitted, and therefore, the scope and effectiveness of consequent vehicle-to-vehicle (V2V) applications. The computational requirements in the vehicle are modest.

Technological and policy issues abound. As its name suggests, DSRC has a short range—typically a few hundred yards—and its standardized transmission packets that are sent 10 times per second may be blocked, absorbed, or reflected by other vehicles (especially large trucks), buildings, or roadside objects. Reliability of transmission may also depend on the number of vehicles transmitting in the immediate vicinity. Vehicles need effective antennas for both DSRC and GPS.

The continuing availability and reliability of the assigned 5.9-GHz band is an important issue, with current consideration by the Federal Communications Commission (FCC) of auctioning part of the until now reserved and protected band (8).

The U.S. DOT has entered the early stages of rulemaking for the provision of V2V at the original equipment vehicle stage (9). Rulemaking is likely to apply to the presence and capability of the DSRC platform, but probably not to specific applications, the nature of which will be left to automakers. The U.S. DOT's role is to ensure that the transmission packets sent by a vehicle of one make will be seamlessly received by a vehicle of another make.

Beyond the U.S. national priority for transforming safety, CVs and infrastructure offer major improvements in traffic flow, intersection efficiency, energy wasted in stop-start operations, and vehicle emissions. CVs also have advantages for electrified vehicles: lower energy use means longer range between battery charges, and connectivity may reduce the range anxiety experienced by electric vehicle owners.

The deployment of DSRC roadside equipment in the infrastructure—especially at intersections and on curves—is a necessary development, along with a sufficient density of

equipped vehicles in a given traffic stream. This equipment is typically housed in traffic control cabinets, with transmission equipment high-mounted on signal arms, poles, and gantries.

While equipment vendors and the traffic control industry have the necessary technology, the business case for paying for the installation, operation, and maintenance of the roadside equipment is not at all clear.

A minimum level of roadside equipment is needed for CV support functions—such as the operation of security systems—and higher levels of deployment will provide important V2I advantages for traffic operations and safety (beyond those which V2V has to offer).

Several model deployments have been developed around the country—such as Ann Arbor (10). New projects have been announced (11) in New York City, Tampa, and Wyoming. Model deployments usually involve partnerships between state agencies, cities, consultants, universities, and companies.

In addition to the roadside equipment, it is necessary to have a data backhaul (getting data to a point from which it can be distributed over a network) to centralized locations. This data appears to have great potential from the perspective of road managers. The data, and the ability to communicate securely with vehicles, also offers untapped commercial opportunities.

Considered on a per-vehicle basis, the costs for vehicle and infrastructure deployment are modest. Requirements for standards development, testing, and compliance are modest.

The successful deployment of CVs on a nationwide scale will require a highly strategic and coordinated public–private effort, along with strong decision making by a range of companies from the automotive, traffic control, infrastructure, and the technology industry. Deployment of CVs will be a more demanding institutional than technological endeavor. The national dialogue created by TRB could be a major factor in sustaining this complex and often fragile process.

3.1.3 Technology Description and Trends: The Automated Vehicle Stream

Automated vehicles utilize a range of sensing technologies and maps to create situation awareness; software and actuators to provide control functions (steering, accelerating, and decelerating); and driver interfaces. Automated vehicles host significant computational and data storage capabilities.

Vehicles may also use Internet connections to host less time-critical data, or to download relevant software, and software updates. Such links may also provide manufacturers with powerful R&D information as they develop automation features from the beta to the commercial stage.

High levels of automation open the door to radical changes in the architecture and design of vehicles. As the driver becomes more removed from requiring the ultimate driving machine, dramatic changes in powertrains, size, weight, seating arrangements, amenities, and cargo capacity may be realized.

There is a wide range of levels of automation, as companies from the technology sector and automotive industry vie to create the automated product. Concepts range from “everything somewhere” (totally automated but suited only to certain environments) to “something everywhere” where worthwhile but limited automation may be used quite widely (for example while traveling on major highways).

So far, governments have played a limited role for automated vehicles. A number of U.S. states have adopted legislation applying to the testing and operation of automated vehicles. There

may be requirements for licensing, incident reporting, and human occupants, and limitations on driverless operation. However, many states have no such legislation.

Many expect federal safety rules to eventually apply to automated vehicle performance. Standards development is underway on several fronts, and it is likely that standards will operate on at least two levels: (1) the more traditional performance specification where physical testing is implied, and (2) safe systems design standards. The development of norms for human intervention with the machine, or for the coexistence of automated and traditional vehicles on the same roadways, is considered by many to be a significant challenge.

Automated vehicle development is highly vehicle-centric. Proponents of autonomous vehicles tend to emphasize the self-contained nature of the technology. However, the potential role of infrastructure design and maintenance is under consideration in some transportation agencies. Will we see lanes restricted for automated vehicle operation? Or narrower lanes for high volumes of automated vehicles? Would there be any particular requirements for roadway markings, or even opportunities to embed relevant data in the roadway?

Certain nontraditional manufacturers of automated vehicles are oriented to new mobility services, such as low-speed driverless shuttles in early-adopting host cities, or on restricted campuses (like airports and shopping complexes).

So far, we have not seen federally funded demonstration projects in the United States, as has occurred in La Rochelle, France (12), and in Milton Keynes, England. In these projects, low-speed, driverless, specialty shuttle vehicles are operated as a mobility service in busy business and tourist centers. In terms of public-private deployment of automated vehicle capabilities in the United States, the platooning of freight trucks is the main early adopter (13). This represents an interesting case in terms of transportation agency approvals, but also is noteworthy in requiring *both* automated and connected technologies due to the very short headways involved.

Relative to the connected technologies discussed in Section 3.1.2, automated vehicle technologies are more technologically demanding and cost more. They are more amenable to rapid industry innovation and require much less public-private cooperation in the early stages. However, the potential barriers to automation as a widespread national mobility solution are daunting as barriers arise from major national preoccupations such as manufacturers' responsibility for delivering a safe vehicle, liability, and cybersecurity.

3.1.4 The Impact of Transportation Shared-Use Services

Shared-use mobility generally comprises transportation services that are shared among users, including traditional public transit; taxis and limos; bike sharing; car sharing (roundtrip, one-way, and personal vehicle sharing); ridesharing (carpooling and vanpooling); ride-sourcing; shuttle services; and commercial delivery vehicles providing flexible goods movement (14). The terminology does not include the fact that some shared-use services also have innovative approaches to how users source the underutilized transportation asset (including vehicles and drivers).

The advent of automation provides a new set of possibilities for shared-use services and the shared use concept potentially revolutionizes the impact of automated vehicles. Vehicles that are both automated and shared could completely change the impact of motor vehicles in cities and could help to alleviate traffic and environmental issues.

Shared-use mobility—along with automation—raises new possibilities for sustainable transportation systems that could meet goals for safety, traffic movement, energy efficiency, and emissions that previously appeared to be unattainable (15).

Advances in personal devices, sensors, wireless communications, and automation have made a large-scale sharing of assets feasible. Automakers, communications companies, transportation services companies, and rental car companies are actively pursuing shared-mobility opportunities. Cities are initiating new programs and are accommodating demonstrations and deployments. Some of these programs are also tied to electric car initiatives.

We are also seeing the rise of some of the hottest mobility companies under the general umbrella of shared use. Transportation network companies (TNCs) (sometimes known as ridesourcing) like Uber and Lyft have seen rapid growth (16), and Uber for one is investing in automated technology in the hope of dispensing with the cost of human drivers. A similar concept is being applied to freight delivery where ubiquitous communications allow the spare capacity in truck loads to be utilized.

The key players in shared-use services are included in the fuller discussion concerning connected and automated vehicles (see Section 3.1.8).

The broader sharing economy includes many ways of collaborating and repurposing that reduce the consumption of resources, increase communication, and provide open data. While transportation represents a prime, large-scale application for the shared-use services sector, applications exist in many other fields, such as accommodation sharing (e.g., AirBnB).

3.1.5 Key Connected and Automated Vehicle Applications and Deployments

In the United States, R&D in CVs and infrastructure has been underway for more than 10 years. The U.S. DOT has overseen a tightly integrated program of research, bench testing, test beds, field trials, standards development, and model deployment. Now larger deployments are being developed in order to reveal the benefits in different and challenging environments.

We have seen the creation of partnerships in multiple parts of the country, where relevant government agencies, companies and universities come together to install, operate, and evaluate V2X zones or corridors. The partners generally have a local motivation to be involved, but all such sites adhere to the same technology standards, and often use the same technology suppliers and the same large national consultants who serve state DOTs. The U.S. DOT instills cooperation between these programs.

In the United States, most of the testing of highly automated vehicles is carried out by manufacturers on public roads, although some new off-roadway test facilities have been constructed or adapted. Automotive products with lesser degrees of automation are becoming available to consumers, but there are no organized processes for deploying technology at this level.

This approach contrasts with Europe, where programs such as CityMobil2 field test automated urban shuttle service selected locations (such as in La Rochelle, France). Various off-roadway facilities are also being adapted for testing automated vehicles.

Although many have a goal to converge connected and automated vehicles, and may have certain testing underway, it does not appear that there are any deployments that currently merge the two technologies.

Table 3.1 shows the key CAV test sites and deployments currently active in the United States. The on-roadway sites tend to be CV and infrastructure deployments where automated

vehicles could be added. The off-roadway sites tend to focus on testing of automated vehicles, with the capability to include connectivity. It is also apparent that industry partners are diverse and each tends to be involved with a specific site. Most sites have a specific, local university partner.

3.1.6 Key Groups of Players in Connected and Automated Vehicles

Further national progress with CAVs, and significant acceleration of that process require concerted work from both the initiators and supporting players. In this context, national progress means larger deployments, supporting datasets, satisfied customers, empowered road managers, and committed vendors. Ultimately, barriers to large-scale national deployment will best be addressed by coordinated efforts of industry and a variety of other stakeholders.

It is clear from a review of current deployments and sites (Section 3.1.5) that these activities are geographically dispersed and idiosyncratic in terms of partner pools. There is a need and opportunity to present an overarching approach for CAV as a national mobility solution. In this regard, the efforts of U.S. DOT to ensure cooperation between the three recent awardees for CAV deployment pilots (New York City, Tampa, and Wyoming) should be recognized.

Furthermore, for CAVs to represent a definitive national mobility solution, that solution will need to be livable, equitable, affordable, and environmentally sustainable. This requires a broad range of stakeholders.

In this section, the key players will be considered in the following eight broad categories, each with many industry segments, and multiple levels of government, academic, and research activity. Section 3.1.8 contains a fuller list of government agencies, associations, companies, and universities who are currently engaged in CAV and related shared use.

I. Policy development. Largely carried out by government at the federal, state, and local levels. Industry, academia, and research play a supporting and advisory role. Policy development applies to motor vehicles, infrastructure equipment, and telecommunications.

II. Vehicles. Designed, manufactured, and distributed by original equipment manufacturers and suppliers in several tiers. Certain equipment is also designed, manufactured, and distributed in the aftermarket.

III. Infrastructure. The nation's system of streets, roadway structures, and associated equipment and roadside furniture. Designed, constructed, maintained, and operated by state and local agencies, with federal government assistance. Equipment such as traffic management systems is designed, manufactured, and supplied by traffic equipment suppliers.

IV. Personal technology ("tech"). Manufacturers and providers of personal devices and services to consumers, and to other business sectors such as vehicle manufacturers. Includes inroads by tech companies into vehicle development: tech cars that are automated, connected, and electrified.

V. Communications, computation, and big data. The underlying telecommunications technology, the carriers, and the retail providers of phone and data services. Included are cellular and wireless regimes such as wi-fi, as well as the Internet and computation services on the vehicle and in the cloud. Also include are big data services creating information and applications

TABLE 3.1. Major CAV Test Sites in the United States

Project–Location	Government Partners	Industry Partners	Universities–Research	Key Assets	Comment
Accelerate Texas	Austin Metro; Texas DOT; Central Texas Regional Mobility Authority; Harris County Regional Tollway Authority; North Central Texas Council of Governments; North Texas Tollway Authority	BMW; Continental; Cubic; Econolite; Iteris; Nvidia; Serco	Texas A&M Transportation Institute; Southwest Research Institute	Multiple corridor test beds; truck platooning operations; and TTI Riverside Test Facility	Both on-roadway and off-roadway test facilities cater to connected and automated technologies.
GoMentum Station Contra Costa, California	Contra Costa Transportation Authority	Stantec Consulting; EasyMile; Honda		Off-roadway facility	Caters mainly to automated vehicles
University of Michigan Mobility Transformation Center (and Mcity) Ann Arbor, Michigan	Michigan DOT; U.S. DOT; City of Ann Arbor	Bosch; Delphi; Denso; Econolite; Ford; GM; Honda; Iteris; Navistar; Nissan; Qualcomm; State Farm; Toyota; Verizon; Xerox	University of Michigan	Ann Arbor Connected Vehicle Test Environment; Mcity	Both on-roadway and off-roadway test facilities cater to connected and automated technologies
Virginia Automated Corridors	Virginia DOT; Virginia Department of Motor Vehicles; Town of Blacksburg	Here; Transurban	Virginia Tech Transportation Institute	Northern Virginia Highways and Arterials; Virginia Smart Road	Both on-roadway and off-roadway test facilities cater to connected and automated technologies
New York City CAV Pilot Deployment	New York City DOT	Transcore Cambridge Systematics; Cohda Wireless; Savari; Security Innovation	Battelle	Connected corridors; 10,000 public service vehicles connected	CVs only
Tampa, Florida, CAV Pilot Deployment	Florida DOT; Tampa Hillsborough Expressway Authority; City of Tampa; Hillsborough Regional Transit Authority	HNTB; Booz Allen; Global5-Communications; Hamilton; Siemens	Center for Urban Transportation Research, University of South Florida	Connected downtown grid and corridor	CVs only
Wyoming DOT CAV Pilot Deployment	Wyoming DOT; National Center for Atmospheric Research	ICF International; McFarland Management	University of Wyoming; University of Maryland, CATT Lab	Connected corridor for freight vehicles	CVs only

in and around the high velocity and high-volume data streams being created by CVs and infrastructure (see Section 4.3 on big data).

VI. Insurance, standards, and security. Motor vehicle insurers are active in data-intensive insurance products and may develop new insurance concepts for automated vehicles. This refers to national and international standards bodies covering automotive and communications and to the security approaches adopted by vehicle and equipment manufacturers.

VII. Mobility services. This is a relatively new segment reaching critical mass through a diverse range of consumer-oriented services. Included are the more-established services such as fleet services, telematics, tolling, and fare payment. Also included are smart parking, carsharing, ridesharing, ridesourcing, and trip planning. This includes on-demand, networked ride services (Uber, Lyft).

VIII. Convening, deployment, and evaluation. The more traditional aspects of convening are carried out by industry associations and professional bodies. Universities and local agencies also organize efforts for deployment and economic development. Such consortia usually carry out evaluation activities.

Table 3.2 delves a little deeper into these eight categories, showing key sectors in each category, and examples of relevant companies and related organizations. Also considered are the main disruptors for each category, and the most interesting adjacencies for each category.

The examples of companies and organizations included in Table 3.2 are intended to help explain the nature of each CAV category. A fuller listing of government agencies, associations, companies, and universities is given in **Table 3.3**.

The following observations can be drawn from Table 3.2:

- The sectors termed mobility services, vehicles, and tech represent the most important nexus for automated vehicles.
- For the successful nationwide deployment of CAV, the remaining five sectors described in Table 3.2 need to be added:
 - Policy development;
 - Infrastructure;
 - Communications, computation, and big data;
 - Insurance, standards and security; and
 - Convening, deployment, and evaluation.
- Adjacent sectors are likely to be influenced by at least some of the additional key topics in this study: smart cities, big data, IoT, cybersecurity, and the shared-use economy.

3.1.7 The Evolution of Connected and Automated Vehicles

The national CAV enterprise described above may provide part of TRB's high-value national dialogue. A sustained leading-edge dialog may be constructed around the eight key CAV categories of players as they are inspired and influenced by several big techno-economic and societal drivers: smart cities, big data, IoT, cybersecurity, and shared-use economy. In addition, certain technologies are likely to directly influence CAV technologies and our key players: UASs, NextGen, and 3-D printing.

TABLE 3.2 Sector Dynamics for Key CAV Players

Category	Key Sectors	Examples	Disruptors	Adjacencies
I. Policy Development	Federal; state; city	National Highway Traffic Safety Administration; FCC; DOTs; departments of motor vehicles	Industry solutions (Qualcomm, Cisco)	Policies overseas; smart cities; cybersecurity
II. Vehicles	Original equipment manufacturers; Tier 1s; aftermarket	GM; Ford; Delphi; Bosch	Tech companies (Google, Tesla)	Tech industries; mobility service industries; smart cities
III. Infrastructure	State; local; traffic equipment	MDOT; Oakland County; Econolite; Iteris	Public-private partnerships; corridor coalitions; freight coalitions	Big data; cybersecurity
IV. Personal Technology	Tech companies; tech car and specialty vehicle manufacturers	Google; Apple; Tesla; Faraday	On-demand networks (Uber)	Smart cities; IoT; shared use economy; cybersecurity
V. Communications, Computation, and Big Data	Telecoms; big data; Cloud; Internet	Verizon; IBM; Cisco	New cellular; FCC; free data (New York City)	Smart cities; consumer electronics products; IoT; cybersecurity
VI. Insurance, Standards, and Security	Insurers; standards bodies	State Farm; SAE; IEEE; Qualcomm; Cisco	Liability shift (OEMs, governments)	Privacy; security industry; Homeland Security; big data
VII. Mobility Services	Fleet services; telematics; tolling; fare payment; smart parking; car sharing; ride sharing; trip planning; on-demand ride services	Verizon; Xerox; Cubic; ParkMobile; Zipcar; RideScout; Uber	Automation; work practices; city policies	Shared-use economy; financial services; smart cities; real estate; parking
VIII. Convening, Deployment, and Evaluation	Industry associations; professional bodies; universities; local consortia	ITS America; AASHTO; ITE; TRB; GoMentum; Metropolitan Transportation Commission	City consultants; conference industry; new associations; new consortia	Regional economic development; nontransport associations

3.1.8 Key Organizations and Players

Table 3.3 summarizes with a national perspective the current key players in CAV (and related shared-use services) in terms of public agencies, associations, private industry, and universities.

3.1.9 Business Models

An increasing number of companies, as discussed above, are developing CV and connected infrastructure products. Developments include personal devices (i.e., smartphones) and new products apply to both new vehicles and to the automotive aftermarket.

It is anticipated that automakers will incorporate DSRC-based features as the national rulemaking process proceeds. Deployment of DSRC in the infrastructure may be more problematic and the value proposition for business is not clear.

Tech companies, tech car manufacturers, specialty vehicle manufacturers, established vehicle manufacturers and their suppliers are all involved in extensive automated vehicle R&D. Products offering lower levels of automation or automation in well-defined situations are becoming available to consumers, among whom there is high interest and excitement. The value proposition for these companies is obviously well accepted. However, the value proposition at higher levels of automation and broader operating environments is much less clear. There are significant unknowns with regard to state-by-state legislation and liability.

Companies involved in CV product, or automated vehicle product, likely have good reasons to seek common precompetitive solutions. In the case of CVs, commercial success will likely be closely related to density of equipped vehicles and connected infrastructure. In the case of automated vehicles, companies may be attracted to a constructive dialogue on legal and liability issues or system security.

Turning to mobility services, a number of start-up companies have excelled in providing consumer-oriented ride services accessed and paid for through personal devices. The success of these companies—a number of which involve sharing models like carsharing and ridesharing—has possibly started long-established automakers to move into the world of mobility services.

Recent examples from GM include a major investment in Lyft and the launch of the carsharing service Maven.

TABLE 3.3 Current Organizations Involved in CAV

Key Sectors—Categories	Examples of Key Players
Public Agencies: federal; state; regional; city	U.S. DOT; NHTSA; ITS Joint Program Office; FHWA; FCC; MDOT; New York DOT; Florida DOT; Vermont DOT; Caltrans; Texas DOT; Wyoming DOT; NYC Transportation; Tampa Hillsborough Expressway Authority; City of Ann Arbor, Michigan; city governments; managers of public facilities (such as airports)
Associations	ITS America; AASHTO; TRB; Associations for Unmanned Vehicle Systems International (AUVSI); SAE; ITE; IEEE; Shared Use Mobility Center (SUMC)
Private Industry	Google; Tesla; GM; Ford; Nissan; Delphi; Bosch; Continental; Denso; Econolite; Iteris; Qualcomm; Xerox; Cohda Wireless; Savari; Siemens; Sound Transit; car2go; Pronto; Getaround; RelayRides
Universities	University of Michigan; Virginia Tech; Texas A&M; Carnegie Mellon; University of California, Berkeley; University of Washington

Motivations for the more-established thus-more disrupted companies include long-term projections of auto sales and new auto market demographics. Increasing urban populations and influential, savvy urban dwellers are starting to request a more cooperative, shared, unobtrusive approach to urban mobility.

3.1.10 Key Efforts in Convening and Publicizing

Model deployments of CVs and infrastructure have provided significant opportunities for outreach and publicity, and that has been a key part of all the U.S. DOT-funded V2X work. These efforts have focused on professional and technical media and have reached the mass media on a regular basis, though the efforts for this work have been slow.

Nevertheless, steady progress has been made in involving institutions engaged in workforce training—covering both infrastructure and vehicles—and in broad professional awareness. For example, ITE has shown interest in professional development activities for V2X.

ITS America has played an important role in capacity building for V2X, and important training sessions and regional symposia have been held around the country. Major events such as the ITS World Congress play a critically important role in advancing CVs and infrastructure (known as cooperative systems in other countries).

In particular, the 2014 Detroit and 2015 Bordeaux ITS conferences highlighted the steady CVs progress made by industry and government. The congress format of conference, the exhibits, and demonstrations has likely facilitated advancing V2X, and, more recently, vehicle automation.

More recently, the TRB-organized 2015 EU–U.S. Symposium Towards Road Transport Automation: Opportunities in Public–Private Collaboration identified significant opportunities in research collaboration. An important issue discussed at this symposium was the potential for “twinning” of automated research and deployment projects on both sides of the Atlantic. A key feature of this symposium was the targeted invitation of certain industry, government, and research constituencies.

TRB has been collaborating with AUVSI in recent years to convene the Automated Vehicles Symposium, the premiere technical conference on automated vehicles. Important features of these conferences are highly focused and specific breakout sessions and automated vehicle demonstrations.

Demonstrations are a key part of all CAV convening activities and deployment sites. Such demonstrations are critical elements of CAV progress, as are research programs.

Shared-use mobility has moved into the national discourse in response to the tensions between traditional taxi services and ride-sourcing companies. However, shared-use services have proved to be extremely popular in many cities, and jurisdictions are working to address many of the issues that have been raised.

One TNC recently announced its intention to foster driverless technology, generating concerns about the imminent loss of professional driving jobs in personal transportation, as well as freight transportation.

SUMC plays an active role in convening public- and private-sector leaders, conducting research and helping cities to scale shared mobility systems. SUMC serves to connect the bikesharing, carsharing and ridesharing industries with cities and regions.

3.1.11 Adjacent Technologies and Interconnected Matters

Automated vehicles have a powerful affinity with shared-use services: the inherent efficiency and low cost of shared use is multiplied when driverless vehicles are included.

If CAVs are viewed as a long-term broad scale mobility solution—including shared mobility services—the potential impact of the following mega-trends should be considered:

- Smart cities,
- IoT, and
- Big data.

Further analysis will be needed to understand these interactions. Some assumptions proposed in this paper are:

- Smart cities potentially provide deployment opportunities for CAV;
- CAV could be viewed as representing one sizable aspect of the IoT; and
- CAV represents a rich source of big data.

REFERENCES

1. Connected Vehicle Technology. ITS Joint Program Office, U.S. Department of Transportation. http://www.its.dot.gov/connected_vehicle/connected_vehicle_tech.htm.
2. Overview of Dedicated Short-Range Communications Technology. ITS Joint Program Office, U.S. Department of Transportation. <http://www.its.dot.gov/DSRC/>.
3. Preliminary Statement of Policy Concerning Automated Vehicles. NHTSA, U.S. Department of Transportation. [file:///Users/sweatman/Downloads/Automated_Vehicles_Policy%20\(1\).pdf](file:///Users/sweatman/Downloads/Automated_Vehicles_Policy%20(1).pdf).
4. Vehicle Platooning. www.tech-faq.com/vehicle-platooning.html.
5. Wikipedia definition of autonomous. https://en.wikipedia.org/wiki/Autonomous_car.
6. NHTSA Reviewing ADAS Technology for New Car Assessment Guidelines. C3 Report. <http://www.cthreereport.com/nhtsa-reviewing-adas-technologies-for-new-car-assessment-guidelines/>.
7. DSRC Implementation Guide. SAE International. www.sae.org/.../dsrc/DSRCImplementationGuide.pdf.
8. O’Rielly and Rosenworcel. Steering into the Future with More WiFi by Sharing the Upper 5 GHz Band. FCC Blog. <https://www.fcc.gov/blog/steering-future-more-wi-fi-sharing-upper-5-ghz-band>.
9. U.S. Department of Transportation Issues Advance Notice of Proposed Rulemaking to Begin Implementation of Vehicle-to-Vehicle Communications Technology. NHTSA, U.S. Department of Transportation. <http://www.nhtsa.gov/About+NHTSA/Press+Releases/NHTSA-issues-advanced-notice-of-proposed-rulemaking-on-V2V-communications>.
10. Connected Vehicle Safety Pilot. ITS Joint Program Office, U.S. Department of Transportation. http://www.its.dot.gov/safety_pilot/.
11. CAV Pilot Deployment Program. ITS Joint Program Office, U.S. Department of Transportation. www.its.dot.gov/safety_pilot/.
12. CityMobil2. Cities Demonstrating Automated Road Passenger Transport. <http://www.citymobil2.eu/en/>.
13. Martin, E. W. Automation in Freight and Goods Movement in Trucking. TRB Automated Vehicles Symposium 2014. http://www.its.ucdavis.edu/files/freight_goods_21.pdf.
14. Shared-Use Mobility Center. <http://sharedusemobilitycenter.org/>.

15. Mobility Transformation Center, University of Michigan. <http://www.mtc.umich.edu/>.
16. There Are More Than 40,000 Uber Drivers Working in NYC. *New York Post*.
<http://nypost.com/2015/10/07/there-are-more-than-30000-uber-drivers-working-in-nyc/>.

3.2 UNMANNED AERIAL SYSTEMS

3.2.1 Introduction

Historically, unmanned aircraft (UA) have been known by many names including “drones,” “remotely piloted vehicles,” “unmanned aerial vehicles (UAV),” “models,” and “radio control aircraft”(1). Today, the term UAS is used to emphasize the fact that separate system components are required to support airborne operations without a pilot onboard the aircraft. In the past two decades, the number of UA operations has been increasing dramatically, highlighting the need for a structured approach for safe and efficient integration.

Since the early 1990s, UAS have operated on a limited basis in the NAS. Until recently, UAS mainly supported public operations, such as military and border security operations. The list of potential uses is now rapidly expanding to encompass a broad range of other activities, including aerial photography, surveying land and crops, communications and broadcast, monitoring forest fires and environmental conditions, and protecting critical infrastructures.

Following is an excerpt from a presentation, “Embracing new thinking,” by Michael Huerta, FAA Administrator, at the Aero Club in Washington, D.C., on October 21, 2015:

From the beginnings of aviation in America, the Aero Club has been the place where we have marked great milestones in aviation and aerospace. This forum has played host to people responsible for amazing accomplishments: Wilbur Wright, Charles Lindbergh, Amelia Earhart, Neil Armstrong, to name just a few.

These pioneers gave us firsthand accounts of the evolution of aviation—from the advent of controlled flight, to the first solo flight from New York to Paris, to the first steps on the moon. At each step they applied the highest scientific principles of their time, added in heaping doses of imagination and courage, and took the human race to places it had never been before.

Perhaps one of the greatest evolutions in our thinking is occurring today. After 112 years of focusing on carrying humans safely aloft, we face a different kind of challenge. It has become apparent to all of us that we are at the dawn of a time when unmanned aircraft are playing a growing role in world aviation.

Somebody called the birth of the unmanned aircraft industry the Wright Brothers moment of our time. Maybe so. Maybe not.

But, there’s no question that innovation in this new segment is taking place at the speed of imagination.

Let me give you a small peek at the next few months. Major retailers such as Walmart have indicated that they plan to sell unmanned aircraft in their retail stores this holiday season. And it’s not just retail stores. Just last week, in addition to the usual booths hawking amazing floor cleaners and knives that can cut through tin cans, a vendor at the Texas State Fair in Dallas was selling drones of varying sizes. And a major computer supplier is offering a free drone if you buy a new computer—as long as you act before November 2.

By some estimates, 700,000 new unmanned aircraft could be in the homes of consumers by the end of the year. Think about it: by the end of the holiday season, drones could far outnumber manned aircraft operating in the nation's airspace.

These new aircraft are bringing an entirely new type of users into the airspace—most with little or no experience with our regulations.

Many of them don't even consider themselves to be pilots. Yet hundreds of times over the last year, unmanned aircraft have come uncomfortably close to manned aircraft, at altitudes of thousands of feet—well above the 400 feet or so that our current rules spell out.

Groups such as AUVSI, the Academy of Model Aeronautics, and the Small UAV Coalition share a common goal with the FAA. We all want to safely integrate unmanned aircraft. We've seen proposed uses ranging from the headline grabbers such as Amazon's desire to use them to someday drop a package at your door, to ones that can be used to safely conduct dangerous tasks that are now done by manned aircraft.

Someday, maybe we will look back and say this truly was our Wright Brothers moment. If we do our job correctly, we will marvel at how far we have come in such a short time.

We are in a fundamentally different place in aviation than even a couple of years ago. And we know that this pace is only going to accelerate. This is both challenging and exciting.

UASs provide new ways for commercial enterprises (civil operations) and public operators to enhance some of our nation's aviation operations through increased operational efficiency and decreased costs, while maintaining the safety of the NAS.

FAA in *Destination 2025* (2011) stated: "The Federal Aviation Administration's mission is to provide the safest, most efficient aviation system in the world. What sets the United States apart is the size and complexity of our infrastructure, the diversity of our user groups, our commitment to safety and excellence, and a history of innovation and leadership in the world's aviation community. "FAA is working to develop new systems and to enhance a culture that increases the safety, reliability, efficiency, capacity, and environmental performance of our aviation system."

The FAA created the Unmanned Aircraft Systems Integration Office to facilitate integration of UAS safely and efficiently into the NAS. Toward that goal, the FAA is collaborating with a broad spectrum of stakeholders, which includes manufacturers, commercial vendors, industry trade associations, technical standards organizations, academic institutions, research and development centers, governmental agencies, and other regulators.

"Ultimately, UAS must be integrated into the NAS without reducing existing capacity, decreasing safety, negatively impacting current operators, or increasing the risk to airspace users or persons and property on the ground any more than the integration of comparable new and novel technologies. Significant progress has been made toward UAS-NAS integration, with many challenges and opportunities ahead."

A key activity of the FAA is to develop regulations, policy, procedures, guidance material, and training requirements to support safe and efficient UAS operations in the NAS, while coordinating with relevant departments and agencies to address related key policy areas of concern such as privacy and national security. Today, UAS are typically given access to airspace through the issuance of Certificates of Waiver or Authorization (COA) to public operators and special airworthiness certificates in the experimental category for civil applicants.

The FAA is responsible for developing plans and policy for the safe and efficient use of the United States' navigable airspace. This responsibility includes coordinating efforts with

national security and privacy policies so that the integration of UAS into the NAS is done in a manner that supports and maintains the U.S. government's ability to secure the airspace and addresses privacy concerns. Further, the FAA will harmonize, when appropriate, with the international community for the mutual development of civil aviation in a safe and orderly manner.

The International Civil Aviation Organization (ICAO), a special agency of the United Nations, promotes "the safe and orderly development of international civil aviation throughout the world. It sets standards and regulations necessary for aviation safety, security, efficiency, and regularity, as well as aviation environmental protection." The goal of ICAO in addressing unmanned aviation is to provide the fundamental international regulatory framework to support routine operation of UAS throughout the world in a safe, harmonized, and seamless manner comparable to that of manned operations (3). Current ICAO guidance material for UAS provides basic guidelines for member states to introduce and integrate UAS into airspace in a consistent manner, to ensure global interoperability and regulatory compatibility when possible.

Integration will lead us from today's need for accommodation of UASs through individual approvals to a time when standardized or routine integration into the NextGen environment is well defined (4). Six high-level strategic goals were developed to reflect the principal objective of safe UAS integration into the NAS. These goals were derived from existing goals provided by the partner agencies and should therefore resonate with the wide range of UAS stakeholders. The overarching approach for the goals is to allow public integration to lay the framework for civil integration.

The first two goals apply to small UAS (under 55 lb) within visual line of-sight, assuming the public realm would be accomplished first and the civil aviation sector would follow; the third and fourth goals apply to the other UAS, with the same process: public would occur first and civil would follow. The fifth goal was established to plan and manage growing automation capabilities through research and the sixth goal provides the opportunity for the United States to remain international leaders. The sum of these goals shows a phased-in approach for UAS integration in the NAS.

In addition, the above goals support the engineering process of incorporating UAS-specific changes into the NextGen Implementation Plan. Understanding and prioritizing the R&D needs associated with each of the UAS national goals is key to achieving robust integration of UAS in the NAS. The need for new capabilities, mitigations, and verification and validation methods to enable safe and secure operations will require the development, integration, and implementation of emerging and new technologies. Each agency presents varying needs and possesses a significant body of expertise resulting from historical investments in UAS operations.

The two additional activities that are critical to the integration of UAS include the small UAS Rule and the test range program are as follows:

- The FAA announced a Notice of Proposed Rulemaking (NPRM) that is intended to lead to requirements and parameters for how small UAS will be integrated into the NAS. The 60-day public comment period for the small UAS NPRM closed on April 24, 2015. The final rule is planned to be issued by spring 2016.
- In October 2015, the U.S. DOT announced that they are going to require UAs to be registered, in much the same way as larger manned aircraft have been for decades.

3.2.2. Technologies and Application

“No ROADS? There is a DRONE for that!” —Matternet, a California-based start-up that is seed-funded by investors such as Andreessen Horowitz, with previous interests in Skype and Groupon (<https://mtr.net/company>).

“1 billion people don’t have access to all season roads. 85% of the roads in sub-Saharan Africa are not usable in wet seasons”—CEO Andreas Raptopoulos on a TED talk (https://www.ted.com/talks/andreas_raptopoulos_no_roads_there_s_a_drone_for_that?language=en).

A UAS (Figure 3.1) is the UA and all of the associated support equipment, control station, data links, telemetry, communications, and navigation equipment that is necessary to operate the UA.

The UA is the flying portion of the system, flown by a pilot via a ground control system, or autonomously through use of an onboard computer, communication links, and additional equipment that is necessary for the UA to operate safely. The FAA issues an experimental airworthiness certificate for the entire system, not just the flying portion of the system.

UAVs have most often been associated with the military, but they are also used for search and rescue, surveillance, traffic monitoring, weather monitoring, journalism, and firefighting, among other things.

In late 2012, Chris Anderson, Editor-In-Chief of *Wired* magazine, retired to dedicate himself to his personal drones company, 3-D Robotics. Personal drones are currently a hobbyist’s item most often used for aerial photography, but the market and potential applications are both expected to expand.

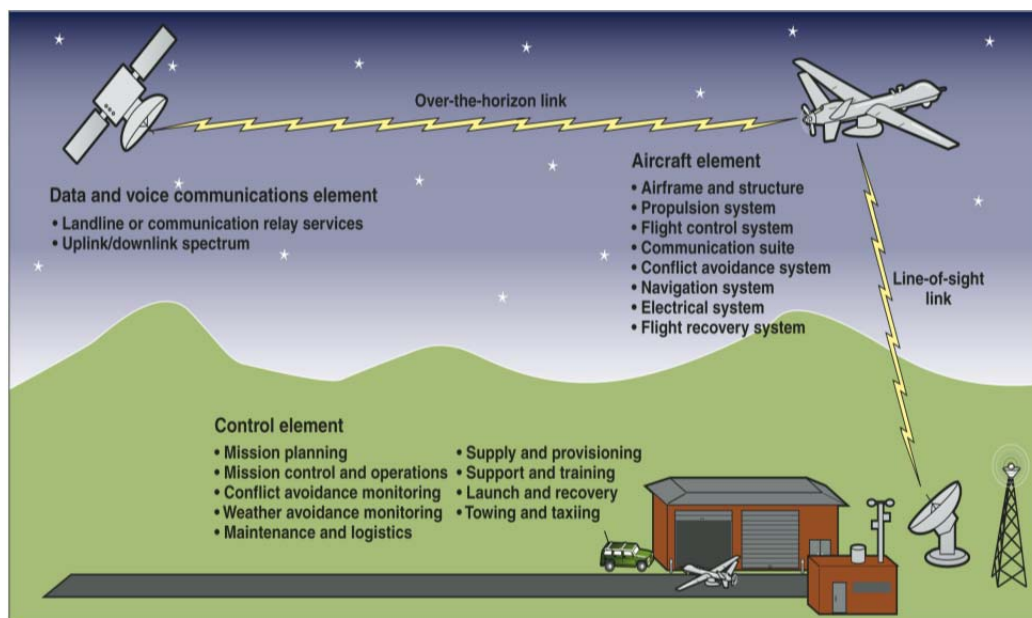


FIGURE 3.1 Conceptual rendering of UAS.
(Source: GAO and NASA, GAO-15-486T.)

The use of UAS in commercial applications (5) is expected to expand in a number of areas. Some of the currently proposed civil and commercial applications of UAS include the following:

- Security awareness;
- Disaster response, including search and support to rescuers;
- Communications and broadcast, including news–sporting event coverage;
- Cargo transportation;
- Spectral and thermal analysis;
- Critical infrastructure monitoring, including power facilities, ports, and pipelines;
- Commercial photography, aerial mapping and charting, and advertising (Figure 3.2); and
- Farming, such as selective pesticides spray, and crop monitoring.

While many of the above applications are already common today, the use cases for logistics are still in their early stages (16) and are best viewed as visionary.

Electrical multicopters (characterized by vertical take-off and landing) may be promising for the logistics industry. Here are a few examples:

- Urban “First and Last Mile.” UAS could provide relief for urban areas, reducing congestion. Currently payloads are limited but a network of UAS could support first- and last-mile logistics networks. Some airborne first- and last-mile network examples are as follows:
 - Shipments that arrive from outside the city limits are sorted at existing facilities (hubs, warehouses, crossdocking sites), and shipments meeting certain criteria are separated automatically. In addition to size, weight, and time criticality, these criteria could also include dynamic metrics (e.g., current road conditions, air pollution, and network load). Each UAS automatically picks up assigned shipment(s) from a conveyer



FIGURE 3.2 UAV with an off-the-shelf camera attached. (Source: Fast Company.)

belt and takes off. On its way back to the hub, the UAS could carry out point-to-point deliveries that lie on its route.

- Despite its tangible impact in the logistics industry, this example has privacy and safety concerns particularly in the densely populated urban environment. And it is the most challenging in terms of regulatory framework conditions and infrastructure, especially integration into existing urban infrastructures.
- Rural delivery. The potential of UAS technology may also be seen in rural locations that lack sufficient infrastructure or that have challenging geographic conditions. For the logistics industry, rural delivery by UAS can be attractive not only in emergency applications because low-volume remote locations could be a costly part of standard networks.
 - BBC, November 2, 2015, <http://www.bbc.com/news/technology-34704868>;
 - Search giant Google has announced a date for the launch of its drone delivery service. Called Project Wing, the initiative aims to be delivering goods to consumers using the robot aircraft sometime in 2017. The announcement came from David Vos, the project leader for the delivery service.
 - Online retailers such as Amazon, Alibaba and others are also experimenting with drone delivery.
- Surveillance of infrastructure. UAVs can help with security and safety surveillance in large-scale facilities such as warehouse sites, yards, docks and even pipelines. They can also help to guide various operations (e.g., the movement of trucks and forklifts on site).

A promising application is using UAVs to provide customers with a value-added service like on oil fields. One oil company has used UAVs to patrol their Alaskan oil fields, which is the first authorized commercial UAV operation in the United States. In the future, these UAVs will be used to monitor specific maintenance activities on roads, oil pipelines, and other infrastructure in the vast arctic environment of northern Alaska.

According to DHL trends research (16), the two most promising uses in the logistics industry regarding business potential are

 - Urgent express shipments in crowded megacities, improving the delivery speed, network flexibility, and potentially the environmental impact; and
 - Rural deliveries in areas that lack adequate infrastructure (e.g., in Africa), enabling people in remote locations to be connected to global trade networks.

3.2.2.1 Technological Challenges

Current UAS technologies were not developed to comply with existing airworthiness standards (1). Current civil airworthiness regulations may not consider many of the unique aspects of UAS operations. Materials properties, structural design standards, system reliability standards, and other minimum performance requirements for basic UAS design need to be evaluated against civil airworthiness standards for existing aircraft. Although significant technological advances have been made by the UAS community, research would greatly aid in fully understanding the impact of UAS operations in the NAS.

There has also been little research to support the equipment design necessary for UAS airworthiness certification. In the near- to mid-term, UAS research would be most helpful if it focuses on technology for UAS access to the NAS. As UAS are introduced, their expected range of performance will need to be evaluated for impact on the NAS. UAS operate with widely varying performance characteristics that do not necessarily align with manned aircraft

performance. They vary in size, speed, and other flight capabilities. Similarly, the issue of performance gap between the pilot and the avionics will likely impact NAS operations.

Existing standards ensure safe operation via pilots on board the aircraft. These standards may not translate well to UAS designs where pilots are remotely located. Removing the pilot from the aircraft creates a series of performance considerations between manned aircraft and UAs that would benefit from research to determine acceptability and potential impact on safe operations in the NAS. Examples of considerations are as follows:

- The UAS pilot is not onboard the aircraft and does not have the same sensory and environmental cues as a manned aircraft pilot;
- The UAS pilot does not have the ability to directly comply with see-and-avoid responsibilities and UAS systems do not meet current operational rules;
- UAS cannot comply with certain air traffic control (ATC) clearances and alternate means may need to be considered (e.g., use of visual clearances); and
- UAS present air traffic controllers with a different range of platform sizes and operational capabilities (such as size, speed, altitude, wake turbulence criteria, and combinations thereof).

The safe integration of UA into the NAS is a significant challenge. The FAA is dedicated to developing the technical and regulatory standards, policy guidance, and operational procedures on which successful UAS integration depends.

The application of financial and human resources by academia and industry to support critical FAA initiatives may shorten the time required to develop technical and regulatory standards. Together, all stakeholders can overcome the challenge of integrating UAS into the NAS and leverage UAS and associated technologies for the greater benefit of society.

3.2.2.2 Center of Excellence

FAA selected a Mississippi State University team as the FAA's Center of Excellence (COE) (8) for UAS. The COE team will focus on research, education, and training in areas critical to safe and successful integration of UAS into the nation's airspace.

The team brings together 15 of the nation's leading UAS and aviation universities that have a proven commitment to UAS research and development and the necessary resources to provide the matching contribution to the government's investment.

The COE research areas are expected to evolve over time, but initially will include detect and avoid technology; low-altitude operations safety; control and communications; spectrum management; human factors; compatibility with ATC operations; and training and certification of UAS pilots and other crew members.

The FAA expects the COE to be fully operational and engaged in its research agenda by January 2016. Congress appropriated \$5 million for the 5-year agreement with the COE, which will be matched one-for-one by the team members.

3.2.3 Key Activities and Entities

FAA is taking the leadership role in United States, preparing a “roadmap”(1) to illustrate the significant undertaking it is to build the basis for the NAS to transition from UAS accommodation to UAS integration.

UASs and operations have increased in number, technical complexity, and sophistication during recent years without the same oversight as manned aviation. Unlike the manned aircraft industry, the UAS community does not have a set of standardized design specifications for basic UAS design that ensures safe and reliable operation in typical civilian service applications. As a result, the UAS community often finds it difficult to apply existing FAA guidance. In some cases, interpretation of regulations or standards may be helpful to address characteristics unique to UAS. Ultimately, the pace of integration will likely be affected by the ability of industry, the user community, and the FAA to overcome technical, regulatory, and operational challenges.

The purpose of FAA’s roadmap is to outline, within a broad timeline, the tasks and considerations needed to enable UAS integration into the NAS for the planning purposes of the broader UAS community. Government and industry stakeholders would likely benefit from working collaboratively and allocating the necessary resources for this transition while supporting evolving UAS operations in the NAS. The roadmap is organized into three perspectives that highlight the multiple paths used to achieve the milestones outlined, while focusing on progressive accomplishments. These three perspectives—accommodation, integration, and evolution—transcend specific timelines and examine the complex relationship of activities necessary to integrate UAS into the NAS.

Results through Collaboration in Aviation (RTCA), is a private, not-for-profit corporation (6) that develops consensus-based recommendations regarding communications, navigation, surveillance, and air traffic management system issues. RTCA functions as a Federal Advisory Committee, and the FAA considers RTCA recommendations when making policy, program, and regulatory decisions. RTCA Special Committee 203 was established in 2004 to help assure the safe, efficient, and compatible operation of UAS with other aircraft operating within the NAS. This special committee has developed and documented guiding principles for UAS integration, which are summarized below:

- UAS must operate safely, efficiently, and compatibly with service providers and other users of the NAS so that overall safety is not degraded.
- UAS will have access to the NAS provided they have appropriate equipage and the ability to meet the requirements for flying in various classes of airspace.
- Routine UAS operations will not require the creation of new special-use airspace, or modification of existing special-use airspace.
- Except for some special cases, such as small UAS with very limited operational range, all UAS will require design and airworthiness certification to fly civil operations in the NAS.
- UAS pilots will require certification, though some of the requirements may differ from manned aviation.
- UAS will comply with ATC instructions, clearances, and procedures when receiving air traffic services.
- UAS pilots (the pilot in command) will always have responsibility for the unmanned aircraft while it is operating.

- UAS commercial operations will need to apply the operational control concept as appropriate for the type of operation, but with different functions applicable to UAS operations. Through an FAA-established UAS Aviation Rulemaking Committee, the FAA continues to collaborate with government and industry stakeholders for recommendations regarding the path toward integration of UAS into the NAS. This effort will harmonize with the work being done by international organizations working toward a universal goal of safe and efficient UAS airspace operations.

Table 3.4 illustrates the landscape of key players in UAS.

3.2.4 Privacy and Civil Liberties Considerations

The FAA’s chief mission is to ensure the safety and efficiency of the entire aviation system. This includes manned and UA operations. While the expanded use of UAS presents great opportunities, it also raises questions as to how to accomplish UAS integration in a manner that is consistent with privacy and civil liberties considerations. As required by the Federal Modernization and Reform Act (FMRA), the FAA is implementing a UAS test site program (7) to help the FAA gain a better understanding of operational issues relating to UAS. Although the FAA’s mission does not include developing or enforcing policies pertaining to privacy or civil liberties, experience with the UAS test sites will present an opportunity to explore these issues for UAVs.

TABLE 3.4 Current Organizations Involved in UAS

Key Sectors–Categories	Examples of Key Players
Public agencies: federal, state, local	FAA; U.S. Department of Defense; FHWA; State of Nevada; New York Griffiss International Airport; North Dakota Department of Commerce
Associations	Academy of Model Aeronautics; Aerospace Industries Association; Air Line Pilots Association; Aircraft Owners and Pilots Association; American Association of Airport Executives; Association of Unmanned Vehicle Systems International; Consumer Electronics Association; General Aviation Manufacturers Association; Helicopter Association International; Management Association for Private Photogrammetric Surveyors; National Association of State Aviation Officials; National Business Aviation Association; Small UAV Coalition
Private industry	3-D Robotics; Amazon Prime Air; Amazon Retail; Best Buy; Google X; GoPro; Parrot; PrecisionHawk; BNSF Railroad; Walmart; CNN; Matternet; CACI
Universities	University of Alaska; Texas A&M University– Corpus Christi; Virginia Polytechnic Institute and State University; Mississippi State; Drexel University; Embry Riddle Aeronautical University; Kansas State University; Kansas University; Montana State University; New Mexico State University; North Carolina State University; Oregon State University; University of Alabama, Huntsville; University of North Dakota; Wichita State University
Disruptors–emerging key players–influencers	3-D Robotics; Google; Amazon; Matternet

In selecting the six test site operators, the FAA considered geography, climate, and location of ground infrastructure, research needs, airspace use, safety, aviation experience and risk. In totality, these six test applications achieve cross-country geographic and climatic diversity and help the FAA meet its UAS research needs. The following sites were selected:

- University of Alaska (including test ranges in Hawaii, Oregon, Kansas, and Tennessee);
- State of Nevada;
- New York’s Griffiss International Airport (includes test range locations in Massachusetts and Michigan);
- North Dakota Department of Commerce (two broad area COAs were approved for the North Dakota Department of Commerce);
- Texas A&M University–Corpus Christi;
- Virginia Polytechnic Institute and State University (includes test ranges in New Jersey and Maryland);
- Government Accountability Office (GAO) findings (17).

Since becoming operational in 2014, the FAA’s UAS test sites have conducted over 195 flights across five of the six test sites. These flights provide operational and safety data that FAA can use in support of integrating UAS into the NAS. FAA has not provided funding to the test sites for research and development activities but has provided staff time.

GAO noted that other countries have progressed toward UAS integration and allow commercial use. GAO studied the UAS regulations in Australia, Canada, France, and the United Kingdom and found these countries have similar rules and restrictions on commercial UAS operations, such as allowing line of sight operations only. In November 2014, Canada issued new rules creating exemptions for UAS operations based on size and relative risk. As of December 2014, Australia had issued over 180 UAS operating certificates to businesses engaged in aerial surveying, photography, and other lines of business. Under the provisions of FAA’s proposed rules, operating restrictions would be similar to regulations in these other four countries. For example, all countries have UAS altitude restrictions of 500 ft or below.

3.2.5 National Security Issues

Potential national security issues are summarized in the report *Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap* (U.S. DOT, FAA, First Edition, 2013; http://www.faa.gov/uas/media/uas_roadmap_2013.pdf):

Integrating public and civil UAS into the NAS carries certain national security implications, including security vetting for certification and training of UAS-related personnel, addressing cyber and communications vulnerabilities, and maintaining/enhancing air defense and air domain awareness capabilities in an increasingly complex and crowded airspace. In some cases, existing security frameworks applied to manned aircraft may be applicable. Other security concerns may require development of new frameworks altogether. The FAA will continue to work with relevant United States Government departments and agencies, and with stakeholders through various coordinating bodies to proactively address these areas of concern. (1)

3.2.6 Business Opportunities

According to a study by AUVSI, the drone or UAV, industry in the United States could produce up to 100,000 new jobs and add \$82 billion in economic activity between 2015 and 2025.

Privacy concerns represent a significant barrier.

3.2.6.1 Section 333

By law, any aircraft operation in the NAS requires a certified and registered aircraft, a licensed pilot, and operational approval. Section 333 of the FMRA grants the Secretary of Transportation the authority to determine whether an airworthiness certificate is required for a UAS to operate safely in the NAS (2).

This authority is being leveraged to grant case-by-case authorization for certain UA to perform commercial operations prior to the finalization of the Small UAS Rule, which will be the primary method for authorizing small UAS operations once it is complete.

The Section 333 exemption process provides operators who wish to pursue safe and legal entry into the NAS a competitive advantage in the UAS marketplace, thus discouraging illegal operations and improving safety. It is anticipated that this activity will result in significant economic benefits, and the FAA administrator has identified this as a high-priority project to address demand for civil operation of UAS for commercial purposes. As of November 2, 2015, there were 2,134 petitions granted and 399 petitions were closed.

3.2.6.2 Pathfinders

On May 6, 2015, the FAA announced the UAS Focus Area Pathfinders initiative, a partnership with industry to explore the next steps in UA operations beyond the type of operations the agency proposed in the draft Small UAS rule it published in February 2015 (9).

Three companies reached out to the FAA to work on research to continue expanding use of UAS in the nation's airspace in three key areas:

- Visual line-of-sight operations in urban areas. CNN will look at how UAS might be safely used for news gathering in populated areas.
- Extended visual line-of-sight operations in rural areas. PrecisionHawk will explore how UAS flights outside the pilot's direct vision might allow greater UAS use for crop monitoring in precision agriculture operations.
- Beyond visual line-of-sight in rural or isolated areas. BNSF Railroad will explore command-and-control challenges of using UAS to inspect rail system infrastructure.

On October 7, 2015, FAA entered into a Pathfinder agreement (10) with CACI International, Inc., to evaluate how the company's technology can help detect UAS in the vicinity of airports.

In testimony before the House Aviation Subcommittee on October 7, 2015, FAA Deputy Administrator Mike Whitaker said "flying an unmanned aircraft near a busy airfield poses an unacceptable safety hazard." During the hearing titled, Ensuring Aviation Safety in the Era of Unmanned Aircraft Systems, Whitaker told the congressional panel the FAA signed an agreement on October 4–10, 2015, to assess the safety and security capabilities of CACI's

product within a 5-mi radius of airports, and the agency also will collaborate with its government partners.

CACI's prototype UAS sensor detection system will be evaluated at airports selected by the FAA. The agency and its federal government partners will work with the company to evaluate the effectiveness of the technology, while also ensuring that it does not interfere with the safety and security of normal airport operations.

3.2.7 Media Coverage and Attention

Media coverage and attention has been significant and is growing. Here are a few examples:

- September 21, 2015 (11): "Working with the Federal Aviation Administration, the National Football League's San Francisco 49ers are tackling the issue of unmanned aircraft safety."

The team recently became the first professional sports franchise to record a video reminding fans—and everyone else—to abide by the laws covering personal drone use.

The video, which will be featured on the 49ers' Levi's Stadium scoreboard once during each home game, features defensive safety Eric Reid asking people to fly their UAs safely. Reid stresses no one should ever fly over stadiums, over people, or near airplanes and airports. He makes a special plea never to fly drones near wildfires—a serious issue in drought-stricken California.

The video also refers viewers to the knowbeforeyoufly.org website for further information and guidance on flying UA safely and responsibly. The FAA has partnered with leading UA industry and hobbyist groups in the Know Before You Fly education campaign, and the campaign materials are now featured in product packaging for several types of UAS."

- October 13, 2015 (12): "A review of FAA data shows the skies over Los Angeles are a hot spot for reports of drones flying in airspace reserved for aircraft. For LAPD Officer James Schwedler and pilot Kevin Cook, a drone strike could be catastrophic."

- October 23, 2015 (13): The five facts explain the rise of the drones. "The October 15, 2015 release of the so-called Drone Papers, leaked reports that appear to document the U.S. use of drone aircraft for military purposes, has given the world a close look yet at the inner workings of modern drone warfare. But as the five facts in the paper explain, the weaponization of drones is no longer just an American phenomenon."

- November 5, 2015 (14): The Future of Drones: Uncertain, promising and pretty awesome. "When filmmaker George Lucas popularized droids—worker robots designed to tend to humanity's every need—in the 1977 movie 'Star Wars: Episode IV—A New Hope,' he may have seemed like a science fiction visionary. But nearly 40 years later, flying surveillance cameras, robotic companions, and unmanned aircraft carrying supplies is becoming mainstream."

- November 5, 2015 (15): The Minnesota DOT's plan to use drones for bridge inspections. "The Minnesota DOT took another step forward with testing on the state's largest bridge in Duluth. A \$40,000 drone equipped with GPS took off from the John A. Blatnik Bridge as MnDOT conducts Phase 2 of inspections. Instead of closing down roads and sending an inspector up into an \$800,000 snoop machine, the drone is able to reach spots where an inspector cannot."

Bridge inspection officials say there are a few things that need to be done before launching the drone. “We have to do an inspection safety plan for any location that we’re going to use a drone on. We also have to have an aircraft as we call it that’s registered and insured through our aeronautics office. They have to be completely involved with whatever we’re doing,” says Jennifer Zink, MnDOT’s Bridge Inspection Engineer.

Inspections on Blatnik Bridge can take 2 to 3 weeks, but with a drone MnDOT officials say it can reduce inspection time by 30%. If the tests are effective, Minnesota could become the first state to use drones to help inspect the state’s nearly 25,000 bridges.”

REFERENCES

1. Integration of Civil Unmanned Aircraft Systems in the National Airspace System Roadmap. FAA, U.S. Department of Transportation, FAA, First Edition, 2013. http://www.faa.gov/uas/media/uas_roadmap_2013.pdf.
2. FAA Modernization and Reform Act of 2012. Public Law 112-95, 112th Congress, February 14, 2012. <http://www.gpo.gov/fdsys/pkg/CRPT-112hrpt381/pdf/CRPT-112hrpt381.pdf> and http://www.faa.gov/uas/legislative_programs/section_333/.
3. Unmanned Aircraft Systems, Circular 328, AN/190 ICAO, International Civil Aviation Organization, 2011. http://www.icao.int/Meetings/UAS/Documents/Circular%20328_en.pdf.
4. Federal Aviation Administration. The NextGen Experience. <https://www.faa.gov/nextgen/experience/>.
5. Operational Services and Environment Definition for Unmanned Aircraft Systems. RTCA DO-320, 2010.
6. Results Through Collaboration in Aviation. Annual Report, 2014. http://www.rtca.org/files/RTCA%202014%20Annual%20Report_FNL.pdf.
7. FAA Announces Six UAS Test Sites. http://www.faa.gov/uas/legislative_programs/test_sites/.
8. Center of Excellence. FAA legislative programs. http://www.faa.gov/uas/legislative_programs/coe/.
9. Focus Area—Pathfinders, FAA initiative. http://www.faa.gov/uas/legislative_programs/pathfinders/.
10. FAA Expands Unmanned Aircraft Pathfinder Efforts. FAA News. <http://www.faa.gov/news/updates/?newsId=83927>.
11. San Francisco 49ers Tackle Drone Safety. <http://www.faa.gov/news/updates/?newsId=83785>.
12. CBS News by Kris Van Cleave. October 13, 2015. <http://www.cbsnews.com/news/lapd-drones-can-totally-sneak-up-on-our-helicopters/>.
13. Bremmer, I. *Time World*, October 23, 2015. <http://time.com/4084191/these-5-facts-explain-the-rise-of-the-drone/>.
14. Gent, E. *Live Science*. November 5, 2015. <http://www.livescience.com/52701-future-of-drones-uncertain-but-promising.html>.
15. CBS Minnesota, November 5, 2015. <http://minnesota.cbslocal.com/2015/11/05/mndot-uses-drone-to-inspect-duluths-blatnik-bridge/>.
16. Unmanned Aerial Vehicles in Logistics. DHL Customer Solutions and Innovation, Markus Kuchelhaus, and DHL Trend Research, 2014.
17. United States Government Accountability Office. Testimony Before the Subcommittee on Aviation, Operations, Safety, and Security, Committee on Commerce, Science, and Transportation, U.S. Senate March 24, 2015.

3.3 INTERNET OF THINGS

3.3.1 Introduction

The IoT (*I*) is the network of physical objects or “things” embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data. The IoT allows objects to be sensed and controlled remotely across existing network infrastructure, creating opportunities for more-direct integration between the physical world and computer-based systems, and resulting in improved efficiency, accuracy, and economic benefit. Each thing is uniquely identifiable through its embedded computing system, but is able to interoperate within the existing Internet infrastructure. Experts estimate that the IoT will consist of almost 50 billion objects by 2020.

“I think the Internet of Things is the next driver of tech growth,” said LogMeIn president Bill Wagner. “It’s a trillion-plus-dollar market opportunity (2).”

British entrepreneur Kevin Ashton first coined the term in 1999 while working at the Auto-ID Labs [originally called Auto-ID centers, referring to a global network of radio-frequency identification (RFID)-connected objects]. Typically, IoT is expected to offer advanced connectivity of devices, systems, and services that goes beyond M2M and covers a variety of protocols, domains, and applications. The interconnection of these embedded devices (including smart objects), is expected to usher in automation in nearly all fields, while also enabling advanced applications like a Smart Grid, and expanding to the areas such as smart cities.

“The Internet of Things is ground zero for a new phase of global transformation powered by technology innovation, generating significant economic opportunities and reshaping industries.” —Marc Benioff, Chairman and Chief Executive Officer, Salesforce.com, USA (6).

IoT Council (3), a think-tank for the IoT stated “The Internet of Things is a vision. It is being built today. The stakeholders are known, the debate has yet to start. In hundreds of years our real needs have not changed. We want to be loved, feel safe, have fun, be relevant in work and friendship, be able to support our families and somehow play a role—however small—in the larger scheme of things. So what will really happen when things, homes and cities become smart? The result will probably be a tsunami of what at first looks like very small steps, small changes.”

The council further defines IoT as (3) “a term covering the near future situation where everything will be connected. Both everyday things, like cars, TVs and washing machines and also industrial things like pumps, shipping containers, and machinery. All these connected things combined with cloud and mobile devices, will bring on a new kind of society. A connected society.

“Imagine the world before and after the Internet. The Internet has transformed our lives through online sales channels, new products, online marketing and social media, data driven innovation, new competitors, and new efficiencies.

IoT is expected to have a similar transformative effect. It will be a profound opportunity for new business, innovation and efficiencies. It will also mean that organizations will have to adopt new technologies and transform.”

3.3.2 Technology, Trends, and Application

As of 2014, the vision of the IoT (3) had evolved due to a convergence of multiple technologies, ranging from wireless communication to the Internet and from embedded systems to micro-electromechanical systems. This means that the traditional fields of embedded systems, wireless sensor networks, control systems, automation (including home and building automation), and others all contribute to enabling the IoT. Figure 3.3 illustrates a technology roadmap for IoT.

The concept of the IoT first became popular in 1999, through the Auto-ID Center at Massachusetts Institute of Technology and related market analysis publications. RFID was seen by Kevin Ashton (one of the founders of the original Auto-ID Center) as a prerequisite for the IoT at that point. If all objects and people in daily life were equipped with identifiers, computers could manage and inventory them. Besides using RFID, the tagging of things may be achieved through such technologies as near field communication, barcodes, QR codes, and digital watermarking.

Things, in the IoT sense, can refer to a wide variety of devices such as heart monitoring implants, biochip transponders on farm animals, electric clams in coastal waters, automobiles with built-in sensors, or field operation devices that assist firefighters in search and rescue operations. These devices collect useful data with the help of various existing technologies and then automatically flow the data between other devices. Current market examples include smart thermostat systems and washer–dryers that use wi-fi for remote monitoring.

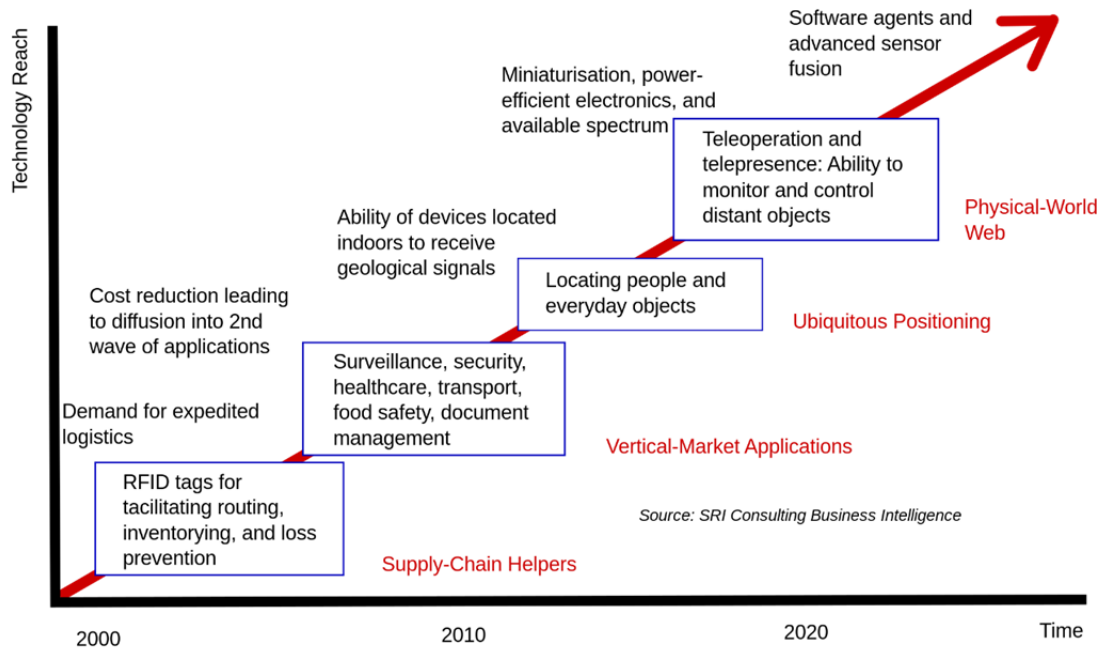


FIGURE 3.3 IoT technology roadmap.

Besides the plethora of new application areas for Internet-connected automation to expand into, IoT is also expected to generate large amounts of data from diverse locations that is aggregated very quickly, thereby increasing the need to better index, store, and process such data. **Figure 3.4** shows Cisco's projections for the growth of IoT.

Some projections are lower, but still impressive. According to Gartner, Inc. (a technology research and advisory corporation), there will be nearly 26 billion devices on the IoT by 2020. ABI Research estimates that more than 30 billion devices will be wirelessly connected to the IoT by 2020 (3). As per a recent survey by the Pew Research Internet Project, 83% of technology experts and engaged Internet users who responded agreed with the notion that the Internet–Cloud of Things, embedded and wearable computing (and the corresponding dynamic systems) will have widespread and beneficial effects by 2025. IoT will likely consist of an exceedingly large number of devices being connected to the Internet.

An overview of some of the application areas (3) is provided here. Based on the application domain, IoT products can be classified broadly into five different categories: smart wearable, smart home, smart city, smart environment, and smart enterprise. The IoT products and solutions in each of these markets have different characteristics. Later in this section Smart Cities will be described.

The IoT can assist in integration of communications, control, and information processing across various transportation systems. Application of the IoT extends to all aspects of transportation systems, i.e., the vehicle, the infrastructure, and the driver or user.

Dynamic interaction between these components of a transportation system enables inter- and intravehicular communication, smart traffic control, smart parking, electronic toll collection systems, logistic and fleet management, vehicle control, safety and road assistance.

It is said that by leveraging Enterprise Asset Intelligence, transportation and logistics can dramatically improve the following areas (4):

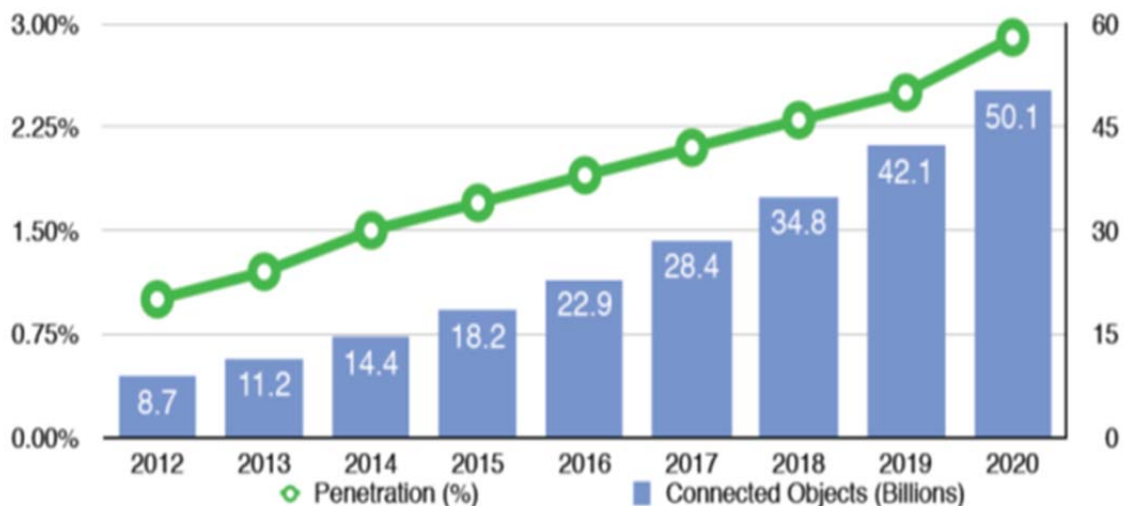


FIGURE 3.4 Cisco's projections for the IoT. (Source: Cisco.)

- **Vehicles (8).** For the automotive industry, the emergence of the rapidly evolving IoT and growth of connected car constitutes a transformative environment. According to ABI Research and practice director Dominique Bonte, this trend is characterized primarily by value chain and business model upheaval.

“The absorption of the automotive industry in the wider IoT is driven by new connected car use cases such as EVs as a mobile grid and vehicles used as delivery locations,” he explained. Furthermore, he said that “(a)s this IoT revolution unfolds, automotive innovation and value creation will be shifting to the boundaries with other verticals such as home automation, smart grids, smart cities, healthcare and retail.”

- **Growth in adoption of connected car V2X technology.** Vehicle-to-infrastructure (V2I) and vehicle-to-retail (V2R) are projected to be the dominant segments with respectively 459 and 406 million vehicles featuring smart car IoT applications by 2030, followed by vehicle-to-home (V2H) and vehicle-to-person (V2P) with 163 and 239 million vehicles respectively. Meanwhile, vehicle-to-grid (V2G) services will be offered on 50 million vehicles in 2030.

“However, in order to fully unlock the automotive IoT potential it will be critical to address a wide range of barriers including security, safety, regulation, lack of cross industry standards, widely varying industry dynamics and lifecycles and limited initial addressable market sizes,” Bonte added.

- **End-to-end visibility.** Transportation and logistics businesses around the globe are focused on maximizing supply chain efficiency in order to sustain profitability and viability. However, to reach this level of performance, they need to make end-to-end improvements. Complete visibility facilitates more effective, timely decisions and reduces delays through quicker detection of issues.

Mobile devices, such as radio frequency identification (RFID), barcode scanners and mobile computers, have become a major influence in supply chain visibility and operations.

- **Warehouse and yard management.** The management of warehouses and yards is at the core of transportation and logistics businesses. Their efficiency directly impacts the cost of doing business and the ability to compete. With IoT-enabled mobile devices designed to track inventory data, equipment and vehicles, enterprises can give their physical assets a digital voice.

By converting the physical to digital, transportation and logistics warehouses can capture and share their mission-critical data across the Cloud, ensuring they have the right products in the right place at the right time. Also, by reducing human intervention and enabling more machine-to-machine information sharing, enterprises can greatly increase efficiency and accuracy.

- **Fleet management.** When it comes to transportation and logistics, fleet management plays a critical role in managing maintenance schedules, everyday vehicle usage and service routes. In order to maximize productivity and operational efficiency, fleet downtime must be minimized. With mobile scanners, computers, and RFID systems alone, enterprises can gain visibility into their assets and better streamline operations to keep their fleet moving.

By replacing manual and hard-copy work orders with mobile devices, technicians save time and increase data accuracy. Furthermore, with real-time accurate insight into maintenance history, parts availability, and inventory records, technicians can relay information back to their central database. By leveraging connected, mobile devices, enterprises can capture, share and

manage data around their moving assets across the enterprise. Connectivity also enables enterprises to communicate with their technicians (drivers) anytime, anywhere, allowing them to be proactive with in-field repairs, maintenance, etc. With real-time updates on certain conditions such as bad weather or traffic, fleet technicians can better respond or prepare.

“From passenger security and fleet management to assembly processes and delivery times, the transportation and logistics industry needs solutions that move its people and cargo safely and efficiently.”⁽⁴⁾—From Supply Chain 24/7, Sept. 9, 2015.

- **Environmental monitoring.** Environmental monitoring applications of the IoT typically use sensors to assist in environmental protection by monitoring air or water quality, atmospheric or soil conditions, and can even include areas like monitoring the movements of wildlife and their habitats. Development of resource constrained devices connected to the Internet also means that other applications like earthquake or tsunami early-warning systems can also be used by emergency services to provide more effective aid. IoT devices in this application typically span a large geographic area and can also be mobile.
- **Infrastructure management.** Monitoring and controlling operations of urban and rural infrastructures like bridges, railway tracks, and on- and offshore wind-farms is a key application of the IoT. The IoT infrastructure can be used for monitoring any events or changes in structural conditions that can compromise safety and increase risk. It can also be used for scheduling repair and maintenance activities in an efficient manner, by coordinating tasks between different service providers and users of these facilities. IoT devices can also be used to control critical infrastructure like bridges to provide access to ships. Usage of IoT devices for monitoring and operating infrastructure is likely to improve incident management and emergency response coordination, quality of service, and reduce costs of operation in all infrastructure-related areas. Even areas such as waste management stand to benefit from automation and optimization that could be brought in by the IoT.

In addition, many other areas such as manufacturing, energy management, medical and health care management, media, building, and home automation will most likely benefit from IoT.

- **Challenges (3).** Among many challenges in IoT, some predict that the most likely issues could be what is called the “basket of remotes” problem, which involves numerous applications that must interface with numerous devices that don’t share protocols for speaking with one another. There are multiple approaches experts propose to solve this problem, one of them called the “predictive interaction” where cloud- or fog-based decision makers predict the user’s next action. Privacy, autonomy, security and control, architecture, design, and environmental and societal impacts are also among the key challenges and issues in IoT. Cybersecurity will be addressed later in this report.

3.3.3 Key Activities and Entities

3.3.3.1 Large-Scale Deployments

There are several planned or ongoing large-scale deployments of the IoT that are designed to enable better management of cities and systems (3). For example, Songdo, South Korea, a first-of-its-kind fully equipped and wired smart city, is near completion. Nearly everything in this city

is planned to be wired, connected, and turned into a constant stream of data that would be monitored and analyzed by an array of computers with little or no human intervention.

Another illustrative application is a current project in Santander, Spain. For the city's IoT deployment, two approaches have been adopted. This city of 180,000 inhabitants has already seen 18,000 city application downloads for their smartphones. This application is connected to 10,000 sensors that enable services like parking search and environmental monitoring, among others.

Other examples of large-scale deployments underway include the Sino-Singapore Guangzhou Knowledge City; work on improving air and water quality, reducing noise pollution, and increasing transportation efficiency in San Jose, California; and smart traffic management in western Singapore.

Another example of a large deployment is the one completed by New York Waterways (NYWW) in New York City to connect all their vessels and being able to monitor them live. The network was designed and engineered by Fluidmesh Networks, a Chicago-based company developing wireless networks. The NYWW network is currently providing coverage on the Hudson River, East River, and Upper New York Bay. With the wireless network in place, NYWW is able to take control of its fleet and passengers in a way that was not previously possible. New applications could include security, energy and fleet management, digital signage, public wi-fi, paperless ticketing, and others.

3.3.3.2 *The Market for Internet of Things*

The IoT market is burgeoning but fragmented (5). Early players include government and academia as well as business and industry.

According to McKinsey & Company (9) “semiconductor executives surveyed in June 2014 as part of a quarterly poll of the components-manufacturing market said the Internet of Things will be the most important source of growth for them over the next several years—more important, for example, than trends in wireless computing or big data.

“McKinsey Global Institute research supports that belief, estimating that the impact of the Internet of Things on the global economy might be as high as \$6.2 trillion by 2025. At the same time, the corporate leaders polled admit they lack a clear perspective on the concrete business opportunities in the Internet of Things given the breadth of applications being developed, the potential markets affected—consumer, healthcare, and industrial segments, among others—and the fact that the trend is still nascent.”

The global IoT market (10) is projected to grow to \$1.7 trillion in 2020 from \$655.8 billion in 2014, according to research firm IDC, as more devices come online and a bevy of platforms and services grow up around them.

The firm predicts that the number of “IoT endpoints” connected devices such as cars, refrigerators, and everything in between will grow from \$10.3 billion in 2014 to more than \$29.5 billion in 2020.

Devices, connectivity and IT services are expected to account for the majority of the global IoT market in 2020, with devices alone accounting for 31.8% of the total. Purpose-built platforms, storage, security, application software and “as a service” offerings are expected to capture a greater percentage of revenue as the market matures.

The Asia Pacific region captured around 58.3% of the revenue from IoT in 2014 and will shrink slightly to 51.2% in 2020. North America is expected to maintain revenue share of just

more than 26% over the forecast period, while the share in Western Europe is expected to jump from 12% to about 19.5%.

As the IoT ecosystem (*10*) continues to grow, companies increasingly will look to platforms and services that help them manage and analyze the streams of data coming from cars, thermostats, and smartwatches. The growth in IoT-enabled devices has been fueled in part by the declining cost of sensors, connectivity, and data processing power. The software needed to analyze this data has improved and companies are using it to boost operations and seek out new business models.

Vernon Turner, research fellow for the IoT for research firm IDC said “embracing IoT may lead to increased use of open source software and standards. Disparate devices will likely need to be managed by the same infrastructure, underscoring the need for common standards” (*10*).

There are several different classes of players that will play major roles in the growth of IoT, namely: commercial, research and academia, government and utilities, and other players. Players in each of these classes are active to varying degrees.

There are many market segments and “verticals” poised to drive IoT growth; these market segments include the following:

- Consumer goods: smartphone, smart home, smart car, appliances, etc.;
- eHealth; fitness, bioelectronics, and healthcare;
- Smart transportation;
- Energy distribution (smart grid);
- Smart city;
- Distribution and logistics;
- Public safety;
- Industrial and manufacturing;
- Agriculture and natural resource management; and
- Big data analytics.

Some anticipate that consumer goods and eHealth are the two primary market segments (application domains) that will initially account for growth of IoT sensors and devices.

In transportation, U.S. DOT, various standard organizations, and key suppliers are leading the activities for V2V, V2I, and certain V2X standard developments. Section 3.1, Connected and Automated Vehicles, addresses the progress and challenges in the communication arena.

In public transportation-integrated mobility platforms, train control, ticketing, common multimodal pass, and logistics to reduce cost and efficiency is anticipated to benefit from IoT. In vehicles, as discussed in Section 3.1, both vehicle control and more openly accessible IoT systems such as navigation, climate control, ADAS, etc., would benefit from IoT (although access to IoT systems might be limited because these systems are highly sophisticated safety systems). Again as discussed above in “share use” Section of 3.1, shared mobility services like Uber and Lyft that are transforming the taxi–limo industry, as are services like ZipCar and community CarShare that provide other car sharing services.

The market for IoT is likely to be significant as various communication technologies, analytics, sensor technologies, computational speed and storage, and institutional issues (i.e.,

privacy, control, security, etc.) evolve. As described in Section 3.1, CAV is rapidly evolving and some believe it is at a market development and adaptation tipping point.

3.3.4 Smart Cities

3.3.4.1 Overview

The term Smart Cities (11) was coined to encompass the dramatic increase in data that are becoming available to city managers, and how cities could make better decisions through smarter, more-efficient decision making. The smart cities movement coalesced loosely around several key city functions that happened to become much more amenable to quantification and analysis:

- Transportation,
- Energy,
- Water, and
- Waste disposal.

An important part of the smart cities movement is based on making data that is routinely acquired by public agencies available to entrepreneurs who then create new business models and start-ups based on the use of data that was until then unavailable. Cities like San Francisco and New York City were instrumental in setting the pace. Within the past 10 years, many cities (and states and regions) have appointed chief technology officers and this has accelerated the trend to more data and new types of data, in cities.

Transportation has been the leading edge of smart cities data and applications. When cities made certain transit and public service vehicle (taxi) data available (12), a host of trip planning and modal connection services and smartphone apps followed. Another early adopter has been parking information and services. Smart parking is based on the notion that the incoming driver could be provided with useful information on parking location and pricing, and allow for more purposeful parking behavior based on “booking rather than looking” (13).

Cities are extremely interested in CVs and infrastructure and some have implemented specific applications and corridors such as signal priority for transit vehicles.

So far, cities have not been active in automated vehicle deployment, although trials are taking place in some well-known locations such as Mountain View, Pittsburgh, and now Austin. This contrasts with some European cities such as La Rochelle (France) who have demonstrated driverless shuttles as part of the green lifestyle they wish to create (14).

Cities have worked with regional energy companies to introduce smart technologies in homes and buildings, in order to reduce energy costs, save on the creation of new electricity generation capacity, increase the fraction of renewable energy, and provide more meaningful pricing signals to consumers and businesses. The energy management of ancient, large, downtown buildings is an important challenge for new technology and new behavior by the real estate industry and building managers.

Again, transportation is high on city leaders’ lists. Facilitation of electrified vehicles—and attendant charging needs—has been taken up in a number of American cities (15). Such deployments have been created by automakers, energy companies, and newer players who specialize in customized electric vehicles combined with mobility service business models.

In addition, complex mathematical models of cities and key functions such as transportation, energy, water, and waste have been created (16). Leading-edge researchers are attempting to predict unexpected interactions and tipping points, such as the urban transmigration that occurred in Paris after the invention of the electric elevator.

The various city services discussed above do have some characteristics in common. Diurnal variations in demand for transportation, energy, water, and waste all create issues for dealing with peak demand, and the potential for smoothing depends on consumer information and behavior. For example, late night charging of electric vehicles can take advantage of excess electricity generation capacity created to meet the daytime peak.

3.3.4.2 Technology Description and Trends

The data sources and analytics available in cities depend on the burgeoning range and number of sensors, and connectivity provided by wireless communications, high-capacity fiber links, and ultimately by the IoT. The value of these are being enhanced by the use of analytics (big data), cloud computing, and software (services operation), and information and machine-learning technology. Related technologies include the smart grid and renewable energy technologies, such as solar.

These technologies have a high economic significance based upon the following:

- Creation of new services and businesses;
- Greater efficiencies and economies in managing and operating a city;
- Attraction of high-value residents and businesses;
- Creation of incubators and start-ups in the city; and
- Migration of millennials and their lifestyle influence.

The technologies also have an important societal impact, especially related to concern for the environment and the desire for healthy lifestyles. Some key influences are

- The “quantified self” movement which ties personal technologies to those in vehicles, homes, and offices;
- Remote health management and diagnosis;
- Facilitation of outdoor activities and large-scale events celebrating personal fitness and endurance; and
- Helping residents and businesses to adopt green practices such as electric vehicles, carsharing, walking and biking, smart buildings, and ecomanagement.

3.3.4.3 Key Applications and Deployments

In September 2015, President Obama launched a new smart cities initiative (17). This initiative packages a number of programs to foster research, increase activity across federal departments, and kick-start industry–university collaborations and deployment. The package is an example of the smart cities opportunities now being developed in cities across the United States.

Highlights of President Obama’s announcement included:

- More than \$35 million in new grants and more than \$10 million in proposed investments to build a research infrastructure for smart cities by the NSF and National Institute of Standards and Technology;
- Nearly \$70 million in new spending and more than \$45 million in proposed investments to unlock new solutions in safety, energy, climate preparedness, transportation, health, and more by the Department of Homeland Security, U.S. DOT, Department of Energy, Department of Commerce, and the Environmental Protection Agency;
- More than 20 cities participating in major new multicity collaborations that will help city leaders effectively collaborate with universities and industry; and
- The U.S. DOT announcing awards of up to \$42 million in its first wave of CVPilots, including \$20 million for the installation of this technology in midtown Manhattan, and \$17 million to address congestion in downtown Tampa.

The announcement included the launch of the MetroLab Network, with 20 city–university partnerships, as follows:

- Atlanta with Georgia State University and Georgia Institute of Technology;
- Boston with Boston Area Research Initiative;
- Chicago with the University of Chicago;
- Cuyahoga County with Case Western University;
- Dallas with Texas Research Alliance;
- Detroit with Wayne State University;
- Houston with Rice University;
- Madison with University of Wisconsin–Madison;
- Memphis with University of Memphis;
- Minneapolis–St. Paul with University of Minnesota;
- Montgomery County with University of Maryland and Universities at Shady Grove;
- New York City with New York University;
- Philadelphia with Drexel University and University of Pennsylvania;
- Pittsburgh with Carnegie Mellon University;
- Portland with Portland State University;
- Providence with Brown University, College Unbound, and Rhode Island School of Design;
- San Diego with University of California San Diego;
- San Jose with San Jose State University;
- Seattle with University of Washington;
- South Bend with University of Notre Dame; and
- Washington, D.C., with Howard University, Georgetown University, and George Washington University.

Very recently, Transportation Secretary Foxx announced a \$50-million Smart Cities Challenge to consolidate data-driven ideas to make transportation safer, easier, and more reliable. It is likely that VAC technologies will play a major role in competing smart cities concepts.

3.3.4.4 Business Models

Frost & Sullivan research estimates a combined market potential of \$1.5 trillion globally for the smart city market in segments of energy, transportation, healthcare, building, infrastructure, and governance (18).

While the potential is huge, there are daunting challenges in finding funding and developing the right business model, as many cities in the western world do not have the finances to take on such mammoth projects. As such, four main models are expected to be used by companies to engage with city authorities and utilities and to tap into this market: build–own–operate, build–operate–transfer, build–operate–manage, and open business model.

Of these, the open business model is expected to foster the most innovation due to the level of flexibility and scalability such platforms offer. This model allows city planners to give permission to any qualified company or business organization to build city infrastructure and provide city services. The city planner, however, will impose some regulatory obligations.

The market is also changing in terms of competition and collaboration. Smart city market participants will assume one or more of the four main roles in such engagements: integrators (the end-to-end service provider); network operators (the M2M and connectivity providers); product vendors (hardware and asset providers); and managed service providers (third-party providers overseeing management and operation of smart solutions–services).

From a transportation perspective, a number of questions arise. It is not yet known how far cities will go in implementing connected infrastructure, and in encouraging automated vehicles. Will cities eventually own and operate fleets of automated vehicles to provide mobility services? Will cities use technology to reinvent city centers for safety, efficiency, livability, and to revolutionize freight delivery to consumers and businesses?

3.3.4.5 Key Efforts in Convening and Publicizing

Smart cities is a mega-trend in the urbanization of the world's population. As such it is less a technology than an umbrella movement promoted by big data firms, Internet companies, and companies involved in technology for the infrastructure. Leading companies are involved in the construction of model new technology cities in China (19). In some respects it is easier to create smart cities from the ground up, rather than retrofitting older cities.

The Smart Cities Council (20)—operating in Europe and the United States—is active in promoting conferences and summits that bring together thought leaders and representatives of industry and government.

Despite the recent announcements from the White House, the smart cities movement does not have a distinctive national profile and tends to reside in the efforts of certain cities, regardless of their nationality. For example, Amsterdam and San Francisco are known for their smart cities leadership and have achieved this via public–private partnerships with federal assistance.

According to *Forbes*, it is expected that there will be around 26 global smart cities by 2025. Around 50% of these will be located in North America and Europe.

The smart cities movement does not have a high profile in the national media and attention is restricted to occasional feature articles. One recent report in *The Atlantic* (21) discussed a plan to build an entire city without residents in the New Mexico desert.

The Center for Innovation, Testing, and Evaluation (or CITE), will be, when finished, a to-scale fabricated town, built to code, complete with schools, roads—basically

everything you would consider the necessary components of a functional city. Except, of course, no residents. You can think of CITE as a sort of ghost town in reverse. First the vacant buildings will be constructed, and then the people will come. And while there won't be actual residents at CITE, there will be visiting scientists, business leaders, and government representatives all passing through. According to its own website, "CITE will be a catalyst for the acceleration of research into applied, market-ready products by providing 'end to end' testing and evaluation of emerging technologies and innovations from the world's public laboratories, universities, and the private sector." In other words, this ghost town is going to be a giant petri dish for city planning.

When construction is completed in about four years, CITE will be the largest scale testing center on Earth. Meant to simulate a town with a population of 35,000—about the size of Bennington, Vermont—it will cover about 26 square miles and include a city center as well as suburban and rural zones. There will be a city hall, airport, regional mall, power plant, school, church, and gas station. As models go, this one is a behemoth, but necessarily so. Large-scale efficiency and industrial product tests require a lab this size. The bigger the better, in fact. And that's why Pegasus Global Holdings, the technology company financing CITE, is willing put up the billion dollars that the project is expected to ultimately cost. Pegasus plans to rent the facility out to parties interested in conducting large-scale tests, and they're anticipating demand.

3.3.4.6 *Adjacent Technologies and Interconnected Matters*

Relating as it does to the planet's long-term trend to urbanization, it appears that the smart cities movement has a long-term future. It will likely continue to be rooted in public-private partnerships, requiring innovative financing. It is also likely that transportation will continue to provide technological and business models for the smart cities movement.

Two industry sectors involved with the world of transportation are likely to play an important role:

- Infrastructure financing, construction, and operation, and
- Mobility service providers oriented to consumers and city managers.

At the same time, certain key smart cities players may come more into the orbit of transportation, including:

- Real estate developers and managers;
- Large financial companies concentrating on the tech sector; and
- Broad-based communications and network companies who deal with diverse wireless communication networks and the IoT.

The tendency of the smart cities movement to create demonstrations and build new high-tech cities is a parallel with CAV's model deployments. It is likely that the transportation sector will be able to benefit from the large-scale deployments that will occur along the way to the creation of 26 (large) global smart cities.

3.3.5 Key Organizations and Players

Due to the fact that IoT and smart cities have such a strong interrelationship, the stakeholders are combined into one table (Table 3.5).

3.3.6 Security, Risks, and Opportunities

IoT and its implementation in smart cities can be a complex environment. Understanding the risks, opportunities and challenges is the first critical step towards an effective and secure implementation (7).

As IoT is gaining momentum, enterprises are vying to put more and more of their devices on the connected grid so that larger amounts of data can be harnessed. Large-scale data are needed to curate a better consumer and market understanding, as well as improve supply chains and business processes. But reliance on connected devices brings significant risks to businesses, especially with the huge amounts of consumer data and proprietary information that may be involved.

Most industry standards applicable to IoT deal with data privacy and information security. Any enterprise entities looking to augment data using connected devices will need to keep a close eye on the regulatory standards. Most enterprise IoT implementations today face pertinent issues such as insufficient control over collected data, ambiguous user content in using data, and the consequent risks in handling data. At all points, the data is vulnerable to external attacks and breaches.

As IoT gets traction and expands, so will the challenges in cybersecurity, as discussed in the next section. The area of cybersecurity is a fast-growing industry and businesses are realizing the importance of being equipped with the tools to protect their data, network, and systems.

REFERENCES

1. Internet of Things. Wikipedia.
2. Hiawatha Bray, *Boston Globe*, November 7, 2015.
3. IoT Global Council. <http://www.councilglobal.com/>.
4. Supply Chain 24/7. September 9, 2015. http://www.supplychain247.com/article/how_the_internet_of_things_is_improving_transportation_and_logistics/zebra_technologies.
5. IEEE. Internet of Things Ecosystem Study. January 2015. <http://standards.ieee.org/innovate/iot/study.html>.
6. World Economic Forum. Industrial IoT. January 2015. http://www3.weforum.org/docs/WEFUSA_IndustrialInternet_Report2015.
7. Pepijn, D. Internet of Things: Security, Compliance, Risks and Opportunities. November 6, 2015. <http://www.business.com/technology/internet-of-things-security-compliance-risks-and-opportunities/>.
8. Pubnub. August 15, 2014. <https://www.pubnub.com/blog/2014-08-15-connected-car-technology-shifts-internet-things-boundaries/>.
9. Bauer, H., M. Patel, and J. Viera. The Internet of Things: Sizing Up the Opportunity. McKinsey & Company, December 2014. http://www.mckinsey.com/insights/high_tech_telecoms_internet/the_internet_of_things_sizing_up_the_opportunity.

TABLE 3.5 Organizations Currently Involved in IoT and Smart Cities

Key Sectors–Categories	Examples of Key Players
Public agencies, city managers, elected officials, city and state CTOs, city sectors (transportation, energy, etc.), metropolitan transportation agencies (MPOs), county IT directors, CTOs, state and city IT directors and managers, White House	<ul style="list-style-type: none"> • San Francisco: Metropolitan Transport Commission, Municipal Transportation Agency • City of Austin • New York City Department of Transportation • California Air Resources Board • Environmental Protection Agency • U.S. Census Bureau • City of San Jose, California
Associations	<ul style="list-style-type: none"> • IPSO Alliance • Association of Information Technology Professionals • Telecommunication Industry Association • National Association of Manufacturers • AllSeen Alliance • The industrial Internet Consortium • The International Telecommunication Union • World Economic Forum • Smart Cities Council • Urban Land Institute • American Planning Association • IEEE • European and Asian associations
Private industry	<ul style="list-style-type: none"> • IBM • Cisco • Siemens • Swarco • Bollere • Mercedes Benz • Nissan • Accenture • Hitachi • Microsoft • SAP • Schneider Electric • Toshiba • Honeywell International • Oracle • OSISoft • Verizon • NEST (Google) • PHILIPS • QUIRKY • JAWBONE • SMARTTHINGS • WITHINGS • BELKIN • INTEL • LOGMEIN • R/GA
Universities	<ul style="list-style-type: none"> • University of Pennsylvania-Drexel University • Georgia Institute of Technology • Georgia State University • Many university-city partnerships • Carnegie Mellon University • Massachusetts Institute of Technology • University of Wisconsin-Madison • Oxford University • Bentley University

10. Norton, S. The CIO Report. *The Wall Street Journal*, June 2, 2015. <http://blogs.wsj.com/cio/2015/06/02/internet-of-things-market-to-reach-1-7-trillion-by-2020-idx/>.
11. Definition of “Smart City.” Wikipedia. https://en.wikipedia.org/wiki/Smart_city.
12. Hagen, R. Exploration of NYC Taxi Data. <http://hafen.github.io/taxi/>.
13. Smart Parking and the Connected Consumer. ITS America. <http://www.itsa.org/knowledgecenter/market-data-analysis/smart-parking>.
14. Urban Road Transport Automation in La Rochelle. *Brussels Diplomatic*. <http://brusselsdiplomatic.com/2015/04/22/urban-road-transport-automation-in-la-rochelle-transport-larochelle-france-eu/>.
15. Ann Arbor DDA. EV Charging Ready When You Are. <http://a2ev.powerdash.com/home/>.
16. Meeting of the Minds Final Report. <http://detroitfuturecity.com/2014/10/meeting-of-the-minds-final-report/>.
17. Fact Sheet. Administration Announces New “Smart Cities” Initiative to Help Communities Tackle Local Challenges and Improve City Services. <https://www.whitehouse.gov/the-press-office/2015/09/14/fact-sheet-administration-announces-new-smart-cities-initiative-help>.
18. Smart Cities—A \$1.5 Trillion Market Opportunity. *Forbes*. <http://www.forbes.com/sites/sarwantsingh/2014/06/19/smart-cities-a-1-5-trillion-market-opportunity/>.
19. Cisco collaborates with InSigma to accelerate the development of Smart+Connected communities in China. Cisco Blogs. logs.cisco.com/emerging/citycloud.
20. Smart Cities Council. <http://smartcitiescouncil.com/>.
21. A Giant, Fake City in the Middle of the Desert. *The Atlantic*. <http://www.theatlantic.com/technology/archive/2015/05/a-giant-fake-city-in-the-middle-of-the-desert/391652/>.

3.4 CYBERSECURITY

3.4.1 Overview

Cybersecurity is a worldwide, high-profile mega-trend impacting national security, global political, policy development and business dealings and every industrial sector in the United States. The integrity and security of all software, data and operating systems in both the public and private sectors is a matter of intense public interest. Exposure to hacking and release of private information, and cybercrime, is a concern for governments, companies, and individuals.

The cybersecurity industry has become highly entrepreneurial and is characterized by a race to expose and audit vulnerabilities, educate company leadership, develop intellectual property, and populate a high-tech workforce. New positions and divisions are being created in a variety of companies and government agencies, including the position of digital risk officer.

According to Cybersecurity Ventures (*1*), many of the top-ranked cybersecurity companies are based in Silicon Valley, California. Heavy auto manufacturing states tend not to be well represented with entrepreneurship in cybersecurity.

The current state of resistance to hacking in the automotive industry is generally regarded as too low, and many feel that the auto industry needs to move faster to build in fundamental tenets of security to its central software and its access and communication systems.

The stakes are raised even higher with the advent of CAVs. Driverless vehicles may not only represent tempting targets for malicious interlopers, but also new risks and consequences. For example, successful human intervention would be much less likely, and multiple vehicles could be affected by a single attack.

Similar risks exist for the control and communication systems used in managing traffic and the roadway infrastructure. Providers of mobility services will need to exercise care in protecting private data concerning traveler identities and trip details.

While transportation systems have many characteristics that create cyber vulnerabilities, the cybersecurity industry is not currently focused on traditional transportation industries. However, the newer industry sectors represented in the CAV ecosystem—such as personal technology and communications, computation, and big data—are being served directly by the emerging class of highly innovative cybersecurity companies.

It is important to recognize that the very developments that are revolutionizing transportation, including connectivity, automation, instant access to mobility services, and integration of personal devices, are acting to multiply vulnerabilities. Attention to best cybersecurity practices in transportation is in the early stages and will need to evolve and keep pace with the technological reinvention of transportation.

3.4.2 Technology Description and Trends

The world of IT is changing rapidly. Cybersecurity experts now have to deal with threats created by the Cloud, the IoT, and mobile–wireless and wearable technology. Data that were once contained within systems are traveling through a huge variety of networks and hosts.

Cyber criminals and hackers are developing elaborate scenarios to develop attacks, including:

- Man-in-the-middle attacks to eavesdrop on entire data conversations;
- Spying software to track fingerprint movements on touch screens;
- Memory-scraping malware on point-of-sale systems; and
- Bespoke attacks that steal specific data (instead of compromising an entire system).

Systems can no longer be protected by firewalls, antivirus measures, and tool-based security approaches. By 2020, a Gartner report predicts that “60 percent of digital businesses will suffer major service failures due to the inability of the IT security team to manage digital risk in new technology and use cases.” Digital hazards are so pervasive that Gartner reports that the worldwide security software market grew 4.9% and totaled \$19.9 billion by the end of 2013.

Companies providing protection against cyberattacks tend to see the biggest threats for connected systems and mobile systems. This trend highlights transportation as a critical sector for cybersecurity R&D and deployment.

IT entrepreneurs and venture capitalists are launching startups to meet demand. Research group PrivCo (2) noted companies in the cybersecurity sector jumped by nearly 60% in early stage funding from 2012 to 2013, and worldwide, listed investments at \$244 million.

Government Technology interviewed several emerging security companies to hear about their strategies for protecting their customers’ digital assets. These companies services include enterprise-level crowdsourced security testing; protection for mobile devices, enterprise networks, and smart devices within the IoT; protection of Web applications at the user interface level; next-generation endpoint security technology; and Cloud security for data. Quotes from some companies about the threats that they perceive as most dangerous are as follows:

- “Existing approaches to security—containerization, centralized data analysis, firewalls and antivirus—cannot deal with new threats and especially, cannot work on new types of smart devices.”
- “We are threatened by the increasing reliance on more and different types of connected devices from phones to cars to thermostats to insulin pumps.”
- “Automation is the most dangerous threat and is what all attacks—from malware, botnets, and scripts—have in common. These sophisticated attacks—such as account takeovers, application DDoS, database scraping, and fake account creation—use automation to evade even the best security defenses.”
- “Malware that is targeted to steal a specific set of data from a customer, not compromise an entire system, is the most dangerous type of malware today.
- “We see an exponentially growing threat surface represented by mobile and cloud applications and services. Businesses are self-selecting cloud solutions and outpacing traditional IT and security. This means that there is a very large threat surface that is addressed with legacy mindset and solutions.”

3.4.3 Key Organizations and Players

The key players in cybersecurity tend not to be directly involved in transportation. However, the advent of CAV brings in new companies who do engage with key cybersecurity players.

Current key players are shown in [Table 3.6](#). There is a wide range of federal agencies involved. Associations often have an international scope. Private industry includes a mix of large, established companies and newer, highly regarded tech companies. When it comes to universities, there is limited crossover with universities known for transportation (e.g., Carnegie Mellon, Purdue).

3.4.4 Key Applications and Deployments

The U.S. DOT has included a security system as an integral part of its V2X programs, and the first-generation security system was incorporated in the Safety Pilot Model Deployment of approximately 3,000 vehicles in Ann Arbor (3). A second-generation security system has been developed and will be deployed by the University of Michigan Transportation Research Institute (UMTRI) in the current Ann Arbor Connected Vehicle Test Environment, which is being expanded up to 9,000 vehicles.

Similar security systems are being deployed in the recently announced CV pilot deployments in New York City, Tampa, and Wyoming.

U.S. DOT has also advocated for an Information Sharing and Analysis Center (ISAC) for cyberattacks and vulnerabilities in motor vehicles. ISACs already exist in a number of related areas, including infrastructure.

More generally, the U.S. DOT has a number of efforts in automotive cybersecurity. The U.S. DOT’s GROW AMERICA legislative proposal included liability for hackers, clarifying authority for the agency to issue process rules or guidelines for the safe development of new systems, and imminent hazard authority that would enable swift action to protect the public from cybersecurity vulnerabilities and other safety threats.

NHTSA is involved in a number of cybersecurity organizations and activities, including: DefCon; Blackhat; Embedded Security in Cars; the Defense Advanced Research Projects

Table 3.6 Organizations Currently Involved in Cybersecurity

Key Sectors– Categories	Examples of Key Players		
Public agencies	<ul style="list-style-type: none"> • Department of Homeland Security (Cyber Security Division) • Cyber Information Sharing and Collaboration Program • Department of Defense • Department of Commerce • National Telecommunications and Information Administration • National Institute of Standards and Technology • Environmental Protection Agency • Government Accountability Office • Secret Service • National Association of State CIOs 		
Associations	<ul style="list-style-type: none"> • Information Systems Security Association) • Center for Internet Security • Information Security Forum • National Council of ISACs • Internet Security Alliance • International Association of Privacy Professionals • National Cyber Security Alliance • Telecommunications Industry Association • Alliance of Automobile Manufacturers • Association of Global Automakers 		
Private industry	<table style="width: 100%; border: none;"> <tr> <td style="vertical-align: top; width: 50%;"> <ul style="list-style-type: none"> • IBM • Intel Security Group • Cisco • AT&T Network Security • Verizon Enterprise • FireEye • Lancope • Alien Vault • Norse • Easy Solutions • AVG Technologies • Veracode </td> <td style="vertical-align: top; width: 50%;"> <ul style="list-style-type: none"> • Lockheed Martin • Clearwater Compliance • Palo Alto Networks • Trend Micro • NuData Security • Code Dx • Sera-Brynn • DFLabs • Cavinrin • PwC • Herjavec Group </td> </tr> </table>	<ul style="list-style-type: none"> • IBM • Intel Security Group • Cisco • AT&T Network Security • Verizon Enterprise • FireEye • Lancope • Alien Vault • Norse • Easy Solutions • AVG Technologies • Veracode 	<ul style="list-style-type: none"> • Lockheed Martin • Clearwater Compliance • Palo Alto Networks • Trend Micro • NuData Security • Code Dx • Sera-Brynn • DFLabs • Cavinrin • PwC • Herjavec Group
<ul style="list-style-type: none"> • IBM • Intel Security Group • Cisco • AT&T Network Security • Verizon Enterprise • FireEye • Lancope • Alien Vault • Norse • Easy Solutions • AVG Technologies • Veracode 	<ul style="list-style-type: none"> • Lockheed Martin • Clearwater Compliance • Palo Alto Networks • Trend Micro • NuData Security • Code Dx • Sera-Brynn • DFLabs • Cavinrin • PwC • Herjavec Group 		
Universities	<table style="width: 100%; border: none;"> <tr> <td style="vertical-align: top; width: 50%;"> <ul style="list-style-type: none"> • Carnegie Mellon • Purdue • University of Maryland University College • University of Massachusetts Amherst • Oklahoma State University </td> <td style="vertical-align: top; width: 50%;"> <ul style="list-style-type: none"> • George Mason University • University of Texas at San Antonio • Bellevue University • University of Washington • Southern New Hampshire University </td> </tr> </table>	<ul style="list-style-type: none"> • Carnegie Mellon • Purdue • University of Maryland University College • University of Massachusetts Amherst • Oklahoma State University 	<ul style="list-style-type: none"> • George Mason University • University of Texas at San Antonio • Bellevue University • University of Washington • Southern New Hampshire University
<ul style="list-style-type: none"> • Carnegie Mellon • Purdue • University of Maryland University College • University of Massachusetts Amherst • Oklahoma State University 	<ul style="list-style-type: none"> • George Mason University • University of Texas at San Antonio • Bellevue University • University of Washington • Southern New Hampshire University 		

Projects Agency’s High Assurance Cyber Military Systems and NSF’s Principal Investigators conferences; and the CyberAuto Challenge (4).

With respect to V2X cybersecurity, NHTSA and its partners are developing a Public Key Infrastructure (PKI) based system, termed the Security Credential Management System (SCMS), for ensuring trusted and secure V2V and V2I communications.

PKI security architectures and methodologies are already used extensively in the auto industry. The SCMS will employ innovative methods, encryption, and certificate management techniques to address the challenging task of ensuring trusted communications between entities that previously have not encountered each other—but also wish to remain anonymous (as is the case when vehicles—drivers encounter each other on the road).

In addition, U.S. DOT and NHTSA aim to adhere to industry consensus standards applicable to V2V and V2I DSRC-based communications. These include IEEE P 1609 and 802.11 P standards that cover communication protocols, as well as SAE International standards that address communications performance, applications, and data coding requirements.

3.4.5 Key Efforts in Convening and Publicizing

There are many examples of “hackathons” focusing on software development for mobility. In these events, competing teams may set out to develop applications that solve transportation problems, use or create large data sets, and provide users with access to large data sets. Examples of mobility-related hackathons include:

- MIT’s Transportation@MIT (2012);
- Boston’s Reinvent Transit (2013);
- Seattle’s Hack the Commute (2015); and
- Massachusetts DOT’s Visualizing Transportation (2013).

The question of motor vehicle resistance to hacking is regularly covered in the media, and the following excerpt from recent article called “Hackers Remotely Kill a Jeep on the Highway—With Me in It” by Andy Greenberg (*Wired*, July 21, 2015) provides an example of what could happen if a vehicle were overtaken by hackers.

As the two hackers remotely toyed with the air conditioning, radio, and windshield wipers, I mentally congratulated myself on my courage under pressure. That’s when they cut the transmission.

Immediately my accelerator stopped working. As I frantically pressed the pedal and watched the rpms climb, the Jeep lost half its speed, then slowed to a crawl. This occurred just as I reached a long overpass, with no shoulder to offer an escape. The experiment had ceased to be fun.

3.4.6 Business Models

According to Greg Shannon “cyberspace encompasses our national defense, critical infrastructure, industries, communications, transportation, commerce and personal lives. It’s woven throughout the fabric of our economy. These interrelationships will only deepen with time, especially with the Internet of Things” (*J*). [Note: Greg Shannon is chief scientist for the CERT Division at Carnegie Mellon University’s Software Engineering Institute, and chair of the IEEE Cybersecurity Initiative.]

Director of National Intelligence James Clapper recently testified before Congress that his fundamental concern focuses on the “moderate, iterative and constant barrage of cyber-attacks on U.S. infrastructure” that will “impose cumulative costs on U.S. economic competitiveness and national security.”

One central cybersecurity question is whether companies can afford not to invest. According to the World Economic Forum, in the past 20 years, the nature of corporate asset value has changed significantly. Eighty percent of the value of Fortune 500 companies now consists of intellectual property (IP) and other intangibles. With this rapidly expanding “digitization” of assets comes a corresponding digitization of corporate risk.

Recent research shows that corporations worldwide are losing hundreds of billions of dollars annually from the loss of IP, trading algorithms, destroyed or altered financial and consumer data, diminished reputations, as well as risking increased regulatory and legal exposure.

Cybersystems, which were designed without security in mind, are becoming even more insecure with the explosion of mobile devices and the networked connection of almost every physical asset from security cameras to refrigerators—the IoT. In addition, the attack community is vastly improving its techniques.

The sort of sophisticated cyberattacks seen only between nations a few years ago are now being practiced by common criminals. In other cases, attacks are being launched by nation states against commercial entities for political or economic purposes.

Finally, the economics of cybersecurity may favor the attackers. Cyberattacks are often relatively cheap and easy to mount. The attackers’ business plans are expansive with extremely generous profit margins. Meanwhile, defense tends to lag behind the attackers. In addition, it can be difficult to show return on investment for attacks that are prevented. Law enforcement is almost nonexistent as evidenced by how fewer than 2% of cybercriminals are successfully prosecuted.

The imbalance of the economic incentives may be exacerbated by how many of the technologies and business practices that have affected corporate growth, innovation, and profitability may also undermine cybersecurity. Technologies such as VOIP or cloud computing may bring cost efficiencies, but can also complicate security. Business practices such as the use of long supply chains and BYOD (bring your own device) are also economically attractive but could be problematic from a security perspective.

According to the *Economist*, the emerging and rapidly expanding cybersecurity industry entails a wide range of products that may not be well understood by company executives (6). These products are in some cases obscure, and they vary widely in quality. It is also recognized that protection against attacks not only requires high-quality technical solutions, but also requires effective training and vetting of employees as hackers use deceptive techniques to entice and manipulate the humans who interface with digital systems.

The *Economist* article refers to estimates of a \$575 billion annual global cost of 90 million cyberattacks. According to a report by Bank of America Merrill Lynch, the current cybersecurity market is \$75 billion, growing to \$170 billion by 2020.

Fortunately, the main burden of such attacks and costs do not fall on the transportation industry. Criminals are attracted to the “low-hanging fruit” of identity theft, bank accounts, driving license numbers, and medical records. There have not yet been large-scale criminal motivations for hacking vehicles, traffic signals, and tolling systems. But the “fifteen minutes of fame” associated with subverting the operation of large public infrastructure may appeal to “black-hat” hackers.

The increasing use of connected systems, automated technologies, and personal devices in transportation raises the cybersecurity stakes for transportation in the future.

3.4.7 Adjacent Technologies and Interconnected Matters

The broad topic of cybersecurity interacts strongly with the broad topics of IoT, big data, and smart cities. In particular, the advent of the IoT is often seen as an exacerbating factor in maintaining the security of digital systems.

Within the field of transportation, cybersecurity may be seen as a system requirement of rapidly increasing importance. As vehicles themselves become connected, and drivers bring personal technology into the vehicle, the risks of cyber vulnerability increase significantly.

Finally, with the wide introduction of CAV, cybersecurity becomes a high priority, and represents a potential barrier to the full deployment of CAV. Cybersecurity represents a critical component of a new mobility solution based on automation.

REFERENCES

1. Cybersecurity and the Future Digital Economy. *TechCrunch*, March 10, 2015. <http://techcrunch.com/2015/03/10/cybersecurity-and-the-future-digital-economy/>.
2. Cybersecurity Ventures. <http://cybersecurityventures.com/cybersecurity-market-report/>.
3. PrivCo. <http://www.privco.com/private-company/industry/cyber-security/page/1>.
4. Connected Vehicle Safety Pilot. ITS Joint Program Office, U.S. Department of Transportation. http://www.its.dot.gov/safety_pilot/.
5. Automotive Cybersecurity. NHTSA. <http://www.nhtsa.gov/Research/Crash+Avoidance/Automotive+Cybersecurity>.
6. The Cost of Immaturity. *The Economist*, November 7, 2015. <http://www.economist.com/news/business/21677639-business-protecting-against-computer-hacking-booming-cost-immaturity>.

Potential Transformational Technologies

4.1 NEXT-GENERATION AIR TRANSPORTATION SYSTEM: NEXTGEN

4.1.1 Overview

NextGen (5) is a portfolio of FAA-led programs to transform the air traffic control (ATC) system. NextGen entails changing from a ground-based system of ATC to a more air- and space-centric system that takes full advantage of advanced avionics- and satellite-based navigation. The new system will scale to support a higher volume of air traffic more safely and efficiently—reducing delays, saving fuel, and reducing aviation’s environmental impact. While the FAA is responsible for much of the legacy and new ATC infrastructure, a significant portion of the NextGen development cost lies with airlines and airports that are responsible for complementary pieces of infrastructure necessary to achieve operational transformation. NextGen transformation is occurring in stages with incremental improvements to the core capabilities of ATC and management: communications, navigation, surveillance, and automation. The success of NextGen hinges upon integrating a system-of-systems comprising advanced ATC automation and avionics capabilities. It also requires an evolution in policy, airspace design, and workforce competencies to deliver the expected operational benefits from these systems. A unique challenge for NextGen systems engineering and integration is coordinating capability development and deployment efforts between the public and private-sector stakeholders to synchronize technology investments, implementation, and use.

According to the FAA’s *Destination 2025*, (2011):

NextGen is series of inter-linked programs, systems, and policies that implement advanced technologies and capabilities to dramatically change the way the current aviation system is operated. NextGen is satellite-based and relies on a network to share information and digital communication so all users of the system are aware of other users’ precise locations.

NextGen (1) was born on the 100th anniversary of the Wright brothers’ flight when Congress and President George W. Bush in 2003 established an interagency office to manage work related to the Next Generation Air Transportation System.

“The vision for NGATS, as it was known for the first few years, included improved aviation safety, security, efficiency, quality and affordability using new ground- and space-based communications, navigation and surveillance technologies to accommodate and encourage “substantial growth. All by 2025.” (7)

According to FAA, the agency is nearing a milestone of the NextGen foundational and infrastructure elements planned to be in place by the end of 2015 (1). NextGen’s foundation creates new potential, making it possible for different NextGen components to come together and provide new functions.



Four fundamental approaches are being pursued to guide NexGen's progress:

- Executing programs to support the infrastructure of NextGen;
- Delivering capabilities to benefit users of the NAS;
- Advancing collaboration with partners in the aviation community; and
- Examining work done and renewing goals to ensure the initiative remains on the right track

“When you land at Jackson Hole (Airport), Wyoming, you land at one of the most scenic airports in the world. The airport is nestled in the valley between the tall peaks of the Teton Mountain Range and is entirely located in the Grand Teton National Park. But for arriving flights, which turn onto a *narrow approach path* between the mountains and descend to a short runway at a high elevation, it is one of the most demanding places to land in the United States.

“In the winter, when thousands of tourists arrive to hit the powdery ski-slopes, up to 10 feet of snow can accumulate in the mountains and up to 5 feet in the valley. Turbulence and mountain-wave air formations are also common. In the summer, tourists arrive to enjoy the wilderness experience of the Grand Teton and Yellowstone National Parks. *But high temperatures and the airport's elevation create 'hot and high' conditions* that require increased airspeeds, which also increase the *risk of overshooting the runway*.

“There is no margin for error, no latitude for a single mistake on these approaches, or in the landing environment.... We have heavy weather [November to April], with deteriorated runway braking conditions.”

—Richard (Rick) Schmidt, Jackson Hole Airport tower manager (*I*)

In March 2013, the FAA provided a NextGen solution: a satellite-based precision procedure that makes the landing path to Jackson Hole both safer and shorter for equipped aircraft.

The new procedure, which keeps aircraft on a tightly defined track along a smooth, curved path, provides a safety cushion between the approach path and the higher terrain to the west, according to Wayne VanDeGraaff, support manager for Airspace and Procedures at FAA's Salt Lake City Air Route Traffic Control Center. The center controls traffic into Jackson Hole, which does not have radar coverage.

The new approach also avoids the noise-sensitive areas in the national park, while aircraft using the traditional approach cut into a noise containment area, said Ray Bishop, Jackson Hole Airport director. The new, curved approach is a “win-win situation for the aviation and environment communities.”

At Jackson Hole Airport, FAA analyses indicate aircraft flying the new procedure save just over 4 Nm in flight, compared to the traditional approach, which uses navigation equipment installed on the ground at the airport. For operators equipped to fly the procedure, this means a 4- to 7-min reduction in flight time, depending on the aircraft, said Bishop. Less flight time translates to fuel savings and reduced emissions.

Edward L. Bolton, Jr., FAA Assistant Administrator for NextGen wrote (*I*):

“From its start, NextGen required us to make the commitment that having the safest and most-efficient airspace today is not enough for tomorrow. It demanded that we challenge conventional ways of doing business, consider new ideas and turn those concepts into better ways to manage air transportation from gate to gate.

We have made tremendous progress since the Next Generation Air Transportation System was just a collection of ideas. The FAA has upgraded much of our foundational infrastructure with state-of-the-art technology and equipment.

We installed a nationwide network of radio stations that is enabling the Automatic Dependent Surveillance–Broadcast system, which allows us to benefit from the precision of satellites when tracking aircraft.

We are nearly complete with the installation of new automation in our en-route facilities, and we are making steady progress upgrading our terminal automation.

One example is our Metroplex (2) initiative, where we are reducing congestion in the nation’s busiest metropolitan areas. New satellite-based air traffic procedures near cities such as Houston, Dallas, and Washington, D.C., are helping to increase on-time arrivals, while reducing fuel consumption and emissions.”

4.1.2 Technology Description and Application

NextGen comprises a series of technologies and programs as follows (1) (Figure 4.1):

- Automatic Dependent Surveillance-Broadcast (ADS-B) is FAA’s satellite-based successor to radar. ADS-B makes use of GPS technology to determine and share precise aircraft location information, and streams additional flight information to the cockpits of properly equipped aircraft.
- Collaborative Air Traffic Management Technologies (CATMT) is a suite of enhancements to the decision-support and data-sharing tools used by air traffic management personnel. These enhancements will enable a more-collaborative environment among controllers and operators and improve efficiency in the NAS.
- Data Communications (Data Comm) will enable controllers to send digital instructions and clearances to pilots. Precise visual messages that appear on a cockpit display can interact with an aircraft’s flight computer. Offering reduced opportunities for error, Data Comm will supplant voice communications as the primary means of communication between controllers and flight crews.
- National Airspace System Voice System (NVS) will supplant FAA’s aging analog voice communication system with state-of-the-art digital technology. NVS will standardize the voice communication infrastructure among FAA facilities, and provide greater flexibility to the ATC system.
- System Wide Information Management (SWIM) is the network structure that will carry NextGen digital information. SWIM will enable cost-effective, real-time data exchange and sharing among users of the NAS.
- NextGen Weather will help reduce weather impact by producing and delivering tailored aviation weather products via SWIM, helping controllers and operators develop reliable flight plans, make better decisions, and improve on-time performance. NextGen Weather is accomplished through collaboration between FAA, National Oceanic and Atmospheric Administration (NOAA), and NASA.

With 2015 marking the completion of NextGen’s foundation and initial set of capabilities, FAA is focused on the following expanded or new capabilities:

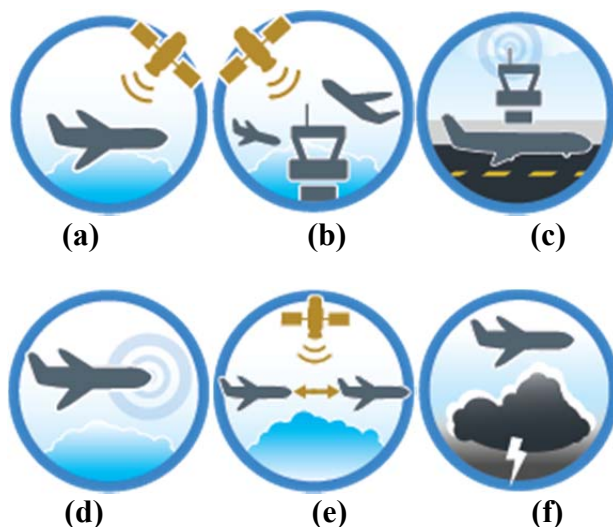


FIGURE 4.1 (a) ADS-B; (b) CATMT; (c) Data Comm; (d) NVS; (e) SWIM; and (f) NextGen Weather.

- ADS-B,
- Required navigation performance,
- Collaborative air traffic management,
- Closely spaced parallel operations (CSPO),
- Wake turbulence recategorization,
- Data Comm,
- Aeronautical Mobile Airport Communications System,
- Airborne Collision Avoidance System X (ACAS X), and
- Aviation safety information analysis and sharing.

Some of the technologies and capabilities are described below (*I*):

- CSPO procedures enable aircraft to use parallel runways separated by fewer than 4,300 ft at their centerlines, even when weather conditions reduce visibility.
 - Safety analyses completed in 2014 support reductions in separation that make it possible for airports to employ double and triple simultaneous approaches. This will increase arrival and departure efficiency, along with capacity.
 - According to their website, FAA has committed to implementing CSPO procedures at the following airports by the close of 2017: Atlanta, Boston, Cincinnati, Dallas, Louisville, Minneapolis–St. Paul, Memphis, New York (John F. Kennedy), Phoenix, Portland, Raleigh–Durham, San Francisco, Seattle, and Washington Dulles (*I*).

ACAS X is the next evolution in collision avoidance technology, which alerts flight crews when their aircraft fly too close together. It will eventually replace the Traffic Alert and Collision Avoidance System, mandated by the FAA in 1989. CAS X is being designed to meet the demands of NextGen.

ACAS X is intended to reduce unnecessary alerts during closely spaced operations, accommodate more aircraft types, and function with new sensor systems. The collision-avoidance software will take advantage of ADS-B avionics and a trend toward modular avionics. This approach will make future changes easier to implement.

The FAA plans to develop minimum operational performance standards for ACAS X by 2018. Once these standards are in place, vendors will be able to develop and market the system. ACAS X is scheduled to be operational by 2020.

Aviation Safety Information Analysis and Sharing (ASIAS) is a program that merges government and industry data so safety experts can identify safety issues and proactively seek solutions.

- During the next 5 years, the ASIAS program plans to increase the amount of, and improve delivery of safety information to continually reduce risks in aviation. Participation will expand to cover general aviation, rotary wing, and UA, as well as international air carriers.
- Data will become available through new sources, such as ADS-B. Studies will also include data collection from international air carriers and monitoring of known NextGen risk factors. NextGen-enabled technology will provide a better ability to analyze all phases of flight.
- Information will be stored on a secure private network that is more flexible, efficient, and able to blend information on determining factors. ASIAS collaboration will grow across the FAA and provide enhanced capabilities, including 3-D visualizations.

4.1.3 Business Models

The FAA estimates that NextGen improvements will generate \$133 billion in benefits to NAS users between 2013 and 2030 (3). Those improvements will cost the FAA and NAS users \$29 billion over the same time period. After discounting to present value, that is a benefit-to-cost ratio of more than 3:1. The business case for NextGen is a comprehensive view of the costs and benefits associated with modernizing and transforming the NAS. It provides the only systemwide analysis of benefits and costs by combining data from a number of sources, including business cases for individual programs, third-party studies, and systemwide modeling.

NextGen improvements in technology and procedures represent a widespread, transformative change in the management and operation of the way we fly. Aviation contributes \$1.3 trillion to the U.S. economy, generates more than 10.2 million jobs with earnings of nearly \$400 billion, and makes up 5.2% of our gross domestic product. The aerospace sector is a vital element in the country's economy.

Whether it's a large cabin jet, a light jet, turboprop, or piston-powered aircraft, business aviation enables professional travelers to conduct business throughout the United States (4). Long-range business jets span the oceans. Because business aviation has such a large range of aircraft and operational characteristics, the modernization of the NAS uniquely benefits this group of stakeholders. The NextGen infrastructure increases situational awareness and flight options. It reduces flying time and fuel burn, increases predictability and airport access.

As indicated above, although FAA is responsible for much of the NextGen infrastructure, a significant portion of the development cost lies with airlines and airports that are responsible for much of the needed infrastructure necessary to complement and achieve the intended operational transformation (5). These investments are envisioned to be coordinated

with the parallel activities of FAA for mutual benefit of both parties and ultimately a successful business model.

4.1.4 Key Organizations and Players

While FAA plays a primary role in NextGen, a large group of stakeholders participate in this transformational technology. [Table 4.1](#) highlights some of the stakeholders in various categories.

4.1.5 Efforts in Convening and Publicizing

FAA has been conducting series of training, education, and other conferences such as:

- Annual FAA National Small Business Procurement Opportunities, Training Conference, and Trade Show;
- Series of videos describing the technologies and programs;
- Series of presentations and articles by the administrator and the FAA executive team; and
- NextGen update series.

Various industry associations and manufacturers have also been convening and planning conferences and summits where NextGen is either the main topic or included as part of the program. Here are some examples:

- Global Connected Aircraft 2016 Summit, June 6–8, Los Angeles (<http://www.gcasummit.com/conference-schedule/>).
- National Business Aviation Association 2015: Business Aviation Convention and Exhibition, November 17–19, 2015, Las Vegas.
- Aviation Insurance Association, November 5, 2015, at Lloyds of London.
- ATCA 60th Annual Conference, November 1–4, 2015, National Harbor, Maryland (<http://www.atca.org/60annual>).
- Avionics for NextGen, October 14–15, 2015, Washington, D.C. (<http://www.avionicsfornextgen.com/>).
- NextGen 101 Seminar, in conjunction with Avionics NextGen 2015 Conference, by Embry-Riddle Aeronautical University, October 13, 2015, Herndon, Virginia (<http://proed.erau.edu/programs/specialized-industry-training/nextgen-101-seminar/>).

4.1.6 Adjacent Technologies and Interconnected Matters

There appears to be a strong correlation between NextGen and UAS's, big data, smart cities, and IoT. Big data may be the common platform. The strongest correlation possibly exists between NextGen and UAS. As UAS are evolving rapidly and as discussed in Section 3.2, FAA, in collaboration with stakeholders, is working to address regulations and integration issues. In addition, several entities are addressing environmental impacts and noise issues.

Table 4.1 Key Organizations and Players in NextGen

Key Sectors–Categories	Examples of Key Players	
Public Agencies: federal, state, regional, local	<ul style="list-style-type: none"> • FAA • DOD • FCC • Airport authorities nationwide • GAO • NASA • U.S. Air Force • U.S. Navy • Oregon Department of Aviation • NOAA 	
Associations	<ul style="list-style-type: none"> • General Aircraft Manufacturing Association • Aircraft Electronics Association • National Air Traffic Controllers Association • National Association of State Aviation Officials • National Business Aviation Association • Ohio Aviation Association • Aircraft Owners and Pilots Association • Airline Pilots Association • National Alliance to Advance NextGen • Aerospace States Association • Airport Council International • Air Carrier Association of America • Aerospace Industries Association • American Institute of Aeronautics • Air Routing International • Airports Consultants Council • American Association of Aviation Executives 	
Private industry	<ul style="list-style-type: none"> • Boeing • Rockwell Collins • American Airline • Airbus Americas • Bombardier • Accenture • AECOM • Alcatel-Lucent • Booz Allan Hamilton • United Airlines • Delta Airlines • FedEx • Lockheed Martin • Harris Corporation • Garmin International • Honeywell International • Raytheon • Jet Blue • Southwest Airlines 	
Universities	<ul style="list-style-type: none"> • Mississippi State University • University of California–Berkeley • Drexel University • Embry Riddle Aeronautical University • North Carolina University • University of North Dakota • Wichita State University • Purdue Polytechnic Aviation and Transportation Technology • Lewis University • Kansas State University 	

As we look at the correlations among the various transformational technologies, it appears that they have a profound impact on how research and development is conducted in the private sector. This is particularly true in the transportation industry, where the “test and evaluation” is often in the open environment (field tests–pilot deployments as opposed to laboratories). The open environment tends to expedite the validity and effectiveness of technologies, and at times may lead to adjacent and potentially augmenting technologies.

McKinsey Global Institute (6) notes:

“We view technology both in terms of potential economic impact and capacity to disrupt, because we believe these effects go hand-in-hand and because both are of critical importance to leaders. As the early 20th-century economist Joseph Schumpeter observed, the most significant advances in economies are often accompanied by a process of ‘creative destruction,’ which shifts profit pools, rearranges industry structures, and replaces incumbent businesses. This process is often driven by technological innovation. Schumpeter describes how the Illinois Central railroad’s high-speed freight service enabled the growth of cities yet disrupted established agricultural businesses.

“Some economists question whether technology can still deliver the kind of wide-ranging, profound impact that the introduction of the automobile or the semiconductor chip had, and point to data showing slowing productivity growth in the United States and the United Kingdom—often early adopters of new technology—as evidence. While significant challenges lie ahead, there is also considerable reason for optimism about the potential for new and emerging technologies to raise productivity and provide widespread benefits across economies. Achieving the full potential of promising technologies while addressing their challenges and risks will require effective leadership, and the potential is vast. As technology continues to transform our world, business leaders, policymakers, and citizens must look ahead and plan.”

REFERENCES

1. A “Win-Win” at Jackson Hole, FAA, January 2014. <https://www.faa.gov/nextgen/snapshots/stories/?slide=29>.
2. Metroplex, FAA. http://www.faa.gov/nextgen/library/media/getsmart_metroplex.pdf.
3. NextGen: The Business Case, FAA, 2014. <https://www.faa.gov/nextgen/media/BusinessCaseForNextGen-2014.pdf>.
4. NextGen Works for Business Aviation. FAA, May 2014. http://www.faa.gov/nextgen/library/media/getsmart_businessaviation.pdf.
5. Transforming the National Airspace Systems. Booz Allen Hamilton. <https://www.boozallen.com/media/file/engineering-services-case-study-FAA.pdf>.
6. McKinsey Global Institute. Disruptive Technologies: Advances That Will Transform Life, Business, and the Global Economy, May 2013. http://www.mckinsey.com/insights/business_technology/disruptive_technologies.
7. NextGen: From Where We’ve Come. FAA. http://www.faa.gov/nextgen/update/from_where_weve_come/.

4.2 3-D PRINTING

4.2.1 Overview

A recent report from the Atlantic Council predicts that 3-D printing “has the potential to be as disruptive as the personal computer and the Internet” (1, 2). All of the flow-on disruptive economic effects of 3-D printing cannot be foreseen, but there seems little doubt that we are dealing with a mega-disruptive technology.

3-D printing, or additive manufacturing, is a relatively recent technology with a potentially transformative impact on the manufacturing sector, and eventually the broader economy (3). Early adopters of 3-D printing included automotive, medical, aerospace, and consumer electronics. These industries have been able to produce complex, high-performance prototypes and a limited number of high-performance production parts.

In 2012, 28.3% of the \$2.2-billion global 3-D printing market was tied to the production of parts for final products rather than prototypes, according to the *Wohlers Report 2013*. That shift could have profound implications for the economy and for public policy.

In the first instance, it is possible to create more-complex efficient parts and reduce the need for long supply chains, assembly plants, and delivery. However, the abilities to experiment, innovate, customize, increase complexity, and add intelligence combine to suggest a profound effect on a manufacturing sector that currently represents \$2 trillion in our economy. The development and manufacture of products will potentially be collapsed from a long, linear, multipartner process of design, prototyping, testing, and refinement to individual inventors becoming manufacturers.

The technology of 3-D printing has clear applications, but also brings much uncertainty about the eventual scope of its industrial impact. A 3-D printing-based production process circumvents many of the challenges and limitations of traditional manufacturing, especially those that lead to trade-offs between production and design and between production and transport. Even small shifts in these trade-offs could have a major impact on industries such as design, prototyping, manufacturing, assembly, warehousing, distribution, and transportation.

3-D printing takes a digital file describing an object and divides it into many, carefully dimensioned layers that can be progressively “printed” to create the complete object. Depending on the materials involved, various methods are used to fuse the layers together. Materials may include high-performance metals such as titanium (4). In the case of aircraft, for example, it is possible to create components that are significantly lighter, and are stronger at the same time.

It is envisaged that consumers will be able to download design files and go to a local “print shop” to manufacture the item. The potential disruption to manufacturing and assembly plants, warehousing, trucking, distribution, and retail is tremendous.

Potential disruption also extends to regulatory and certification processes, which rely on relatively few identifiable, approved designs. In the case of safety-critical automotive products, the increased potential for customization may place the compliance emphasis at the “safe design” stage.

3-D printing could potentially have a major impact on research and development carried out by industrial companies. It could also change research methodologies (e.g., transportation) where products and systems are evaluated, and sometimes improved, by independent researchers in universities and institutes. The ability of researchers to move beyond the testing

of specific products from specific manufacturers will enable new experimental designs and increase the power of the research.

There may also be strong implications for IP, given that variations and complexities based on others' inventions will come within the reach of many more companies and individuals. This could be extremely difficult to manage within our current public–private IP development and protection processes. The value of the industrial economy and its workers is strongly dependent on its intellectual property.

4.2.2 Technology Description and Trends

The IBM Institute for Business Value has considered a range of scenarios for the role and impact of 3-D printing in the global transportation services sector (5). Two broad categories of impacts are considered. First, 3-D printing could reduce prices while improving selection and fulfillment, including:

- Price: lower costs and lower prices;
- Selection: limits are removed;
- Personalization: customization at no additional cost; and
- Delivery: parts of the supply chain become irrelevant.

Second, 3-D printing has the potential to transform most aspects of manufacturing, including:

- Quality: more direct control;
- Scale: economies of scale are no longer relevant;
- Automation: no longer relevant to production;
- Labor: no longer relevant to production and can be redirected to design and personalization; and
- Design: individual producers make decisions, and cost-complexity trade-offs fade away.

Moving from the point in 2006 when consumers became aware of 3-D printing, the IBM authors believe that several scenarios are possible.

These scenarios are based on two key issues:

- Willingness of end-consumers to embrace 3-D printing and
- Rate at which 3-D printing technologies improve.

The most active scenario was termed “The Reinvention of Consumption” and was considered to entail:

- Positive customer disposition;
- Rapid technology advancement;
- Large and small retailers leveraging 3-D printing for a significant share of products ;
- Customization becomes a market necessity;

- Shortened lead times to reduce inventories; and
- Transformation of the transport–supply chain

The authors predict a shift in the importance of raw materials transport for all provider segments (5). Freight logistics companies and rail freight operators that rely on the transport of both intermediate and finished goods today will need to adjust to the needs of clients that choose to employ 3-D printers close to the final distribution or consumption points and, therefore, require the delivery of more 3-D printing cartridges.

Container shipping companies would likely benefit from 3-D printing-driven supply chain changes that make it more economical to position raw materials closer to the points of final consumption.

Despite the considerable uncertainties, 3-D printing is in its early stages, and it seems likely that its impact will go well beyond prototyping, design, and manufacturing. Even considering prototyping, 3-D printing can bring about flow-on benefits. For example, during the design and construction of a 125-m bridge in Gdansk, Poland, engineers constructed an intricate prototype simulation of the bridge to better understand test conditions, and used the prototype to develop transportation and construction methods for large components of the bridge (6). The engineers considered that 3-D printing would have a major impact on infrastructure and construction methods around the world.

In a somewhat different vein, Advanced Paving Technologies will be launching a Kickstarter, in partnership with the University of California–Davis, Pavement Research Center, to fund its 3-D Asphalt Paving Machine (7). The 3-D asphalt paving machine uses lidar 3-D scanning to scan fractured roads before compacting the pavement and applying new asphalt over it. All of this is meant to take place within a single 3-D scanning, compacting, and laying machine that performs all of this work in a dynamic process as it moves over a damaged road.

The automotive and aerospace industries were early adopters of 3-D printing for prototyping, advanced design, and selected manufacturing. The potential for manufacturing may be seen in the current plans of mining companies to cater to exotic mineral powders needed in 3-D manufacturing for the aerospace industry. The transportation of powder is much more efficient than that of made parts, where considerable space is taken up by their immovable shapes and packaging.

In the field of specialty vehicle manufacture, Local Motors has designed the Strati, a car for which the main structure was 3-D printed on the floor of the 2015 Detroit Auto Show (8). The electric car's body is made from thermoplastics on a 3-D printer. Nonprinted parts include the motor, transmission, wheels, and steering column. The maximum speed is around 40 mph. The car does not meet requirements for highway use.

Local Motors plans to build the cars in micro-factories typically located within 100 mi of major urban centers.

Local Motors are also working on automated vehicles such as the type of low-speed shuttles that are being used in mobility-on-demand demonstration projects in certain urban settings (such as CityMobil2 in Europe).

Crowdfunding is currently being sought for the URBEE 2, a car being prototyped using 3-D printing (9). It is expected to weigh some 1,200 lb, comprising about 40 pieces of thermoplastic. Its production will require far less material than a traditional car. It will need almost no labor and take little time to assemble. Its designers can employ unorthodox shapes and materials to maximize efficiency.

The technology of 3-D printing is still young. And as the IBM Institute for Business Value points out, there are great uncertainties about the mainstream quality and capability of the technology, as well as overall consumer acceptance. Nevertheless, Hod Lipson and Melba Kurman write in *Fabricated: the New World of 3-D Printing* (10) that the technology will be “the platypus of the manufacturing world, combining the digital precision and repeatability of a factory floor with an artisan’s design freedom.”

There are already applications of 3-D printing in the industries of transportation vehicles and transportation infrastructure. And there are already implications for the freight and logistics industries. The potential for disruptive mobility products and services is already being developed, with a strong logic for printed, electrified, automated, low speed shuttle vehicles.

According to the independent research firm Gartner, the 3-D printing market, which was worth \$4.1 billion in 2014, is projected to grow over 500% with a year-over-year growth rate of 45.7% in the next 5 years (11).

4.2.3 Key Organizations and Players

In 2012, the White House created the National Additive Manufacturing Innovation Institute (NAMII) (12), a public–private partnership dedicated to advancing 3-D printing. The goals are to help train the workforce in this technology, build curricula at technical schools, offer sites and equipment where businesses can validate ideas, and support research that will let domestic suppliers produce the advanced machinery that the industry will need.

3-D printing is considered to be a national priority because the United States is—and is expected to remain—a global powerhouse of innovative design, IP, and manufacturing. NAAMI plans to catalyze a nationwide network of regional manufacturing innovation institutes. Five federal agencies (U.S. DOD, U.S. DOE, U.S. DOC, NSF, and NASA) jointly committed to invest in the pilot institute.

On August 16, 2012, after a competitive process, the Obama Administration announced the selection of a new consortium led by the National Center for Defense Manufacturing and Machining to establish the NAMII.

Key players involved with NAMII are listed as follows:

- Forty companies: Allegheny Technologies, AlphaMicron, Applied Systems and Technology Transfer, Autodesk, Boeing, Catalyst Connection, Energy Industries of Ohio, ExOne, FMW Composites, General Dynamics, General Electric, Honeywell, IBM, Johnson Controls, Kennametal, Kent Displays, Laser Technology Assts, Lockheed Martin, Lubrizol, M-7 Technologies, MicroFab Technologies, Morris, Northrop Grumman, nScript, OSRAM Sylvania, Optomec, Oxford Performance Materials, Paramount Industries / 3-D Systems, Parker Hannifin, Plextronix, POM, RTI, Ruger, Sciaky, Stratasys, Stratonics, Timken, Touchstone Research Lab, Westinghouse Nuclear, and Wohlers Associates.
- Nine research universities: Carnegie Mellon University, Case Western Reserve University, Kent State University, Lehigh University, Penn State University, Robert Morris University, University of Akron, University of Pittsburgh, and Youngstown State University.
- Five community colleges: Eastern Gateway Community College, Lorain County Community College, Northampton Community College, Penn College of Technology, and Westmoreland County Community College.

- Eleven non-profit organizations: Association for Manufacturing Technology, Ben Franklin Technology Partners, JumpStart Ohio, Manufacturing Advocacy and Growth Network, MT Connect, NorTech, National Digital Engineering and Manufacturing Consortium, Ohio Aerospace Institute, Robert C. Byrd Institute, the Youngstown Business Incubator, and the Society of Manufacturing Engineers.

The 3-D printing technology industry includes companies producing a wide range of subtechnologies: ranging from ultra-high end industrial machines with liquid molten jet technology, to large-scale construction 3-D printers, to open-source desktop models, to all-in-one multifunctional personal fabricators that combine 3-D printing with several other key robotic and machining capabilities.

Examples of such technology companies who have attracted interest in financial markets include: Alphaform, Arburg, Arcam, Aspect, Beijing, Tiertime, BigRep, Blueprinter, DWS, Envisiontec, Fabrisonic Solidscape, Mcor, Matrialise, Optomec, Prodways, ReaLizer, Sisma, Renishaw, 3-D Systems, Voxeljet, and Xery.

According to a Market Research Reports.biz report (13), the 3-D printing materials market is set to overtake the 3-D printer (technology) market by the year 2023, and reach \$8.3 billion dollars by 2025. Companies that supply 3-D printing materials include Cookson Gold and Evonik.

At this time there is little evidence of direct connections between the sectors of 3-D printing and the transportation, either in the industry or government spheres. However, the involvement of Boeing, General Electric, IBM, Johnson Controls, Lockheed Martin, Northrop Grumman, and Parker Hannifin in NAMII should be noted.

At the same time, many leading companies in automotive, aerospace, and infrastructure are utilizing 3-D printing as a source of innovation in their existing product range. And this section has noted some examples of early-stage specialty vehicle manufacturing companies that are attempting to employ 3-D printing as a significant part of their manufacturing process.

Table 4.2 illustrates examples of the most important transportation-related organizations that are known or believed to be currently active in 3-D printing.

4.2.4 Key Applications and Deployments

Aside from the early-stage specialty vehicle manufacturers, there do not appear to be any orchestrated programs to demonstrate or deploy 3-D printing in transportation.

4.2.5 Business Models

3-D printing is a highly disruptive technology that is in its early stages of application in industry. Gartner estimated a 3-D printing market of \$4.1 billion in 2014, and projected it to grow five times over during the next few years. The market is currently based on 3-D printing technologies. There is likely to be strong growth in the mining, chemicals, and processing industries that produce the materials for 3-D printing.

3-D printing is already influencing several large industry sectors, including automotive, medical, aerospace, and consumer electronics. It is expected that this impact will increase to the extent that 3-D printing exerts a noticeable influence on the automotive industry and the creation of customer value in that industry.

TABLE 4.2 Examples of Key Players in 3-D Printing

Key Sectors–Categories	Examples of Key Players
Public agencies: federal	<ul style="list-style-type: none"> • U.S. DOE • U.S. DOD • NAMII
Associations	<ul style="list-style-type: none"> • Aerospace Industries Association • Alliance of Automobile Manufacturers • American Trucking Association • Motor and Equipment Manufacturers Association • NAAMII • National Association of Manufacturers • Society of Manufacturing Engineers • Specialty Equipment Manufacturers Association
Private industry	<ul style="list-style-type: none"> • Advanced Paving Technologies • Boeing • General Electric • IBM • Johnson Controls • Local Motors • Lockheed Martin • Northrop Grumman • Parker Hannifin
Universities	<ul style="list-style-type: none"> • Carnegie Mellon • Penn State University

There is uncertainty surrounding the full flow-on effects of 3-D printing in a whole chain of industries (design, prototyping, manufacturing, assembly, warehousing, distribution and transportation). It is at least possible that 3-D printing will be a major disruptor, eventually impacting fundamental national processes of research, innovation, standards, and IP.

4.2.6 Key Efforts in Convening and Publicizing

According to the IBM Institute for Business Value, the general public first became aware of 3-D printing in 2006. It is fair to say that general awareness is still low. However, 3-D printing became a hot topic in the financial and investing community. There are some signs that interest in and awareness of 3-D printing in business development and in the national economy could increase dramatically.

4.2.7 Adjacent Technologies and Interconnected Matters

Significant impacts on the supply chain and transportation industries are also anticipated once 3-D printing becomes entrenched in manufacturing. In terms of specialty vehicle manufacturing, automation, electrification, and the creation of new mobility services, there appear to be strong synergies for 3-D printing.

It is not currently possible to assess the full disruptive potential of 3-D printing, but there are some signs that its effects could eventually lead to change in fundamental national value creation: the very processes of innovation, research, and IP.

REFERENCES

1. D'Avini, R. A. 3-D Printing Will Change the World. *Harvard Business Review*. <https://hbr.org/2013/03/3-d-printing-will-change-the-world>.
2. Will 3-D Printing Have a Larger Economic Impact than the Internet? 3DPrint.com. <http://3dprint.com/55334/3d-printing-economy/>.
3. How 3-D Printing could Disrupt the Economy of the Future. *BloombergView*. <http://www.bloombergview.com/articles/2013-05-14/how-3-d-printing-could-disrupt-the-economy-of-the-future>.
4. Miners Target 3-D Printing. *The Wall Street Journal*. November 14–15, 2015.
5. Shifting Transport Paradigms: Understanding the Implications of 3-D Printing on the Global Transportation Industry. IBM Institute for Business Value. http://www-01.ibm.com/common/ssi/cgi-bin/ssialias?subtype=XB&infotype=PM&appid=GBSE_GB_TI_USEN&htmlfid=GBE03623USEN&attachment=GBE03623USEN.PDF.
6. Engineers 3-D Print Prototype of 2000 Ton Bridge. 3DPRINTR.com. <https://www.3printr.com/engineers-3d-print-prototype-of-2000-ton-bridge-1031877/>.
7. Advanced Paving Tech Plans to Pave the Roads of the Future in 3-D. 3-D Printing Industry. <http://3dprintingindustry.com/2015/09/21/advanced-paving-tech-seeks-to-pave-the-roads-of-the-future-in-3d/>.
8. Local Motors Builds Strati, the World's First 3-D-Printed Car in Detroit. *AutoBlog*. <http://www.autoblog.com/2015/01/12/local-motors-3d-printed-car-strati-detroit-2015/>.
9. URBEE 2. <http://korecologic.com/>.
10. Lipson, H., and M. Kurman. *Fabricated: The New World of 3-D Printing*. ISBN-13:978-1118350638 -ISBN-10:1118350634.
11. 2015 Roundup of 3-D Printing Market Forecasts and Estimates. *Forbes/Tech*. <http://www.forbes.com/sites/louiscolumnbus/2015/03/31/2015-roundup-of-3d-printing-market-forecasts-and-estimates/>.
12. National Additive Manufacturing Innovation Institute. http://www.manufacturing.gov/nmii_pilot_institute.html.
13. 3-D Printing Materials 2015–2025: Status, Opportunities, Market Forecasts. *Market Research Reports*. <http://globenewswire.com/news-release/2015/10/21/778646/10153619/en/The-3-D-Printing-Materials-Market-to-overtake-the-3-D-Printer-Market-in-2023-and-reach-8-3bn-by-2025-MarketResearchReports-Biz.html#sthash.FRbekH8H.dpuf>.

4.3 BIG DATA

4.3.1 Overview

Big data is a broad term for data sets so large or complex that traditional data processing applications are inadequate (*I*). Challenges include analysis, capture, data curation, search, sharing, storage, transfer, visualization, and information privacy. The term often refers simply to the use of predictive analytics or other certain advanced methods to extract value, including unanticipated value, from data, and seldom to a particular size of data set.



Accuracy in big data may lead to more confident decision making. And better decisions can mean greater operational efficiency, cost reduction, and reduced risk.

You can't manage what you don't measure. (2)

There is much wisdom in that saying, which has been attributed to both W. Edwards Deming and Peter Drucker, and it explains why the recent explosion of digital data is so important. Simply put, because of big data, managers can measure, and hence know, radically more about their businesses, and directly translate that knowledge into improved decision making and performance.

In traffic management we have seen this in performance measurement and management. Agencies such as Caltrans currently utilize significant amounts of data they collect in real time through various sensors and vehicle probes. Applying analytics, results are actionable information that can be used for decision making and sharing with travelers. Another example is the traveler information–511 systems many states employ where big data is analyzed and shared with travelers.

Big data plays a significant role in connected and automated vehicles. In both cases, a significant amount of data is collected in real time and processed at a very high speed (see Section 3.1: Connected and Automated Vehicles). Of course, vehicle original equipment manufacturers (OEMs) and their suppliers have been progressive in their use of big data through technologies such as ADAS, navigation, and entertainment systems.

According to Idea Lab founder and CEO Bill Gross:

Google's self-driving car gathers 750 megabytes of sensor data per SECOND! It is capturing every single thing that it sees moving—cars, trucks, birds, rolling balls, dropped cigarette butts, and fusing all that together to make its decisions while driving. I am truly stunned by how impressive an achievement this is. (9)

Several state DOTs are developing a performance measurement dashboard to quickly review system parameters and performance metrics in real time. As such systems evolve, a variety of data could be included such as infrastructure data, systems data, calculated data, environmental, weather, and GIS.

Consider retailing (2). Booksellers in physical stores could always track which books sold and which did not. If they had a loyalty program, they could tie some of those purchases to individual customers. At that time, the tools were not available to glean more complete information. Once shopping moved online, however, the understanding of customers increased dramatically. Online retailers could track not only what customers bought, but also what else they looked at; how they navigated through the site; how much they were influenced by promotions, reviews, and page layouts; and similarities across individuals and groups. Before long, they developed algorithms to predict what books individual customers would like to read next—algorithms that performed better every time the customer responded to or ignored a recommendation. Traditional retailers simply couldn't access this kind of information, let alone act on it in a timely manner. Online book retailers therefore had an advantage over many brick-and-mortar bookstores, and likely affected their ability to stay in business.

The familiarity of the Amazon story almost masks its power. We expect companies that were born digital to accomplish things that business executives could only dream of a

generation ago. But in fact the use of big data has the potential to transform traditional businesses as well. It may offer them even greater opportunities for competitive advantage (online businesses have always known that they were competing on how well they understood their data). The big data of this revolution is far more powerful than the analytics that were used in the past. We can measure, and therefore, manage more precisely than ever before. We can make better predictions and smarter decisions. We can target more effective interventions and can do so in areas that so far have been dominated by gut and intuition rather than by data and rigor. (2)

Recognizing that there is a significant correlation among the TRB hot topics, big data may very likely be the platform that ties them all together.

4.3.2 Technology Description, Trends, and Application

The big data movement (2), like analytics before it, seeks to glean intelligence from data and translate that into business advantage. However, there are three key differences:

1. **Volume.** As of 2012, about 2.5 exabytes of data were created each day, and that number is doubling every 40 months or so. More data cross the Internet every second than were stored in the entire Internet just 20 years ago. This gives companies an opportunity to work with many petabytes of data in a single data set—and not just from the Internet. For instance, one major company collects an estimated more than 2.5 petabytes of data every hour from its customer transactions. A petabyte is 1 quadrillion bytes, or the equivalent of about 20 million filing cabinets' worth of text. An exabyte is 1,000 times that amount, or 1 billion gigabytes.

2. **Velocity.** For many applications, the speed of data creation is even more important than the volume. Real-time or nearly real-time information makes it possible for an organization to be much more agile. For instance, MIT Media Lab used location data from mobile phones to infer how many people were in Macy's parking lots on Black Friday—the start of the holiday shopping season in the United States. This made it possible to estimate the retailer's sales on that critical day even before Macy's itself had recorded those sales. Rapid insights like that can provide a competitive advantage to financial analysts. As indicated above, examples of automated cars highlight the importance of velocity in movement of significant data and the ability to process it for a timely availability of actionable information. The same is true for a connected car electing to exchange significant amount of data with other vehicles or extract-exchange with the traffic signal intersection cabinet or other infrastructure apparatus. High densities of connected cars within large and interacting traffic streams will lead to a high velocity of data in individual cars, especially at intersections.

3. **Variety.** Big data takes the form of messages, updates, and images posted to social networks and allows for readings from detection sensors along the freeway, GPS signals from cell phones, and more. Many of the most important sources of big data are relatively new. The huge amounts of information from social networks, for example, are only as old as the networks themselves: Facebook was launched in 2004 and Twitter in 2006. The same holds for smartphones and the other mobile devices that now provide enormous streams of data tied to people, activities, and locations. Because these devices are ubiquitous, it's easy to forget that the iPhone and iPad were unveiled not too long ago. Thus, the structured databases that stored most corporate information until recently are ill-suited to storing and processing big data. At the same time, the steadily declining costs of all the elements of computing—storage, memory,

processing, and bandwidth—mean that previously expensive data-intensive approaches are quickly becoming economical.

As more and more activities are digitized, new sources of information and ever-cheaper equipment combine to facilitate a new era in which large amounts of digital information exist on virtually any topic of interest. Vehicles, mobile phones, online shopping, social networks, electronic communication, GPS, and instrumented machinery all produce great amounts of data as a byproduct of their operations. Each of us is now a walking data generator. The data available are often unstructured—not organized in a database—and unwieldy, but there’s a huge amount of information in the noise, waiting to be released. Analytics brought rigorous techniques to decision making; big data is at once simpler and more powerful. As Google’s director of research, Peter Norvig, puts it: “We don’t have better algorithms. We just have more data.”

A question that skeptics of big data pose (2) is “Where’s the evidence that using big data intelligently will improve performance?” *Harvard Business Review* (2) studied this question and found that not everyone was embracing data-driven decision making. In fact, they found a broad spectrum of attitudes and approaches in every industry. Across all the analyses, one relationship stood out: the more companies characterized themselves as data driven, the better they performed on objective measures of financial and operational results. In particular, companies in the top third of their industry in using data-driven decision making were, on average, 5% more productive and 6% more profitable than their competitors. This performance difference remained robust after accounting for the contributions of labor, capital, purchased services, and traditional IT investment. It was statistically significant and economically important and was reflected in measurable increases in stock market valuations.

Here are a few examples of use for big data in transportation:

- **Railways.** Just like many other industries, railroad companies have integrated big data into many different aspects of their operations (3). Certain elements of the railway system are predictable. The staff, cars, and schedule are predetermined before a single car is moving, although large amounts of data are also generated once the trains start moving. The big data sources utilized in the railroad industry include the following:

- GPS units combined with weather data (can be used to ensure train safety);
 - Handheld field tablets;
 - Maintenance logs;
 - GPS units that record speed, distance between trains, arrival time and location;
- and
- Visual and acoustic sensors in brakes, rails, switches, and other hardware.

All of these data sources provide rich analytics that can quickly influence both automated and human decision making. As an example of railway automation, one of the nation’s largest railroads invested in a fully automated rescheduling system.

This big data system manages the rescheduling of over 8,000 trains. No matter what unexpected scenario comes up, these 8,000 trains are now able to be on time across 23 states.

- **Traffic management.** The Center for the Management of Information for Safe and Sustainable Transportation (CMISST), one of the UMTRI’s (7) newest initiatives, is a data center that gathers, combines, and analyzes all types of transportation datasets to answer pressing questions in transportation safety and sustainability. CMISST provides members with a

range of services and access to a rich array of UMTRI data, including data on driver behavior, fuel use, heavy truck transportation, crash data, and other relevant linkable datasets. CMISST researchers develop new techniques to combine and statistically analyze these disparate datasets to reveal new information. Results of CMISST analyses can allow the users to better understand the factors that impact transportation safety and sustainability and identify the most effective crash and injury countermeasures.

In one New Jersey town, 22-ft tall sensor screens (3) pick up millions of daily cellphone and GPS signals from commuters passing by. This data translates the following information to road operators:

- Car speeds,
- Sources of acceleration and deceleration,
- Weather conditions, and
- Community events.

The data is then cross-referenced with other data on road conditions from sensors and other sources. All of this data is woven together to form a live-data traffic map of over 2,600 mi of New Jersey roads.

In several state DOT traffic management centers, states including Utah, Michigan, California, and Virginia generate significant traffic information via roadway sensors, video detection, surveillance cameras, construction data, work zone data, transit data, weather information, traffic probe data, and several other sources. Applying analytics, such raw data are turned into actionable information, and inform travelers in simple formats such as travel time, empowering travelers to make smart travel choices.

- **Delivery and trucking companies.** One of the ways big data (3) is saving trucking companies money is with fuel consumption. In some cases, mathematical models are used to optimize shipping routes. By honing in on inefficient driving routes, drivers can see a reduction of nearly 1 mi of driving every day. For a company like UPS, a reduction of 1 mi per day per driver would equal a savings of as much as \$50 million a year in fuel.

Another way trucking companies use data to save money on fuel is by using predictive modeling to select fuel-efficient trucks. One company was depending on this data to help them make the right choice in selecting a new fleet of 50 trucks, a \$6-million decision.

The predictive model used to determine the fuel economy of the trucks analyzed much more than standard metrics. They combined data variables like driving behavior, fuel tank levels, load weight, road conditions, and much more. The detail of the data provided executives with a clear picture of which trucks would provide the most fuel savings over time.

4.3.3 Business Models

Some public agencies have tried (and succeeded in some cases) to leverage the significant data they possess and obtain certain services and products from private industry. In exchange for access to their publicly owned data, they provide an opportunity for the private sector to realize financial gains through repackaging the data and using analytics so as to provide prospective customers with actionable information.

Innovative, sustainable big data business models are as pervasive and sought after as they are elusive (8) (Figure 4.2). For every startup that designs and implements a simple and

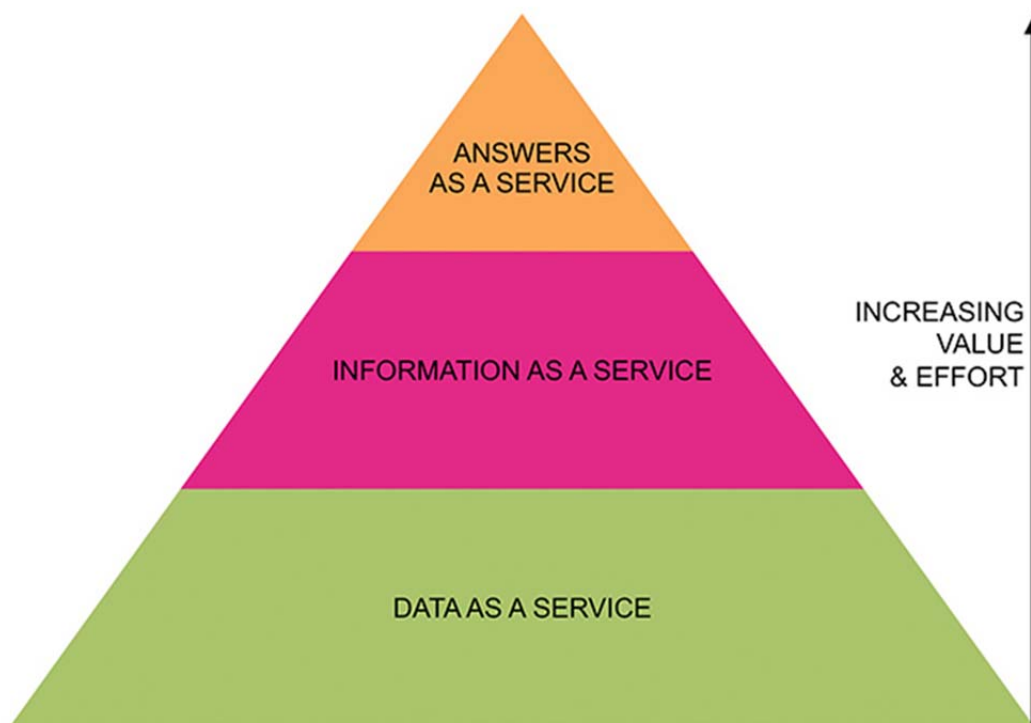


FIGURE 4.2 Big data business model (8).

effective big data business model (e.g., any social network), there are likely hundreds (if not thousands) of larger, more mature companies looking to monetize their own big data in order to capture new revenue streams. Some of the larger, mature companies, which have vastly different business models, have done quite well in this regard. These companies have built solid business models around big data by using big data to present consumers products and services that might be relevant to them. The value proposition underlies these business models so as to help companies create, deliver, and capture value using big data.

Fall in love with the problem, not the solution! —Uri Levine, Waze cofounder

Most mature companies (8) first ask “What big data do we have today?” followed by, “how might we sell this data?”

Here are highlights of three categories of big data business models, called Data as a Service (DaaS), Information as a Service (IaaS), and Answers as a Service (AaaS), as based on their value propositions and customers. Rather than focus on the myriad of ways that a company can monetize the big data ecosystem, like the transportation of big data, these business models center on companies that have valuable big data that they want to monetize.

The first of these business models, DaaS, is focused on providing customers a way to mine their own insights. This business model hinges on a value proposition for supplying large amounts of processed data with the idea that the customer’s job-to-be-done is to find answers or develop solutions for their customers. The customers in this case may be solution providers looking to use raw data to enhance their own offerings (i.e., value proposition) or even

developers wanting to develop niche applications. The data in this business model is aggregated from the company's own customers or from outside sources (e.g., key partners). In DaaS' business model, its key objectives are to create, market, and sell a viable value proposition at a relatively low cost. However, in order to engender trust among all customers, the most important—and probably expensive—activity in this business model is processing data such that it is stripped of any sensitive customer details. Once the data has been processed and cleaned up by the companies' key resources (or key partners), the rest of this business model involves ensuring that customers are able to use the data to enhance their own value propositions. The data in this case is only valuable as a support mechanism for customers to create other value propositions; the revenue stream is typically lower than in the other business models. Examples of organizations that use this business model are government open data sites (e.g., datasf.org), and commercial vendors, like Gnip and Twitter. Many of the public agencies in transportation /traffic management industry typically provide their data free to users.

The second big data business model, IaaS, focuses on providing insights based on the analysis of processed data. In this case, the customer's interest is in being able to come up with their own conclusions or even to sell an idea based on certain information. Additionally, IaaS customers do not want or have the resources to process and analyze data. Rather, they are willing to exchange value for analysis from trusted parties. Unlike the DaaS business model, which aggregates and disseminates processed data for customers' own use, the IaaS business model turns data into information for customers who need and are willing to pay for a tailored product. To do this, key activities must include analysis and data visualization as well as research that can enhance the data analysis. This business model's value proposition may also be more targeted for specific customer segments. For instance, location information companies, like HERE is selling is maps and other information to companies for use in their own navigation systems. To do this, HERE collects, aggregates, and cleans data, eventually turning it into information in the form of stylized, visual maps (i.e., information) that can be sold to customers. Another example is INRIX that sells traffic information and data to public and private customers. Health tracking companies like FitBit sell products with value propositions that focus on providing analytics based on tracking consumers' activity. These abovementioned companies collect, aggregate, and turn data into consumable information.

The third big data business model, AaaS, is focused on providing higher-level answers to specific questions rather than simply the information that can be used to come up with an answer. AaaS customers often need specific direction in order to make decisions. In fact, the customers in this case may be willing to make spontaneous buying decisions given the right value proposition (i.e., answers). This business model is the top of the pyramid when it comes to big data. The key with this business model is that, given the company's ability to create real, trusted value in the answers it provides to customers, customers in turn will exchange an increased amount of value in kind. An example is Mint, the personal money management service available both online and as an app. Mint facilitates the ability of people to provide basic information, like bank details. Mint then uses that data to track, analyze, and visualize the resulting information for consumer consumption. However, where answers come into play is when the consumer provides credit card details. Mint will not only make transaction information for those credit cards available, but will also sell the resulting information to other credit card companies in return for the ability to advertise credit cards with better rates (i.e., answers). Whereas, customers typically become uneasy with the notion of some company selling their credit card information, in this case there is true, defensible, and desired value

exchange for the answers returned back to consumers. Likewise, Google's new Google Photos service will churn through photos identifying people, places, and situations—some of the most personal data. However, in return the service creates real value in the form of curated stories, auto-stylized photos, and GIF animations, all of which can be considered as answers in this case.

There are plenty of other business model options that can be designed to exchange the value that big data creates. For big data business models, the data in question can come from many sources, from aggregated customer data, free and commercial sources, and from single parties.

4.3.4 Key Organizations and Players

Organizations and players in big data arena are broad based. Examples are illustrated in [Table 4.3](#).

4.3.5 Efforts in Convening and Publicizing

There have been a significant number of conferences, summits, and organizational gatherings on big data in recent years. The focus of these gatherings have been both in education as well as specific topics related to big data such as interfaces, standards, security, analytics, etc.

Examples of these events include:

- 2nd International Conference on Big Data Analytics and Data Mining (OMICS International), November 30–December 2, 2015, San Antonio, Texas. <http://10times.com/big-data-analysis-and-data-mining-sanantonio>.
- Big Data Summit (CDM Media event), November 10–11 2015, Phoenix, Arizona.
- Big Data and Marketing Innovation Summit (by innovation enterprise). <https://theinnovationenterprise.com/summits/calendar>.
- Big Data, Bigger Marketing, November 5–6, 2015, Miami, Florida.

There are many more planned in the upcoming months for various groups, such as:

- IEEE International Conference on Big Data, October 29–November 1, 2015, Santa Clara, California.
- American Association of Big Data Professionals, Washington, D.C., October 29, 2015.
- INNS Conference on Big Data (“We emphasize new approaches to solving hard big data problems”), August 8–10, 2015, San Francisco.
- Big Data Value Association, BDVA Summit, June 17–19, 2015, Madrid, Spain.
- Digital Analytics Association Symposium, February 10, 2015, Los Angeles.

The media has been covering this subject increasingly since the introduction of analytics a decade ago.

TABLE 4.3 Key Players in Big Data

Key Sectors–Categories	Examples of Key Players
Public agencies: federal, state, regional, local	<ul style="list-style-type: none"> • FAA • FHWA • FTA • U.S. DOD • Caltrans • Florida DOT • Virginia DOT • Michigan DOT • Texas DOT • San Francisco Metropolitan Transportation Commission • Southern California Association of Governments • San Diego Association of Governments • Georgia DOT • New York City DOT • Illinois DOT
Associations	<ul style="list-style-type: none"> • Big Data Value Association • Big Data and Analytics Association • Digital Analytics Association • American Statistical Association and Big Data • American Association of Big Data professionals
Private industry	<ul style="list-style-type: none"> • Amazon • Google • Accenture • SaaS • Oracle • SAP • HP • IBM Cloudera • Mongo DB • Hortonworks • Pivota • Syncsort
Universities	<ul style="list-style-type: none"> • Drexel University • George Mason University • George Washington University • Michigan State University • New York University • Rutgers University • Texas A&M • University of Maryland • University of Michigan • University of Texas at Austin • University of Virginia • Carnegie Mellon University • Fordham • Syracuse • Stanford University • Northwestern • UCSD

4.3.6 Adjacent Technologies and Interconnected Matters

Big data typically interacts strongly with topics of IoT, smart cities, data security, and cybersecurity. In transportation and traffic management, big data has often come from the generation of significant roadway and intersection data generated by sensors. As of late, big data will largely be generated by automated vehicles systems and sensors, and those collected by connected vehicles deployment programs. Vehicle OEMs are accustomed to generating big data in their diagnostic, safety, information, and entertainment systems.

There appears to be a strong correlation of big data with the subject topics reviewed in this report. With the availability of advanced sensors, wideband communication, speed of

processing and storage, and analytics, one could envision big data as a common element or platform among IoT, smart cities, CAVs, UASs, and NextGen.

REFERENCES

1. Big Data, Wikipedia. https://en.wikipedia.org/wiki/big_data.
2. McAfee, A., and E. Brynjolfsson. Big Data: the Management Revolution. *Harvard Business Review*, October 2012. <https://hbr.org/2012/10/big-data-the-management-revolution/ar>.
3. Nemschoff, M. Why the Transportation Industry Is Getting On Board with Big Data and HADOOP. MAPR, August 28, 2014. <https://www.mapr.com/blog/why-transportation-industry-getting-board-big-data-hadoop>.
4. Big Data. SAS. http://www.sas.com/en_us/insights/big-data/what-is-big-data.html.
5. Press, G. A Very Short History of Big Data- Gil Press. *Forbes*, May 9, 2013. <http://www.forbes.com/sites/gilpress/2013/05/09/a-very-short-history-of-big-data/>.
6. Manyika, J., M. Chui, B. Brown, J. Bughin, R. Dobbs, C. Roxburgh, A. Hung. Big Data: The Next Frontier for Innovation, Competition, and Productivity. Byers McKinsey-Global Institute, May 2011. http://www.mckinsey.com/insights/business_technology/big_data_the_next_frontier_for_innovation.
7. CMISST. University of Michigan Transportation Research Institute. <http://www.umtri.umich.edu/who-we-are/research-groups/cmisst>.
8. Business Models Inc. <http://www.businessmodelsinc.us/exploring-big-data-business-models-the-winning-value-propositions-behind-them/>.
9. Gross, B. Linked-in, Google's Self Driving Car Gathers Nearly 1 GB/Sec, May 2, 2013. <https://www.linkedin.com/pulse/20130502024505-9947747-google-s-self-driving-car-gathers-nearly-1-gb-per-second>.

The National Academies of SCIENCES • ENGINEERING • MEDICINE

The **National Academy of Sciences** was established in 1863 by an Act of Congress, signed by President Lincoln, as a private, nongovernmental institution to advise the nation on issues related to science and technology. Members are elected by their peers for outstanding contributions to research. Dr. Ralph J. Cicerone is president.

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

The **National Academy of Medicine** (formerly the Institute of Medicine) was established in 1970 under the charter of the National Academy of Sciences to advise the nation on medical and health issues. Members are elected by their peers for distinguished contributions to medicine and health. Dr. Victor J. Dzau is president.

The three Academies work together as the National Academies of Sciences, Engineering, and Medicine to provide independent, objective analysis and advice to the nation and conduct other activities to solve complex problems and inform public policy decisions. The Academies also encourage education and research, recognize outstanding contributions to knowledge, and increase public understanding in matters of science, engineering, and medicine.

Learn more about the National Academies of Sciences, Engineering, and Medicine at www.national-academies.org.

The **Transportation Research Board** is one of seven major programs of the National Academies of Sciences, Engineering, and Medicine. The mission of the Transportation Research Board is to increase the benefits that transportation contributes to society by providing leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied committees, task forces, and panels annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

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



TRANSPORTATION RESEARCH BOARD

500 Fifth Street, NW
Washington, DC 20001

The National Academies of
SCIENCES • ENGINEERING • MEDICINE

The nation turns to the National Academies
of Sciences, Engineering, and Medicine for
independent, objective advice on issues that
affect people's lives worldwide.

www.national-academies.org

Copyright National Academy of Sciences. All rights reserved.