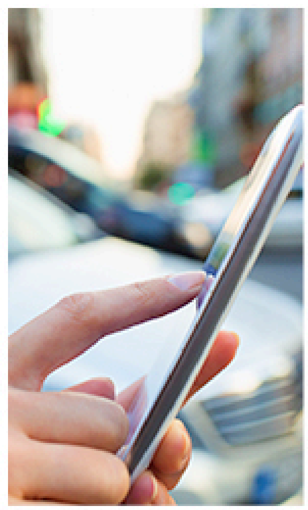
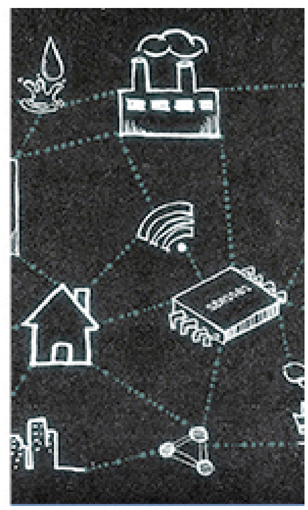
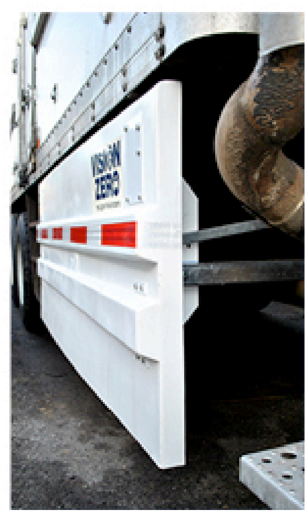
2015 OST-R Transportation Technology Scan: **A Look Ahead**

December 2015
DOT-VNTSC-OST-16-01







U.S. Department of Transportation
John A. Volpe National Transportation Systems Center

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<table>
<tr><td colspan="3">REPORT DOCUMENTATION PAGE</td><td colspan="2">Form Approved
OMB No. 0704-0188</td></tr>
<tr><td colspan="5">Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.</td></tr>
<tr><td>1. AGENCY USE ONLY (Leave blank)</td><td colspan="2">2. REPORT DATE
December 2015</td><td colspan="2">3. REPORT TYPE AND DATES COVERED
Final Report</td></tr>
<tr><td colspan="4">4. TITLE AND SUBTITLE
2015 OST-R Transportation Technology Scan: A Look Ahead</td><td>5a. FUNDING NUMBERS</td></tr>
<tr><td colspan="4">6. AUTHOR(S)
Elizabeth Machek, Joseph Stanford, Stephanie Fischer, Kara Canty, Brian Dechambeau, and Gary Ritter</td><td>5b. CONTRACT NUMBER</td></tr>
<tr><td colspan="4">7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
John A Volpe National Transportation Systems Center
55 Broadway
Cambridge, MA 02142-1093</td><td>8. PERFORMING ORGANIZATION REPORT NUMBER
DOT-VNTSC-OST-16-01</td></tr>
<tr><td colspan="4">9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</td><td>10. SPONSORING/MONITORING AGENCY REPORT NUMBER</td></tr>
<tr><td colspan="5">11. SUPPLEMENTARY NOTES
Project Manager: Elizabeth Machek</td></tr>
<tr><td colspan="4">12a. DISTRIBUTION/AVAILABILITY STATEMENT</td><td>12b. DISTRIBUTION CODE</td></tr>
<tr><td colspan="5">13. ABSTRACT
This report identifies emerging technologies and innovative applications that may begin to have significant impact on our transportation systems within three to five years. They represent several industries and disciplines and could affect all major modes of transportation. The report is intended to stimulate discussion across the U.S. DOT and inform thought leadership on promising areas of innovation and where public research investments should be focused. Identifying these innovations will also enable leaders and policymakers to anticipate important opportunities, as well as potential challenges. There are large areas of overlap among the technologies featured and many of them are intimately interrelated—with a few major overlapping themes, including: the growing role of data and connectivity, changes to the workforce, and uncertain impacts on travel behavior.

This report was developed by leveraging the resources and knowledge of the U.S. DOT; it was prepared by the Volpe National Transportation Systems Center, in consultation with modal agency members of the U.S. DOT Research, Development and Technology planning team. In selecting technologies for this scan, the project team referenced trends identified in U.S. DOT's report Beyond Traffic 2045, conducted a technical literature review, and consulted with research leaders at the U.S. DOT modal administrations.</td></tr>
<tr><td colspan="4" rowspan="2">14. SUBJECT TERMS

Technology, innovation, emerging technology, transformation, automation, transportation systems, impacts, implications, benefits, risks.</td><td>15. NUMBER OF PAGES
39</td></tr>
<tr><td>16. PRICE CODE</td></tr>
<tr><td>17. SECURITY CLASSIFICATION OF REPORT
Unclassified</td><td>18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified</td><td colspan="2">19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified</td><td>20. LIMITATION OF ABSTRACT
Unlimited</td></tr>
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NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18298-102

Contents

Foreword

Transportation is inextricably linked to every facet of life and commerce in the United States—if our transportation systems are capable of meeting demands, our communities and businesses thrive; when they are failing, the consequences are felt everywhere. Throughout the nation's history, technological advancements have played a key role in building and improving our transportation systems. As a result, transportation has been a powerful driver of our economic progress. Technologies like the Global Positioning System (GPS) and broadband wireless communications have already transformed transportation in the 21st century. So I am excited to present this visionary document, the *2015 OST-R Transportation Technology Scan: A Look Ahead*, which examines a number of promising technologies that may have substantial impact on our transportation systems in the near future.

In *Beyond Traffic: 2045*, Secretary of Transportation Anthony Foxx identified a number of challenges we face in the coming decades:

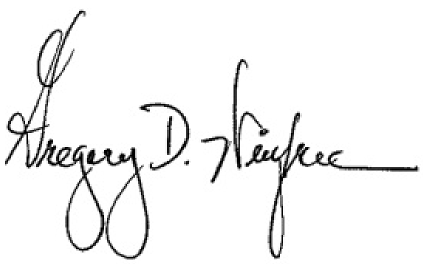
- Our transportation systems will need to accommodate a growing population and a growing economy.
- Our infrastructure will need to adapt and be more resilient as the effects of climate change continue to unfold.
- The solutions we develop must be environmentally sustainable, while maintaining or improving access and social equity.

These are daunting challenges, but I have unwavering confidence in the ingenuity of American inventors, engineers, and entrepreneurs to get the job done. Advances in just the past decade have dramatically changed the way Americans travel and deliver goods, and the pace of change is something we cannot dictate. This is why we must be proactive and look to new technologies that have clear applications for transportation. However, new technologies can also introduce new risks, and we must anticipate the full range of potential impacts. Our approach needs to strike a balance between supporting innovation and mitigating risk.

Technology is fundamental to the mission of the U.S. Department of Transportation (U.S. DOT). As described in *Beyond Traffic*, to restore our global leadership in transportation it will be essential to employ, "…technologies and better design approaches that will allow us to maximize the use of our old and new transportation assets." But the federal role is a complex one: while we promote beneficial technologies, we also need to identify and understand the potential risks and ensure that all transportation technologies are safe.

These responsibilities call on us to support critical research and development, enabling the transportation breakthroughs of tomorrow; to collect and manage data, fulfilling our vital role as the nation's repository for information about transportation systems; and to manage the regulatory regime, reducing regulatory barriers to beneficial technologies, ensuring that regulations address new challenges as they arise, and always striving for the optimal state where regulations do not inhibit innovation, but help guide it toward the most beneficial outcomes.

Ultimately, the right balance of technology and policies will enable us to rise to meet the challenges of the next 30 years—meeting future needs and demands while reducing the social and environmental costs of our transportation systems and their associated infrastructure.



Gregory D. Winfree
Assistant Secretary for Research and Technology
U.S. Department of Transportation

Introduction

This report identifies emerging technologies and innovative applications that may begin to have significant impacts on our transportation systems within three to five years. They represent a sampling from a broad cross section of industries and disciplines; collectively, they could affect all major modes of transportation in the United States and enable new approaches to resolving longstanding problems in transportation, such as safety, network efficiency, and mobility for all users.

The intent of this document is to stimulate discussion across the U.S. DOT and ultimately inform thought leadership on what the most promising areas of innovation are and where public research investments should be focused. Identifying these innovations and leading the conversation about them will also enable leaders and policymakers to anticipate important opportunities, as well as potential challenges. The intent is not to single out any particular subject for special consideration, but to present a diverse and thought-provoking array of innovations.

There are large areas of overlap among the technologies featured, and many of them are intimately interrelated. Looking across the technologies identified, a number of themes emerge:

- *The growing role of data and connectivity.* New sources and uses for data are both an opportunity and a challenge, demanding a balance between access to data and the need to ensure security and protect privacy. Connectivity enables powerful real-time or near real-time data-driven applications.
- *Changes to the workforce.* Many of the technologies examined will have varied impacts across different sectors of the labor force, creating entirely new jobs, requiring new skills in some areas, and causing economic disruption and displacement of jobs in others.
- *Uncertain impacts on travel behavior.* One of the hardest things to predict is how people will use new technologies—both in terms of how existing travel behaviors may change and whether entirely new behaviors will emerge. Such changes present opportunities as well as risks.

Ultimately, we can expect the unexpected: these technologies will evolve and interact in ways we cannot imagine today. Further, the role of basic science research remains a wild card, as breakthroughs in fundamental understanding could spur further advances that cut across many of these areas of innovation.

While some of the technologies featured are still in development, the impacts of others are already being felt. For example, on-demand ride services and shared use mobility are prompting several cities worldwide to initiate ambitious planning to restrict privately operated cars in city centers in order to reduce congestion. One concept being pursued by the City of Helsinki is to integrate a variety of mobility options into one public utility application (app). Users would enter their origin and destination into a smartphone app to calculate the optimal route and identify the best modes—e.g., on-demand ride services, rail, buses, and bike-sharing. The app would function as both a trip planner and a universal payment method.[i] If successful, the scheme could improve mobility for all users while reducing costs, road congestion, and vehicle emissions.

As with any technology survey, some important innovations have necessarily been omitted, particularly those where U.S. DOT is already devoting significant attention and resources to a technology and has a well-established role in the field. In other cases, such as advanced propulsion systems and fuels, much of the research and analysis is being undertaken by other entities, such as the U.S. Department of Energy. U.S. DOT is aware of those efforts, and relationships with those entities are already well established. A few key examples of important innovations that have not been included are acknowledged below:

- **Connected Vehicle Technologies:** These technologies have the potential to transform the way Americans travel, through the use of a safe, interoperable wireless communications network—a system that includes cars, buses, trucks, trains, traffic signals, smart phones, and other devices. U.S. DOT is already heavily involved in this field, with the Intelligent Transportation Systems (ITS) Joint Program Office fostering the development and future deployment of connected vehicle technologies, and with active participation from all agencies within the U.S. DOT as well as several leading auto manufacturers and academic research institutions.
- **Advanced Aviation Systems:** To make best use of emerging technology to meet the needs of the flying public, the Federal Aviation Administration (FAA) has committed to major investments in NextGen—a wide-ranging transformation of the air transportation system, including air traffic management technologies and procedures; airport infrastructure improvements; and environmental, safety, and security related enhancements.
- **High speed rail technologies:** While already well established in other countries, high speed rail could still have a large impact in the United States in the coming years, by competing for airline traffic, alleviating aviation congestion, improving mobility, and boosting regional economies.
- **Advanced propulsion, alternative fuels, and related infrastructure:** Extensive R&D efforts are under way to develop energy technologies for transportation, including improved batteries, electric-drive systems, fuel cells, and systems for producing and delivering biofuels and hydrogen. In addition, the use of natural gas for transportation is likely to continue to grow and expand into new modes. New technologies and infrastructure will be required to enable these advances in alternative-fuel delivery and battery charging, and these changes may have a significant impact on our transportation systems and energy infrastructure. It will be essential to consider the broad spectrum of energy requirements for our future transportation needs and to ensure that the supporting infrastructure is in place.

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Emerging Technologies

The Internet of Things

Image: 123RF

Background

The Internet of Things (IoT) is the network of interconnected, uniquely identifiable devices embedded in physical objects or *things* (which can also include people and animals). These devices can be sensors, actuators, and communications technologies that enable communication and control functions between devices and external operators, external systems, and among devices themselves. They can also include processors to add intelligence at the device level. IoT devices can be embedded at virtually any scale—from locomotive engines and ships, to wearable sensors, and all the way down to the molecular level. With the potential to connect almost any object to a network, the reach of IoT could be practically limitless.

Early and emerging examples of consumer applications include smart-grid applications that monitor and control energy use, smart appliances that add items to a shopping list, and vehicles that coordinate with users' calendars and reserve parking at destinations. Cloud-connected wearable sensors are already being used to track physical activity, sleep patterns, travel patterns, and more. Connected vehicle systems (V2V, V2I, and V2X) currently under development represent a potentially transformative application of IoT to the transportation sector. However, potential applications extend well beyond these examples and include any application for Internet-based sensing, communications, and control of connected devices. More-advanced applications involve machine-to-machine communications and automated control, as well as communications and control across networks of networks.

The rapid growth of IoT represents the convergence of advances in several areas, including embedded computing, wireless communications, sensor networks, control systems, automation, and others. IoT technologies are also benefiting from increases in processing power, reductions in the cost of using wireless bandwidth, and improving capabilities for processing and understanding data. [ii] A report by *MIT Technology Review* predicts that by 2020, the "number of everyday objects, or 'things,' connecting to the Internet will exceed PCs and smartphones." [iii] Additional forecasts estimate that IoT-connected devices could number over 50 billion and generate over $14 trillion in net profits within the next 10 years. [iv]

Opportunities | Challenges | Risks

The ability to monitor and collect real-time data from a growing number of sources provides many new opportunities. This is true particularly for asset management and maintenance, but also for the whole lifecycle of products and systems, from performance monitoring and identification of maintenance issues, to process improvement (e.g., more-efficient maintenance schedules), monitoring of overall system operations, and improvements in engineering and design concepts. Access to unprecedented amounts—and kinds—of data is also leading to more applications for reuse and recycling of data.

To realize these opportunities, however, significant technical and operational challenges will have to be overcome. Fast, universal network coverage must be scalable to billions (or even trillions) of devices, which will involve issues of limited spectrum capacity as well as interoperability issues. Other technical challenges involve finding new ways to power remote devices, and reducing the cost of devices to enable large-scale deployment. Major advances may be needed in big data management and analytics as well, in order not to be overwhelmed by the sheer volume of data.

Given the number of potentially vulnerable connected devices, the most significant risks are expected to emerge around issues of security, privacy, and governance; many experts consider these risks to be very serious, calling into question the whole future of IoT. For example, a recent report from an IEEE forum [v] highlighted the concerns of a number of experts that unless there is a paradigm shift in the way software is developed, IoT applications may not be secure, and as a result, they may ultimately cause more harm than good. The view appears to be widely held that the approaches used to develop the Internet thus far will not provide the level of security and resilience needed in a world of billions of connected machines and sensors.

Implications for Transportation

It would be difficult to overstate the potential implications of IoT. Many of the beneficial near-term implications of IoT technologies for connected vehicle applications are already well understood, and U.S. DOT is actively working to advance them. Some additional related concepts include:

- Bicycle-to-infrastructure and pedestrian-to-infrastructure applications that can track usage patterns to help plan better infrastructure and services for all road users.
- Increasingly granular information from infrastructure components—e.g., from bridge sensors that detect icing and alert approaching vehicles, or structural components within a bridge that monitor conditions and provide advance warning of critical safety and maintenance issues.
- The integration of smart transportation (e.g., traffic management and parking) within broader systems-of-systems (e.g., smart cities).

- Improved contextual awareness, enabling operators and vehicles to know more about what is going on around them from the broader IoT, not just from a discrete set of infrastructure elements; and the use of big data tools to analyze these contextual data and predict hazards.

The implications for operations and asset management are extensive. For example:

- Real-time monitoring of performance variables in transit vehicles would enable manufacturers to advise operators on specific vehicles and provide feedback for system improvements.
- Semi-autonomous freight delivery with robotic loading and unloading could be supplemented by real-time tracking of other parameters related to shipments, beyond location information.

Wearable sensors could combine GPS data with physiological data. Potential benefits include:

- Better understanding of the relationship between transportation and health by combining data on travel patterns, air quality, physical activity, physiological data, and other health indicators.
- Monitoring alertness and physiological conditions of airline pilots and transit and freight vehicle operators, particularly regarding fatigue detection.
- Real-time detection of environmental hazards (e.g., toxic or explosive chemicals) and physiological responses of transportation maintenance and construction workers.

Advanced Analytics and Machine Learning

Image: 123RF

Background

Transportation runs on data. Our transportation system is constantly producing data about asset conditions, vehicle movements, network conditions, and more. Data are used for both short-term decisions, such as helping to decide the best route to take, and for long-term projections and investments. There is enormous potential to improve transportation planning, management, and safety through real-time analysis and longer-term modeling.

Opportunities | Challenges | Risks

Big data analysis has the potential to spur productivity, growth, and innovation, as long as the right policies and enablers are in place. It will be a challenge to unite transportation domain expertise with data science, and transportation agencies must grapple with questions such as how to enter into data-sharing partnerships and which protocols will best protect privacy.

In addition to new data sources, new mechanisms have changed the way data are processed and interpreted. Advanced analytics are using the growing capability of today's computers to identify patterns, which can then be used to make well-informed predictions. Machine learning techniques make it possible to derive patterns and models from large volumes of data as well as to grapple with high-dimensional data, where each data sample consists of many data points. Big-data platforms leverage distributed file systems and parallel computing to enable fast processing of data, enabling both real-time and predictive analysis.[vi] Improved visualization and simulation tools have also greatly expanded the utility of all these new data, making them easier to use for predictive modeling and making the graphical outputs more readily understandable and even more insightful.

Implications

- Real-time traffic analysis permits new paradigms for traffic operations and management, by enabling system-wide rather than roadway-level management.
- The capability now exists for making sense of large traffic data streams in real time, as well as supporting large-scale traffic simulation and near-term traffic forecasts.
- Predictive analytics allow new mobility options and pre-trip guidance for travelers. “Traffic watch” systems display the current location and status of all incidents from multiple sources, including social media. In time, incident duration prediction from machine learning should be able to estimate the duration from response activation to clearance time.
- Sensors currently allow transit system operators to remotely monitor rolling stock equipment vibration (a performance indicator), video cameras, HVAC equipment, temperature, humidity, system alerts, and fault warnings.[vii] These systems can enable a risk-based approach to preventive maintenance. In addition, predictive analytics have the potential to improve defect investigation for all types of vehicles.
- The amalgamation of data from disparate technologies such as E-call, E-911, and vehicle black boxes may provide post-crash data for improving emergency services and crash investigations. Opportunities exist to combine vehicle-related data in a common format that could enhance road safety.

Automated Vehicles

Photo: Google

Background

Recent advances in robotics, machine vision, machine learning, and sensor technologies, with accompanying reductions in the cost and size of powerful computer processors, have brought automated vehicles out of the realm of science fiction and onto public roads. Automated vehicles are those in which at least some aspect of a safety-critical control function (e.g., steering, throttle, or braking) occurs without direct driver input. With few exceptions, major automakers and suppliers, as well as new market entrants such as software companies, have announced plans to release partially or fully automated vehicles within a decade. One forecast[viii] suggests there will be 54 million automated vehicles worldwide by 2035. Some production vehicles available today use partial automation technologies, but they require a human driver to continually monitor the road and surrounding traffic and be prepared to take control.

Opportunities | Challenges | Risks

Automated vehicles have the potential to reshape transportation, and they represent both opportunities and challenges. Putting technical and institutional challenges aside, the expected benefits could be quite substantial. These benefits could include crash avoidance, reduced energy consumption and vehicle emissions, reduced travel times, improved travel time reliability and multimodal connectivity, and improved transportation system efficiency and accessibility, particularly for persons with disabilities and older Americans. The benefits for applying this technology to public transit have been less frequently discussed but could be substantial as well, particularly for applications that could provide low cost first- and last-mile mobility, with potentially dramatic improvements in the reach of transit networks.

On the other hand, widespread adoption of fully automated vehicles, especially as privately owned passenger cars, presents significant uncertainty. Anticipated benefits are as yet unproven, and automated vehicles could create new risks or have unexpected negative operational, environmental, or societal outcomes. For example, vehicle automation could remove some of the most powerful disincentives for driving, causing both an increase in the number and length of trips taken by car and a potential mode shift away from public transit. By removing the need for a driver's full-time attention, the costs incurred by driving (in terms of fatigue, stress, and lost productivity) could be substantially reduced or even eliminated. This could spur radical changes in how people choose to travel and in the amount of traveling they do. Over the longer term, these behavioral changes could lead to entirely new usage patterns, with significant impacts on public transit, transportation infrastructure, land use, and urban form.

Research | Initiatives | Solutions

Research, development, and testing of fully automated vehicles is progressing at a rapid pace; at least one company has logged over a million self-driving miles under a variety of highway and street driving conditions. Transit buses with automated lane keeping and curb docking features are being piloted in Eugene, Oregon, and Apple Valley, Minnesota, and a project in Europe (Citymobil2) is demonstrating low-speed, autonomous mini-buses as a supplement for traditional mass transit in dense urban cores. The Freightliner Inspiration Truck Highway Pilot was issued a Nevada license plate for testing[ix] in May 2015.

Extensive research has been conducted to understand some of the direct and immediate effects of automation—e.g., in terms of reducing crashes, increasing road capacity, etc.—but so far very little research has examined the potential long term, system-wide impacts. As automation technologies begin to come to market, transportation agencies will need to closely monitor and continually assess developments and plan for appropriate actions.

Implications for Transportation

- The near future of vehicle automation is likely to be characterized by uncertainty. Changes to key indicators (vehicle miles traveled [VMT], safety, congestion, fuel consumption, personal mobility) are unknown. Little data exist to indicate the scale of the change and, in many cases, it is uncertain whether the overall change will be positive or negative.
- Long-range urban transportation planning should begin to consider automation-driven changes, especially regarding location choice and land use impacts. However, reliable projections and data are not yet available.
- Automation also introduces a wide range of new potential uses and new driving behaviors for road vehicles. The ability to use a vehicle with no human occupant could spur additional applications, including low-cost deliveries, errand running, and others.
- Increasing automation at intermodal facilities, already in progress, is likely to substantially increase.
- Traditional transit modes could become more flexible and dynamic, dramatically evolving over the long term.

- Vehicle sharing could become a much more attractive option, as shared automated vehicles could provide door-to-door service, and the current challenge of situating vehicles where they are needed could be overcome by the vehicles relocating themselves.
- Automated operation of construction vehicles could improve work zone safety and efficiency.
- Many of the above could have significant productivity and workforce impacts, affecting both the number of jobs and the skills required. Transportation agencies will likely continue to find that information technology skills are increasingly important.
- Current ridesourcing operations (e.g., Uber) could dramatically reduce costs and may become serious competition for transit in some (lower density) situations. However, they may also provide a supplemental service to mass transit and could provide a low-cost solution for paratransit. Planners and policymakers will need careful policy analysis to manage these complex dynamics to arrive at desired outcomes.

Unmanned Aircraft Systems

Photo: 123RF

Background

Unmanned aircraft systems (UAS), sometimes called drones, have a long history originating in military operations, and today have many uses in law enforcement, firefighting, border patrol, disaster relief, search and rescue, and other government operational missions. FAA first allowed the use of UAS in the national airspace system in 1990, and most UAS that are allowed to operate today are used for security, research, and environmental monitoring purposes.

In recent years, private sector interest in UAS has increased rapidly. The private sector sees the potential for a wide range of uses of UAS—from crop dusting and land surveying, to package delivery and filmmaking. A recent U.S. DOT report commissioned by the United States Air Force estimated that, between public and commercial uses, by 2035 the total number of UAS vehicles in operation will reach 250,000 and unmanned aircraft operations could surpass manned aircraft operations.[x] Worldwide spending on UAS is expected to double by 2023. The technologies needed to support increased adoption are developing rapidly, costs are falling, and applications are growing.

Opportunities | Challenges | Risks

UAS technology presents policy challenges, as regulators seek to balance safety, privacy, and new economic opportunities. While there are abundant opportunities for new recreational and commercial uses of drones, many of these uses raise significant concerns about safety, privacy, criminal and terrorist activity, and quality-of-life issues (e.g., noise and visual intrusion). Safety concerns, in particular, have gained media attention, especially in light of an incident in California where firefighting helicopters were grounded due to the presence of recreational drones in the area (presumed to be filming the fire for their owners).[xi]

Existing restrictions on the use of UAS have been based around concerns about the safety and intent of the use of these vehicles. While restrictions currently exist on the use of UAS for commercial purposes, consumer use is largely unregulated. In general, flights at very low altitude and within line of sight of the operator are permitted. Higher-altitude and longer-distance flights are currently a subject of more intense regulatory attention, and potential certification of operators is also under consideration. UAS operation over major urban areas, where there tend to be high densities of manned aircraft, is limited and approved on a case-by-case basis.

Research | Initiatives | Solutions

Since 2013, there have been six test sites around the country conducting UAS research. In order to safely integrate UAS into the national airspace system, several technical and procedural hurdles will have to be overcome (e.g., making sure UAS can detect and avoid other aircraft and maintain communication with pilots). FAA is pursuing a phased integration, and this gradual process is intended to ensure safety and manage risk to the national airspace system. Ongoing research, much of it conducted through public-private partnerships, is expected to help formulate strategies for: safe low-altitude operations; control and communications (including management of the frequency spectrum for communications); human factors; compatibility with air traffic control operations; and training and certification methods of UAS pilots.[xii] R&D efforts are also expected to develop “detect and avoid” capabilities that will allow flight operators to improve on today’s “see and avoid” protocols for detecting other aircraft. New technology solutions are expected to assist UAS in avoiding buildings, ensure that they stay away from sensitive areas, and facilitate a priority flight management and control system in congested air traffic areas.

Implications for Transportation

- The role of UAS in inspecting and monitoring transportation assets is expected to grow, e.g., UAS are now using sensors to supplement visual observation to detect leaks in pipelines,[xiii] and plans exist to use UAS to cost-effectively monitor road conditions from above, thereby reducing risks to transportation workers.[xiv]
- Retail delivery systems are envisioned: Amazon testified before the House Oversight Committee that the company is planning “a future service that will deliver packages of up to five pounds to customers in 30 minutes or less using small drones.”[xv] Amazon representatives suggested that such a service would not only please customers but also reduce road congestion and environmental impacts. Similar applications could emerge to supplement existing ground transportation services by providing first- and last-mile freight and package delivery.
- UAS are expected to enable new “find and deliver” capabilities. This could be an integral part of future search and rescue operations. An advanced system might be able to retrieve a person in distress or a lost item. Such applications could have tremendous benefits for disaster recovery and public safety operations.

Infrastructure Inspection Robots

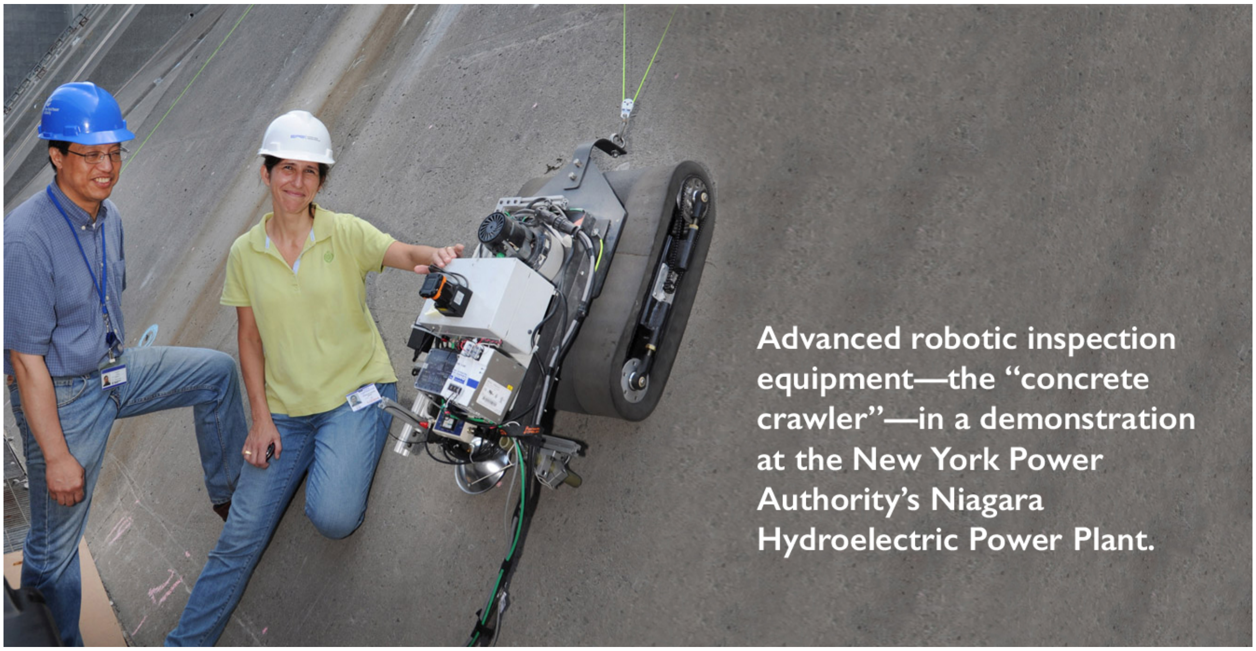

Photo: New York Power Authority

Background

Civil infrastructure that was built in the mid-20th century or earlier is reaching the end of its service life, making assessment of structural integrity and deterioration a top priority. Robotic inspection technologies use tools such as aerial and surface robots, sensors, and 3D imaging to advance inspection methods of aging infrastructure.[xvi]

Opportunities | Challenges | Risks

These technologies have the potential to improve safety and asset management in two ways. First, current prototypes have demonstrated the ability to detect internal and external infrastructure corrosion and damage using advanced sensors, providing more information to inspectors and agency decision makers. Second, robotic technology can reduce workplace injuries by accessing areas of the infrastructure that put even highly trained inspectors at risk, such as elevated rail tracks and underwater bridge pilings. Robotic infrastructure inspection also has the potential to reduce traffic disruption, as faster inspections may shorten the duration of lane closures.

Research | Initiatives | Solutions

A number of research initiatives are under way to develop sensors that can gather more and better data than traditional inspection methods. Some technologies detect slight but significant changes in structures and allow inspectors to be notified instantly. Algorithms under development detect changes such as unusual vibrations or surface anomalies. The addition of panoramic cameras and other data collection methods are allowing inspectors to capture visual images and real-time video feeds. For example, pipeline inspection robots can traverse thousands of feet of pipeline while collecting real-time visual inspection data. In contrast, traditional approaches using tethered systems are limited to an inspection range of 100 to 200 feet per excavation.[xvii] Bridge inspection tools are also being deployed in several states. These use technologies such as ground penetrating radar, electrical resistivity, and acoustic arrays to assess structural conditions. Data sets can be combined to produce instantaneous 3D images of bridge deck conditions. These types of tools not only enhance current visual inspection methods but combine them with a data-driven approach, which could include predictive models.[xviii]

Implications for Transportation

- Advances in robotics, automation, and sensor technology are expected to provide more efficient and comprehensive inspections and asset-management programs, resulting in improved reliability, safety, and longevity of infrastructure.
- New methods of inspection, repair, and maintenance are expected to be less invasive, less disruptive to traffic, and safer for workers. [xix, xx]
- Opportunities to analyze changes in infrastructure over time could emerge from enhanced integration of modeling into the inspection process.
- Additional applications of these advances include building inspections, assessment of infrastructure damage at disaster sites, and general tele-operation of vehicles (i.e., remote control). [xxi]

On-Demand Ride Services: Transportation Network Companies

Photo: 123RF

Background

On-demand ride services, also called transportation network companies (TNCs) or "ridesourcing," use smartphone applications to connect drivers with passengers. These services are part of the burgeoning sharing economy that uses online platforms to connect people seeking services with sellers of those services. In many cases the outcome, from a consumer perspective, is not very different from conventional taxi services: people are still paying for individual, point-to-point, on-demand rides in a car. However, the improvements in convenience, price transparency, and the availability of information about waiting times and travel times have had a powerful effect and are transforming the ways some people think about urban mobility. In addition, carpooling apps are helping to facilitate conventional ridesharing—where the goal is actually to share the expenses of a ride, instead of having a paid driver provide a service.

These innovations have arrived at a time when attitudes about vehicle ownership are changing. They may also play a role in spurring that change: surveys indicate that a majority of young adults would rather give up their cars than their smartphones.[xxii] Whether this attitudinal change is a permanent generational shift or a temporary development, Americans will continue to have mobility needs that cannot always be met with transit, bicycle, or walking trips. On-demand ride services, which can fill some of these gaps, are expected to continue to grow.

Opportunities | Challenges | Risks

The growth of these technology-driven mobility choices raises larger questions about their impacts on congestion, other modes, and emissions, as well as their economic impacts on cities and individuals. Preliminary analysis shows that users tend to be younger, own fewer vehicles, and travel with companions.[xxiii] The effects may be beneficial, if moving away from a car ownership model encourages more multimodal travel. For example, on-demand ride services may increase the accessibility of public transit by bridging gaps in first- and last-mile coverage.[xxiv] These services could also be considered a vital part of a portfolio of travel options that includes bike-sharing, public transit, and walking.

On the other hand, concerns exist that if on-demand ride services become too convenient or too inexpensive (especially if automated vehicles are used), they may end up displacing trips by transit and non-motorized modes, resulting in higher VMT and more congestion.

Research | Initiatives | Solutions

Additional opportunities are being explored, beyond the taxi-style service currently offered. For example, some operators have begun offering ridesharing (or ride-splitting), in which two or more people seeking similar routes share the cost of a ride.[xxv] This could have great potential to reduce VMT in dense areas. Another concept that has emerged is a kind of private, demand-responsive transit service, such as the one currently being pursued by Bridj. In preliminary operation in Boston and Washington, DC, Bridj uses diverse data sources (including social media and transit agency data) to provide on-demand bus service. Companies such as Bridj may be able to fill some gaps in transit system coverage by providing a complementary service; however, they may also compete with existing transit systems.

Implications for Transportation

- The emergence of ridesourcing businesses demonstrates a key challenge for governments—the “sharing economy” defies traditional categories of “business” and “personal,” and new business models are proliferating faster than laws and regulations can adapt to them. Over the next 30 years, our legal and regulatory systems may be increasingly challenged by emerging forms of business and travel that transcend traditional legal and planning concepts. Regulation of TNCs varies by state and municipality. For example, TNCs in California are under the purview of the state, leaving little authority for cities. Policymakers are continuing to grapple with issues such as insurance coverage requirements; paratransit for the disabled; licensing, driver, and vehicle safety checks; socioeconomic implications; and marketplace competition.[xxvi]
- Demand-responsive bus services could have the nimbleness and agility to explore new routes that have uncertain demand. When long-term routes with strong demand became apparent, they could transition to traditional fixed-route services.
- Similar approaches to ridesharing are also being employed to allow independent drivers to deliver meals and packages for businesses and consumers, and freight brokerage firms are using these platforms to match shipments with drivers. With over 20 billion miles per year driven by empty trucks in the United States, matching shipments to drivers could dramatically improve efficiency.
- Ridesourcing and ridesharing business models could help to speed the adoption of automated vehicles by lowering costs of ownership and expanding their accessibility.

Innovative Concepts for Protecting Pedestrians, Bicyclists, and Motorcyclists

Photo: 123RF

Background

Despite long term improvements in traffic safety, pedestrians, bicyclists, and motorcyclists (collectively referred to as "vulnerable road users") face increasing risks on our roadways. In 2013, 4,735 pedestrians were killed and over 65,000 were injured, averaging a death every two hours and an injury every eight minutes. The numbers are equally concerning for cyclists, with 743 deaths and 48,000 injuries in 2013. While traffic fatalities have been declining overall, between 2009 and 2013 the number of bicyclist and pedestrian fatalities increased by 15 percent and 16 percent, respectively.[xxvii]

Opportunities | Challenges | Risks

In response to growing threats to vulnerable road users, new technologies—ranging from hardware installed directly on vehicles to innovative, sensor-based detection systems—are developing at a rapid pace. Challenges are as varied as the solutions. For example, sensor-based systems must correctly interpret pedestrian movements in crowded urban areas and must distinguish necessary interventions from false alarms.

Research | Initiatives | Solutions

Building on successes seen abroad, several U.S. cities—including Portland, Oregon; Cambridge, Massachusetts; and New York City—are piloting programs to install side guards on trucks to help protect pedestrians and cyclists from the rear wheels of a vehicle in the event of a collision. These safety modifications have proven their efficacy: after a national side guard mandate in the United Kingdom, fatalities decreased by 61 percent for cyclists and 20 percent for pedestrians in side-impact collisions with trucks.[xxviii] Side-impact collisions result in a disproportionate number of pedestrians and cyclist fatalities in the United States. Nearly half of bicyclists and more than a quarter of pedestrians killed in impacts with trucks first impact the side of the vehicle.

Nearly **half of bicyclists** and more than **one-quarter of pedestrians** killed by a large truck first impact the side of a truck.

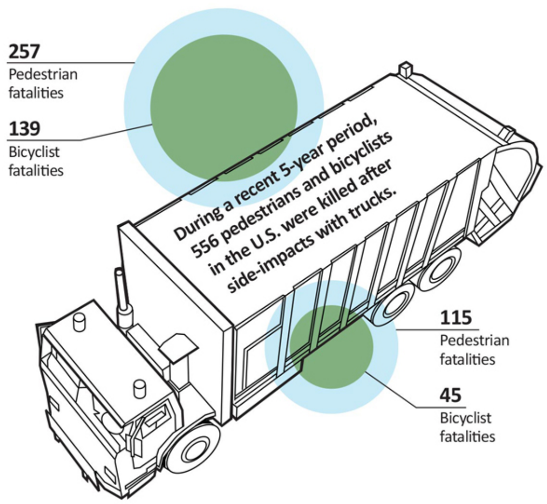

Image: Volpe

Photo: 123RF

Technology is also being developed to reduce the likelihood of crashes involving vulnerable road users. Advanced driver assistance systems (ADAS) are being developed to alert drivers to nearby vulnerable road users. By combining camera- and mirror-based detection methods with radar, sonar, or infrared sensors, ADAS technology can provide 360 degrees of coverage surrounding a vehicle—even at night or in inclement weather, conditions in which collisions are most likely to occur.[xxix] ADAS alerts drivers via visual, auditory, or kinesthetic cues, and at higher levels of sophistication, these technologies can also proactively apply brakes to avoid a crash.[xxx] Honda has demonstrated experimental concepts[xxxi] that employ connected vehicle technology—using cooperative communication between an individual's smartphone and nearby vehicles—to provide warnings to both drivers and vulnerable road users.

Implications for Transportation

It is expected that many more solutions will mature in the coming years as safety officials, manufacturers, and industry groups work to reverse the trend in vulnerable road user fatalities. These may involve technological breakthroughs or design innovations. As the number of cyclists has grown in recent years, these issues are receiving somewhat belated attention, which suggests there may be a number of opportunities for low-tech, low-cost interventions—such as side guards—which could have a substantial impact.

Wireless Power Transfer

One of Utah Transit Authority's electric buses utilizes a 50kW wireless charging system.

Photo: WAVE IPT

Background

Wireless power transfer (WPT) technologies date back to research by Nikola Tesla in 1899. A new wave of advancements in this area began in 2006,[xxxii] motivated by the desire to recharge consumer electronic devices without the hassle of managing multiple separate cables and chargers. Projects are already under way to demonstrate the use of these technologies for charging electric vehicles.

Opportunities | Challenges | Risks

Initially, WPT is most likely to be applied to electric buses and trucks operating on heavily traveled routes that would justify a large capital investment. For example, airports and seaports, which are heavily trafficked by vehicles largely constrained to on-site use, represent promising locations for early application of the technology. Use of WPT by light-duty vehicles could follow quickly, if a sufficient core network is built out to enable range-extending, roadway-embedded charging.

Distributed fast charging is another kind of WPT. Developers claim it can charge electric-powered buses in as little as six minutes. While this would require the bus to be stopped to recharge, it would have the advantage of requiring only a few areas of the roadway to have under-pavement charging systems installed.[xxxiii]

Research | Initiatives | Solutions

For several years, South Korean researchers have been developing shaped magnetic resonance technology for buses. In August 2013, the Korea Advanced Institute of Science and Technology launched a prototype powered-roadway network, beginning with two buses on 15 miles of roadway in the city of

Gumi. In this location, which uses Shaped Magnetic Field in Residence (SMFIR) technology, the buses require only 5 to 15 percent of the road to provide charging. Operators claim an 85 percent transmission efficiency, due in part to the "shaped" aspect of the technology, which targets the electric field more precisely.[xxxiv] Additional buses and WPT infrastructure are planned for the city of Sejong.[xxxv]

Implications for Transportation

- WPT technology could eliminate the need to park a vehicle for several hours at a charging station to recharge, thereby enabling use of electric vehicles by people who do not have reliable access to charging stations.
- Wireless charging would extend the driving range of electric vehicles by providing charging capability right on major roadways. This would have the added benefit of allowing for smaller batteries, which could substantially reduce costs and improve efficiency by reducing weight.
- WPT technology could also provide a novel way for fully automated vehicles to recharge themselves, without the need for a human occupant to hook up to a charging station.

Additive Manufacturing (3D Printing)

Photo: 123RF

Background

Three-dimensional (3D) printing allows three-dimensional objects to be created with great precision, using a laser or an extruder to build an object layer by layer. 3D printers could make it possible to manufacture customized products and parts more quickly and in some cases less expensively. 3D printers have been used for more than a decade, but in recent years they have become much more precise and capable of using a broader range of materials.

A 2014 McKinsey report suggested that 3D printing is "ready to emerge from its niche status and become a viable alternative to conventional manufacturing processes in an increasing number of applications."[xxxvi] *Harvard Business Review* reports that in the United States in 2014, sales of industrial-grade 3D printers reached one-third the volume of sales of industrial automation and robotic manufacturing equipment.[xxxvii] And, as an example of rapid penetration of the technology, "The U.S. hearing aid industry converted to 100% additive manufacturing in less than 500 days." However, it may be important to note that the 3D printing industry has gone through a cycle of hype (which peaked in 2014) followed by a strong correction—particularly in the market for small, home-use printers, as customers and investors realized some of the limitations of the technology.

Opportunities | Challenges | Risks

3D printing technology offers three main advantages. First, it offers far more flexibility than conventional mass-production technologies, largely due to low fixed costs per part, quick setup times, and the ability to change designs almost instantaneously (while fixed costs per part are lower, marginal costs are generally much higher than in typical mass production). This could reduce the cost of rare or one-off parts; drastically reduce inventory, shipping, and facility costs; and offer almost limitless customization options. Second, 3D printing eliminates some need for assembly, as materials can be combined in one product simultaneously. And third, 3D printing can have advantages for manufacturing parts with complex structures, and can produce detailed interior structures that may not be possible with conventional technologies.[xxxviii]

On the other hand, 3D printing doesn't offer many of the process efficiencies and economies of scale of conventional manufacturing, so in many cases the direct costs of producing goods may be higher. Whether 3D printing is cost-effective will depend on the product and the nature of the market. A report by the California DOT listed several potential cost-saving advantages, including: "reducing labor costs, foreign and domestic freight costs, and import duties; saving time (no need to wait for prototypes, spare parts); eliminating capital investments (such as molds, casts and machine tools); reducing inventory, stocking levels, and warehousing requirements; reducing lead times; removing handling and distribution costs on component part transportation; and reducing scrap, waste, and the cost of their disposal." [xxxix]

Implications for Transportation

- Supply chains and distribution networks for certain types of goods may be significantly disrupted.
- Rapid prototyping may facilitate transportation research.
- Many transportation sectors rely on low-volume vehicles or infrastructure (e.g., subway cars), with a high replacement cost for spare parts. In some cases, spare parts may be unavailable at any cost. 3D printing could lower the cost and difficulty of procuring hard-to-find parts.
- 3D printing may allow for more localized production and decentralized manufacturing. Deliveries of finished goods may fall, while shipments of raw materials might rise. This could mean reduced infrastructure requirements, as some of the items currently manufactured overseas shift to domestic production facilities. Overall, wear and tear on the infrastructure could be reduced, but that effect might be partially offset by more local deliveries with smaller vehicles.

Materials Science in Infrastructure

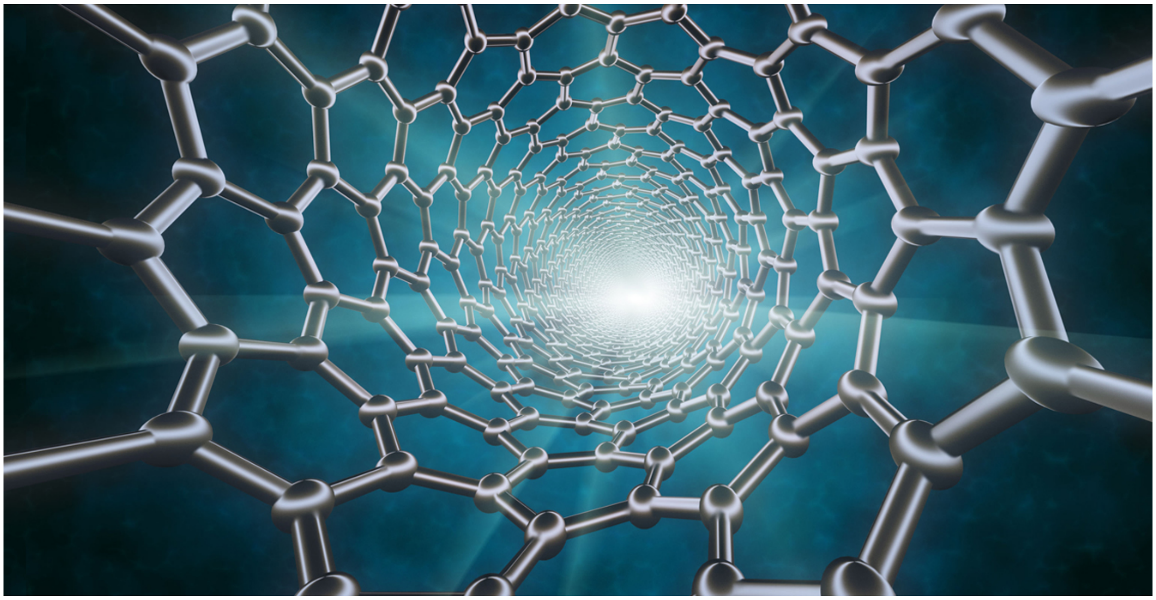

Image: 123RF

Background

Ongoing improvements in materials promise to increase the lifespan of infrastructure components, improve safety and resilience, and reduce maintenance needs. In addition to these advances, new methods of manufacturing and placement of materials offer the possibility of creating forms not conceivable in traditional civil engineering. Materials concepts inspired by biological structures and systems are emerging. Advances in nanotechnology have greatly extended the capabilities of materials science by making it possible to tailor the essential structures of materials at the nanoscale (1-100 nanometers, or billionths of meters) to achieve specific properties.

Opportunities | Challenges | Risks

These advances could enable a revolution in the design, construction, and maintenance of transportation infrastructure. The benefits could include reduced lifecycle costs and repair time, reduced environmental impacts, and improved safety. However, new materials typically require new construction and maintenance techniques, with concomitant changes in training and workforce skills.

Research | Initiatives | Solutions

New ways of using existing advanced construction materials—and new architectures inspired by these capabilities—are already emerging. For example, the "Composite Arch Bridge System" (also known as Bridge-In-A-Backpack™) utilizes lightweight carbon-fiber tubes infused with a vinyl ester resin, which form arches that are then filled with concrete.[xl]

Research and development efforts are under way to pursue materials not only inspired by biological systems, but actually integrating a biological system with conventional infrastructure. In the example of Self-Repairing Roads, a new type of pavement is under development that heals itself when it cracks. The concrete contains very small capsules of bacteria that produce limestone when exposed to water. When a crack develops in the concrete, water will seep in and dissolve the capsules, activating the bacteria, which seal the crack.

Microelectromechanical systems (MEMS)[xli]—devices in the range of 0.02 to 1.0 millimeter (mm)—are being investigated for their potential role in developing intelligent infrastructure. While MEMS are not a new material, per se, incorporating MEMS by embedding them in materials blurs the line between materials and discrete infrastructure components. This approach could work with wireless sensing and control technology, potentially allowing infrastructure to adapt dynamically to changing conditions.

At an even smaller scale, nanotechnology is being used to develop materials that are "stronger, lighter, more durable, more reactive, more sieve-like, or better electrical conductors, among many other traits," according to the federal government's National Nanotechnology Initiative (NNI).[xlii]

Implications for Transportation

- New architectures and designs enabled by advanced materials could simplify construction (especially for larger structures like bridges), reducing the time it takes to build new structures and diminishing traffic disruptions. In particular, some materials may increase opportunities for fabrication and assembly on site, potentially reducing the need for heavy machinery.
- Self-healing roads could improve safety for drivers and cyclists, as cracks would be fixed before road crews even knew about them. Driver costs would also be reduced by moderating or avoiding damage to vehicles from potholes. The technology could shrink costs of road repairs by up to 50 percent and make a dramatic impact on emissions from cement production, which currently accounts for 7 percent of global CO_2 emissions.[xliii]
- An example of a possible application of MEMS is wireless structural control of bridges, in which bridges are fitted with wireless sensor-actuator networks and control systems. Such systems would allow bridges to respond to forces exerted on them during events like earthquakes or changing water currents, to prevent the damage that these events can cause. This would reduce immediate risks to physical infrastructure and reduce overall lifecycle costs.
- The NNI provides a list of automotive applications for nanotechnology, including: polymer composite materials for automobile parts that "can make them simultaneously lightweight, stiff, durable, and resilient"; high-power rechargeable battery systems; thermoelectric materials for temperature control; lower-rolling-resistance tires; high-efficiency/low-cost sensors and electronics; thin-film smart solar panels; fuel additives and improved catalytic converters for cleaner exhaust and extended range; and membranes, catalysts, and hydrogen storage materials needed to enable durable, low-cost fuel cells and hydrogen systems.
- Nanotechnology also has potential applications in transportation infrastructure, including steel, concrete, and asphalt, where it "offers great promise in terms of improving the performance, resiliency, and longevity of highway and transportation infrastructure components while reducing their cost."[xliv] New capabilities may also arise, such as the ability of nano-scale systems to generate or transmit energy, to perform continuous structural monitoring of infrastructure conditions, or even to communicate with vehicle-based systems.

Hyperloop

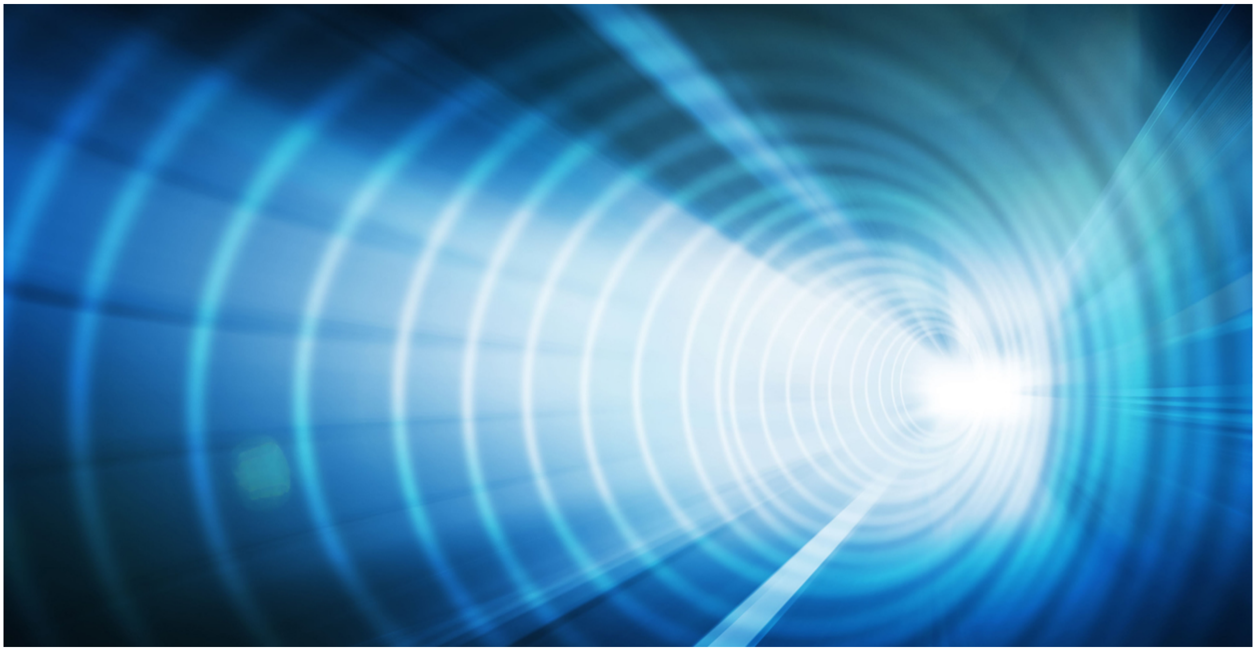

Photo: 123RF

Background

Hyperloop, as described conceptually in an August 2013 white paper[xlv] by Elon Musk of SpaceX and Tesla, is a concept for a very high speed intercity transportation mode. Its guideway would consist of paired bi-directional tubes elevated on pylons, and linear induction motors would propel passenger or freight capsules riding on low-friction air bearings at very high speed (up to 750 miles per hour [mph]) within the tubes. The tubes would be partially evacuated of air, dramatically lowering aerodynamic drag, which is ordinarily the primary limitation on vehicle speed and the major source of energy expenditures at higher speeds. The concept includes arrays of solar panels along the guideway, which would provide most or all of the required electrical power.

The concept is conceived as an open-source platform, in that the white paper is available to others to refine the design. No relevant patents have been filed as yet, though Hyperloop builds on related technologies such as evacuated tube transportation technology (ET3) and magnetic levitation (maglev). Multiple organizations have taken up research into the concept, and there are at least two test track projects in planning. Early results from this activity may inform assessment of the concept's potential.

Opportunities | Challenges | Risks

There are numerous open technical and policy questions regarding Hyperloop, as well as its operational and commercial feasibility. Hyperloop faces many of the same challenges as more conventional guideway-based surface transportation technologies—e.g., high-speed rail and maglev trains—not the least of which are the feasibility and cost of securing the necessary rights-of-way in key locations. The cost-effectiveness of Hyperloop relative to conventional modes also depends on external factors that can be difficult to forecast, such as future fuel prices and performance advances in other modes. In the coming years, more information will be needed for a meaningful technical assessment or benefit-cost analysis.

Implications for Transportation

- In the near term, media and technology industry interest in Hyperloop may feed public interest in new approaches to transportation.
- In the longer term, if the concept is proven feasible, Hyperloop could become an attractive alternative for intermediate-distance intercity transportation corridors, with the potential for significant time, energy, and emissions savings over conventional modes.
- To the extent it succeeds, Hyperloop could unlock new economic development and other benefits in the corridors it serves.
- New technologies and design concepts may spin off from Hyperloop R&D efforts, and these may be applicable to other transportation modes.

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DOT-VNTSC-OST-16-01