From Concrete to Chips: Bringing the Surface Transportation Reauthorization Act Into the Digital Age

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The future of surface transportation lies not simply in pouring more concrete, but in leveraging information and communications technologies to bring intelligence to every asset in the U.S. transportation network, thus making transportation safer, more accessible, and more efficient.

Next-generation information and communications technologies (IT) are set to revolutionize America's transportation system. Whether it is the emergence of innovative connected vehicles or intelligent infrastructure, the future of transportation lies not just in building new roads but in bringing intelligence to every asset in the U.S. transportation network—from roadways and private vehicles to commercial truck fleets and public transit systems—thereby making transportation safer, more accessible, and more efficient. Accordingly, it is time for U.S. transportation policy—principally enshrined through the Surface Transportation Reauthorization Act—to reflect this shift from "concrete" to "chips": in other words, to comprehensively integrate IT into America's surface transportation system.

INTRODUCTION

This report examines the promise of IT-enabled smart transportation systems and vehicles and proposes a number of policy principles and recommendations for how Congress can leverage the 2015 Surface Transportation Reauthorization bill to advance the development and deployment of intelligent transportation systems (ITS) and automated vehicle technologies. By bringing efficiencies to existing transportation assets and systems, ITS solutions deliver the most "bang for the buck" on each dollar the federal government invests in transportation. Put simply, it is time for policymakers to view ITS as the 21st-century, digital equivalent of the Interstate Highway System, with the federal government again taking the lead in declaring a vision, investing in research and development (R&D), developing standards and technologies, shifting incentives to favor the deployment of technology-enabled solutions, constructing a regulatory framework that encourages the deployment of ITS and automated vehicle technologies, and providing the funding necessary to support deployment of these solutions.

This report provides an overview of the wide range of IT-enabled transportation technologies being implemented today and then describes the five key classes of benefits they enable before turning to a discussion of the policy principles and specific policy recommendations that should guide thinking about the 2015 Surface Transportation Reauthorization bill. The following summarizes the report's policy recommendations:

- The U.S. Department of Transportation (DOT) should develop a comprehensive innovation strategy that articulates how it can promote the rapid deployment and adoption of proven intelligent transportation systems across the United States.
- Congress should enact a new "Cement & Chips" funding approach that directs no less than 5 percent (approximately $2.5 billion) of the Highway Trust Fund (HTF) allocated to states to be devoted to digital and ITS-based infrastructure projects.
- Congress should create a new competition program called Race to the Digital Top that awards funding to a select group of six U.S. communities—two small, two mid-size, and two large—to build a comprehensive "smart communities" model.
- Congress should ensure that ITS-related implementations are immediately eligible for funding under the existing highway transportation authorization.
- Congress should tie a share of federal surface transportation funding to states' actual improvements in transportation system performance.
- Congress should lower the share of federal funding for non-toll projects from the current 80 percent to 60 percent, while funding the full 80 percent for toll projects, providing a stronger incentive for state toll projects.
- Congress should authorize a total of $1 billion in pre-construction feasibility assessment grants designed to address a key obstacle that states and localities face in advancing user fee-backed projects.
- Congress should direct the administration to launch two new Institutes for Manufacturing Innovation (IMIs), the first an industry-led intelligent vehicles and infrastructure consortium led by the Department of Transportation, and the second an IMI for surface transportation materials innovation.
- The U.S. Department of Transportation should create an organization that facilitates an interstate dialogue on ITS technologies, including vehicle-miles traveled (VMT) systems and autonomous vehicle regulations so that state officials don't lock in to suboptimal or non-interoperable systems ITS systems, including VMT systems.

- The Government Accountability Office (GAO) should undertake a comprehensive review of existing federal automotive standards, regulations, and policies that present barriers to a competitive marketplace for intelligent transportation systems and emerging vehicular technology development, along with recommendations for removing or mitigating such barriers.

- The White House should convene a meeting of representatives from state Departments of Transportation to spur the creation of high-value, dynamic traffic data sets and application program interfaces (APIs) to be hosted at data.gov.

- The U.S. Department of Transportation should undertake to scale innovative local software and app-based ITS solutions nationally, such as by supporting the provision of shared IT infrastructure, such as cloud storage. The White House should organize a competition to identify the 20 best such applications and task a nonprofit, such as Code for America, to take applications initially developed for individual cities and code them for use on a national basis.

It is time for policymakers to view ITS as the 21st-century, digital equivalent of the Interstate Highway System, with the federal government again taking the lead.

DEFINING IT-ENABLED TRANSPORTATION TECHNOLOGY

Given the wide range of intelligent transportation systems, a taxonomy that arranges them by primary functional intent (with the acknowledgment that many applications can serve multiple functions or purposes) can facilitate understanding. While this list is not comprehensive, it includes the most prominent ITS applications, which are the focus of this report (see Table 1).

ITS Category	Specific ITS Applications
Advanced Traveler Information Systems (ATIS)	Real-time Traffic Information Provision Route Guidance/Navigation Systems
Advanced Transportation Management Systems (ATMS)	Traffic Operations Centers (TOCs) Adaptive Traffic Signal Control Dynamic (or "Variable") Message Signs Ramp Metering
ITS-Enabled Transportation Pricing Systems	Electronic Toll Collection (ETC) Electronic Road Pricing (ERP) Fee-Based Express (HOT) Lanes Vehicle-Miles Traveled (VMT) Usage Fees Variable Parking Fees
Advanced Public Transportation Systems	Real-time Status Information for Public Transit Automatic Vehicle Location (AVL) Electronic Fare Payment
Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) Communication	Cooperative Intersection Collision Avoidance Systems (CICAS) Intelligent Speed Adaptation (ISA)
Driver Assistance Technologies	Advanced Accident Avoidance (e.g., lane departure warnings, collision warnings, etc.)
Vehicle Automation	Autonomous (i.e., driverless) vehicles

Table 1: Taxonomy of ITS Applications[1]

Advanced Traveler Information Systems

Perhaps the most-recognized ITS applications, Advanced Traveler Information Systems (ATIS) provide drivers with real-time travel and traffic information, such as transit routes and schedules; navigation directions; and information about delays due to congestion, accidents, weather conditions, or road repair work. The most effective traveler information systems inform drivers in real-time of their precise location, advise them of current traffic or road conditions at their location and surrounding roadways, and empower them with optimal route selection and navigation instructions, ideally making this information available on multiple platforms, both in-vehicle and out. Three key facets guide the provision of real-time traffic information: collection, processing, and dissemination, with each step entailing a distinct set of technology devices, platforms, and actors, both public and private.

This category also includes in-car navigation systems and telematics-based services, such as GM's OnStar, which offer a range of safety, route navigation, crash notification, and concierge services, including location-based services, mobile calling, and in-vehicle entertainment options, such as Internet access and music or movie downloads.[2] Other advanced traveler information systems make parking easier; cities from San Francisco to Singapore to Stockholm are deploying systems that indicate where vacant spaces can be found, and even allow drivers to reserve spaces in advance. Studies have shown that as much as 30 percent of urban traffic in large cities consists of drivers circulating in search of parking.[3]

Advanced Transportation Management Systems

Advanced Transportation Management Systems (ATMS) include ITS applications that focus on traffic control devices, such as traffic signals, ramp metering, and the dynamic (or "variable") message signs on highways that provide drivers real-time messaging about traffic or highway status. Traffic Operations Centers (TOCs)—centralized traffic management centers run by cities and states worldwide—rely on information technologies to connect sensors and roadside equipment, vehicle probes, cameras, message signs, and other devices to create an integrated view of traffic flow and to detect accidents, dangerous weather events, or other roadway hazards.

Adaptive traffic signal control refers to dynamically managed, intelligent traffic signal timing. Giving traffic signals the ability to detect the presence of waiting vehicles, or giving vehicles the ability to communicate that information to a traffic signal, can enable improved timing of traffic signals, thereby enhancing traffic flow and reducing congestion. Ramp metering represents another advanced transportation management system that can yield significant traffic management benefits. Ramp meters are traffic signals on freeway entrance ramps that break up clusters of vehicles entering the freeway, which reduces the flow disruptions that vehicle clusters cause and makes merging safer. Some 20 U.S. metropolitan areas currently use ramp metering technologies to manage traffic flow.

ITS-Enabled Transportation Pricing Systems

ITS have a central role to play in funding countries' transportation systems. The most common application is electronic toll collection (ETC), also known internationally as "road user charging," through which drivers can pay tolls automatically via an on-board device or tag placed inside the windshield (such as E-Z Pass on the U.S. East Coast). By charging more at congested times, traffic flows can be evened out or reduced. As half the world's population now lives in urban areas, some economists believe that urban congestion and emissions will be virtually impossible to reduce without some form of congestion pricing.[4] Such systems would be vastly easier to introduce if the United States adopted a smart vehicle-miles traveled system so that all vehicles paid on the basis of when and where they drove.

High-Occupancy Toll (HOT) Lanes—lanes reserved for buses and other high-occupancy vehicles that can also be made available to single-occupancy vehicles upon toll payment—are another ITS-enabled mechanism to combat traffic congestion. The number of vehicles using the reserved lanes can be controlled through variable pricing (i.e., via electronic toll collection) to maintain free-flowing traffic at all times, even during rush hours, which increases overall traffic flow on a given segment of road. For example, Orange County, California, has found that, while HOT lanes represent only one-third of its highway lane miles, they carry over half of the passenger traffic during rush hours.[5]

Advanced Public Transportation Systems

Advanced Public Transportation Systems (APTS), including applications such as automatic vehicle location (AVL), enable transit vehicles, whether bus or rail, to report their current location, making it possible for traffic operations managers to construct a real-time view of the position of all assets in the public transportation system. APTS make public transport a more attractive option for commuters by giving them enhanced visibility into the arrival and departure status (and overall timeliness) of buses and trains. Advanced public transportation systems, particularly those providing "next bus" or "next train" information, are increasingly common worldwide, from Washington, D.C., to Paris, Tokyo, Seoul, and elsewhere.

Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) Communication

Vehicle-to-infrastructure and vehicle-to-vehicle (collectively, V2X) communication represent the archetype for a comprehensively integrated intelligent transportation system at a national level. In the United States, the objective of the U.S. Department of Transportation's Connected Vehicle Research Program (formerly called IntelliDrive℠) has been to deploy and enable a communications infrastructure that supports vehicle-to-infrastructure—as well as vehicle-to-vehicle—communications for a variety of vehicle safety applications and transportation operations.[6] DOT's Connected Vehicle Research Program envisions the deployment of technologies that—if widely available in vehicles, highways, and in roadside intersection equipment—would enable the core elements of the transportation system to communicate intelligently with one another, delivering a wide range of benefits. For example, such a system could enable cooperative intersection collision avoidance systems (CICAS) through which vehicles at an intersection could be in continuous communication either with each other or with roadside devices that could recognize when a collision between vehicles appeared imminent (based on the vehicles' speeds and trajectories) and warn the drivers of an impending collision or even communicate directly with the vehicles to brake them automatically.[7] Combining both vehicle-to-vehicle and vehicle-to-infrastructure communication into a consolidated platform could enable a number of additional ITS applications, including adaptive signal timing, dynamic re-routing of traffic through variable message signs, curve speed warnings, and automatic detection of roadway hazards, such as potholes or weather-related conditions such as icing.[8]

Driver Assistance Technologies

A range of vehicle features and innovative technologies assist motorists in driving more safely. Notably these include lane departure warnings (i.e., "lane keep assistance"), blind spot detection and warning, collision warning indicators, and even automatic collision avoidance braking, vehicle-assisted parking, and on-dashboard rearview camera displays, among others. As explained subsequently, these driver assistance technologies are already delivering significant safety benefits in terms of accidents avoided.

BOX 1: NHTSA'S FIVE-PART CONTINUUM OF VEHICLE CONTROL AUTOMATION

Level 0: No Automation. The driver is in complete and sole control of the primary vehicle controls—brake, steering, throttle, and motive power—at all times.

Level 1: Function-Specific Automation. Automation at this level involves one or more specific control functions. Examples include electronic stability control or pre-charged brakes, where the vehicle automatically assists with braking to enable the driver to regain control of the vehicle or to stop faster than by acting alone.

Level 2: Combined-Function Automation. Level 2 involves automation of at least two primary control functions designed to work in unison to relieve the driver of control of those functions. An example of combined functions enabling a Level 2 system would be adaptive cruise control in combination with lane centering.

Level 3: Limited Self-Driving Automation. Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions and in those conditions to rely heavily on the vehicle to monitor changes in those conditions requiring transition back to driver control. The driver is expected to be available for occasional control, but with sufficiently comfortable transition time. The Google car is an example of limited self-driving automation.

Level 4: Full Self-Driving Automation. The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. Such a design anticipates that the driver will provide destination or navigation input, but is not expected to be available for control at any time during the trip. This includes both occupied and unoccupied vehicles.

Vehicle Automation

Vehicles that are capable of automated driving and navigation without human input used to be strictly the purview of science fiction. But today this technology is improving rapidly and could, in the not too distant future, greatly enhance highway safety, increase personal mobility, reduce environmental impact, and significantly transform the nature of America's transportation system.[9] These truly autonomous or "driverless" vehicles will leverage innovative computing and sensing technologies that have the potential to replace the human driver entirely. However, as gradations exist in autonomy among these different types of intelligent vehicle systems, the National Highway Traffic Safety Administration (NHTSA) has defined a five-part continuum of vehicle control automation, as shown in Box 1.[10]

ITS deliver five key benefits by: 1) increasing safety, 2) improving operational performance of the transportation network, 3) enhancing personal mobility, 4) delivering environmental benefits, and 5) boosting productivity and expanding economic and employment growth.

BENEFITS OF INTELLIGENT TRANSPORTATION SYSTEMS

With intelligent transportation systems, once inert physical surfaces such as roadways become intelligent, flexible, dynamic platforms capable of addressing such challenges as congestion and traffic management, pricing and toll collections, and safety and maintenance.[11] Applying information and communications technologies to the U.S. transportation network in the form of intelligent transportation systems, driver assistance technologies, and/or autonomous vehicles can deliver five key classes of benefits by: 1) increasing driver and pedestrian safety, 2) improving the operational performance of the transportation network, particularly by reducing congestion, 3) enhancing personal mobility and convenience, 4) delivering environmental benefits, and 5) boosting productivity and expanding economic and employment growth.

Increasing Driver and Pedestrian Safety

Both intelligent transportation systems and automated vehicle systems can deliver significant safety benefits. Each year, more than 5.5 million traffic accidents occur on U.S. roadways, causing approximately 33,000 traffic fatalities (almost 100 per day), 2.3 million injuries, and an estimated $1 trillion economic cost (almost 6 percent of U.S. GDP) through lost productivity and loss of life.[12] Globally, some 50 million injuries and 1.24 million fatalities occur on the world's roadways each year.[13] A wide range of IT-based applications—from real-time traffic alerts, to cooperative intersection collision avoidance, to on-vehicle systems such as anti-lock braking, lane departure, and pre-crash notification systems—have safety as a principle focus. For example, a study in Minneapolis, Minnesota, found that ramp metering reduced total crashes on area roadways between 15 and 50 percent.[14] The U.S. Department of Transportation's Connected Vehicle Research Program (formerly IntelliDrive[SM]) envisions deployment of connected vehicle and infrastructure technologies that could potentially reduce up to an estimated 80 percent of vehicle crashes involving unimpaired drivers.[15]

In fact, intelligent transportation systems are leading to a fundamental rethinking of vehicle safety. Over the past 50 years, most of the developments in transportation safety—such as the mandatory installation and use of seat belts in the 1970s and the installation of airbags in the 1980s—were designed to protect passengers in the event of a crash. But as Peter Appel, a former administrator at the U.S. Department of Transportation's Research and Innovative Technology Administration (RITA), notes, "All of those technologies assumed there would be a crash. However, much of the work in the next 50 years will be about avoiding the crash altogether and for that [systems like] IntelliDrive have dramatic potential."[16] Or as the NHTSA noted in its *Preliminary Statement of Policy Concerning Automated Vehicles*, "Motor vehicles and drivers' relationships with them are likely to change significantly in the next ten to twenty years, perhaps more than they have changed in the last one hundred years."[17]

In fact, a range of IT-enabled automated driver-assistance technologies, conceived in part during the process of developing autonomous vehicles, are already having a significant impact in reducing accidents and increasing driver and pedestrian safety.[18] As noted, these assistance technologies include blind spot detection, lane departure warnings, dangerous proximity (pre-collision) indicators, rearview cameras, and parking assistance, among others. Since 2010, for example, Volvos equipped with a safety system have experienced 27 percent fewer property-damage claims than Volvos without one.[19] A survey of Toyota Prius and Sienna drivers found that 27 percent believe new front-crash prevention systems prevented an accident, along with 20 percent who believe that automatic braking systems prevented an accident.[20] And according to insurance data, forward collision warning systems lead to a 7 percent reduction in vehicle-to-vehicle collisions, with that number increasing to 15 percent for vehicles with automatic braking systems.[21]

Elsewhere, engineers at Virginia Tech University examined a sample of 2,848 collisions resulting from unintended lane departures from 2007 to 2011. The study found that had lane departure warning systems been incorporated into the vehicles involved in these accidents, 30.3 percent of the crashes could have been avoided.[22] The engineers estimated an associated reduction of 635 injuries from this sample. Likewise, a 2009 study conducted by German insurance companies found that collision-mitigating braking systems (including detection of obstacles and autonomous braking) could prevent up to 17.8 percent of all car accidents involving personal injuries and that lane departure warning systems could prevent up to 7.3 percent of such accidents.[23] Finally, the Eno Foundation cites a study examining forward-collision warning systems, which found a wider range of estimates, but still estimates the systems would prevent at least 9 percent and as much as 53 percent of rear-end collisions.[24]

These technologies will not only prevent vehicles from contacting other vehicles; they will also be designed to enhance pedestrian and bicyclist safety, particularly to avoid accidents at intersections. It is through the hope of such technologies that countries such as Japan and Sweden have publicly announced a goal of achieving "zero traffic fatality" societies by 2020.[25] In fact, Sweden's level of fatalities from traffic accidents, at 3 per 100,000 citizens per year, is about a quarter of the United States', at 11.4 per 100,000 citizens annually. As *The Economist* explains in the article, "Why Sweden Has so Few Road Deaths," the country's "Vision Zero" strategy of planning, adoption of advanced vehicle and intelligent transportation system technologies, cracking down on inebriated driving, and attitude that, "We simply do not accept any deaths or injuries on our roads," has played a key role in enabling Sweden to consistently reduce traffic accidents and fatalities.[26]

Improving the Operational Performance of the Transportation Network

ITS can improve the performance of the U.S. (or any other country's) transportation network by maximizing the capacity of existing infrastructure, reducing the need to build additional highway capacity. Maximizing capacity is crucial because the increase in vehicle-miles traveled has dramatically outstripped increases in roadway capacity. From 1980 to 2006, the total number of miles traveled by automobiles in the United States increased 97 percent, but over the same time period, the total number of highway lane miles grew just 4.4 percent, meaning that over twice the traffic in the country was traveling on essentially the same roadway capacity.[27]

A number of ITS applications can contribute to enhancing the operational performance of transportation networks. For example, traffic signal light optimization can improve traffic flow significantly, reducing stops by as much as 40 percent, cutting gas consumption by 10 percent, cutting emissions by 22 percent, and reducing travel time by 25 percent.[28] Applying real-time traffic data could improve traffic signal efficiency by 10 percent, saving 1.1 million gallons of gas a day nationally and cutting daily carbon dioxide emissions by 9,600 tons.[29] Ramp metering can increase vehicle throughput (the number of cars that pass through a road lane) from 8 to 22 percent and increase speeds on roads from 8 to 60 percent.[30] As up to 30 percent of congestion on highways occurs at toll stops, deploying electronic toll collection systems can significantly reduce congestion. Assessing the impact of intelligent transportation systems, including ramp metering, incident management, traffic signal coordination, and arterial access management, a September 2005 GAO study found that ITS deployments to date had reduced delays in 85 urban areas by 9 percent (336 million hours), leading to a $5.6 billion reduction in annual costs due to reduced fuel consumption and hours of delay.[31]

Intelligent transportation systems and automated vehicle technologies can have a profound impact on reducing the more than 50 million injuries and 1.24 million fatalities that occur from traffic accidents annually on the world's roadways.

Indeed, reducing traffic congestion is one of the principal benefits of both intelligent transportation systems and autonomous vehicles. American commuters spend five days per year (a full work week) stuck in traffic, a "congestion penalty" costing Americans over $1,400 per year.[32] In total, in 2011, congestion in America's 498 largest metropolitan areas cost Americans 5.5 billion hours and caused them to buy 2.9 billion additional gallons of fuel, for a congestion cost of $121 billion.[33] When the impacts on lost productivity, unreliability, cargo delay, and safety are considered, the U.S. Department of Transportation's chief economist thinks congestion's toll is closer to $168 billion annually.[34] At current rates, congestion in the United States is expected to become so severe by 2030 that 58 urban areas will have regional congestion levels high enough to qualify as "severe" (defined as when peak-hour traffic volumes exceed road capacity), up from 28 in 2003.[35] Over the next 20 years, Sam Staley and Adrian Moore, authors of the book *Mobility First*, estimate that the cost of congestion could amount to 4.3 percent of the value of the entire national economy.[36] A more recent study by The Centre for Economics and Business Research and Inrix (a road traffic data service) finds even more dire consequences, estimating that the annual average cost of gridlock across the United States and Europe will rise nearly 50 percent from 2013 to 2030, to $293 billion, costing the average household nearly $3,000 annually, with the cumulative cost of traffic congestion in the United States from 2013 to 2030 reaching $2.8 trillion.[37]

Fortunately, both intelligent transportation systems and autonomous vehicles can play a significant role in alleviating this congestion. Experts predict that, in the United States, areas that use ITS can reduce traffic jams by as much as 20 percent.[38] First, because approximately 25 percent of congestion is attributable to traffic accidents according to the Federal Highway Administration (FHWA), ITS and autonomous vehicles can ameliorate congestion by preventing traffic accidents.[39] Second, ITS-enabled variable or congestion pricing systems can also reduce congestion. Copious research demonstrates that a comprehensive pricing approach that incorporates variable pricing tied to travel demand levels (such as congestion pricing) can provide significant congestion benefits. One study estimated that region-wide congestion pricing could reduce peak travel by 8 to 20 percent.[40] A Brookings Institution study estimated that congestion pricing on the nation's Interstates and other freeways would reduce total vehicle-miles traveled by 11 to 19 percent.[41] And a FHWA report assessing results from its Value Pricing Pilot Program, which implemented tolling on a number of roadways nationwide, found that even targeted pricing can have a number of effects on driver behavior and traffic volumes, including changes in times, routes, or modes of travel; willingness to pay for faster travel times by traveling on toll lanes; reductions in peak-period traffic volumes; and more efficient use of highway capacity.[42]

Both intelligent transportation systems and autonomous vehicles can play a significant role in alleviating congestion that threatens to cost the U.S. economy $2.8 trillion from 2013 to 2030.

Another way intelligent transportation systems and autonomous vehicles can improve the performance of existing transportation assets is by getting more use out of them. For example, passenger vehicles in the United States sit idle 95 percent of the average day, but autonomous vehicles could be shared or otherwise deployed in their spare time (e.g., the car goes to the dry cleaner to pick up your clothes or gets rented out to others). In other words, autonomous vehicles could be shared, much the same way private aircraft are shared today, with computer systems routing and positioning vehicles for minimum wait time.[43] Both intelligent transportation systems and autonomous vehicles also have a role to play in maximizing highway utilization by allowing vehicles such as trucks to drive closer together (a process called "platooning"). Today, highways at peak capacity are only 6 to 8 percent occupied with vehicles, but highways full with autonomous vehicles could possibly accommodate 2 to 3 times as many vehicles.[44]

Enhancing Mobility and Convenience

Intelligent transportation systems can significantly enhance driver mobility and convenience by: 1) decreasing congestion and maximizing the operational efficiency of the transportation system, as described previously, and 2) providing motorists and mass transit users with real-time traveler information and enhanced route selection and navigation capability. In fact, perhaps the most familiar intelligent transportation systems are telematics-based applications, such as satellite-based vehicle navigation or other services that deliver real-time traffic information to drivers. These services help drivers identify and take the most efficient, trouble-free routes and help prevent motorists from getting lost.

Beyond ITS, autonomous vehicles hold the promise to improve personal mobility and convenience for those who cannot drive themselves, particularly the young, the elderly, or the disabled.[45] For example, one compelling video produced by Google shows a blind citizen, Steve Mahan, completing his daily chores and visiting friends thanks to Google's driverless vehicle.[46] As Chris Urmson, leader of Google's Self-driving Car program, notes, "We all at some point will lose the privilege of driving [as we get older], and autonomous vehicles could help people maintain the mobility they've grown accustomed to throughout their lives."[47] Ride-sharing systems such as RideScout and ride-hailing services such as Uber have also made significant contributions to personal mobility and convenience.

Autonomous vehicles could also present a compelling mobility option for those who do not desire to own a vehicle. In the future, instead of turning to taxis, Uber, or a car-sharing service such as Zipcar for transportation needs, those living car free could use smartphone apps to summon autonomous vehicles to take them to their destinations.[48] In fact, a recent study calculated that a fleet of autonomous vehicles acting as a personalized public transportation system would be cheaper and more efficient than taxis, and would use half the fuel and a fifth the road space of ordinary cars.[49]

Delivering Environmental Benefits

Intelligent transportation systems can deliver environmental benefits by reducing congestion, by enabling traffic to flow more smoothly, by coaching motorists how to drive more efficiently, and by reducing the need to build additional roadways by maximizing existing capacity. Vehicle transportation is a major cause of greenhouse gas emissions, accounting for 25 percent of worldwide greenhouse gas emissions and 33 percent of those produced in the United States.[50]

The use of intelligent transportation systems could save approximately 650 million barrels of oil and 120 million metric tons of CO_2 emissions over a 10-year period.

Traffic congestion causes an outsized proportion of CO_2 emissions. In fact, in the United States alone, congestion puts an additional 56 billion pounds of CO_2 emissions into the atmosphere annually.[51] Yet keeping traffic moving smoothly can help reduce emissions. Vehicles traveling at 60 kmph (37 mph) emit 40 percent less carbon than vehicles traveling at 20 kmph (12 mph), and vehicles traveling at 40 kmph (25 mph) emit 20 percent less than the 20 kmph baseline.[52] For example, one study found that computerized operation of 40 traffic signals in northern Virginia's Tysons Corner community decreased the total annual emissions for carbon monoxide, nitrogen oxides, and volatile oxygen compounds by 135,000 kilograms (and improved fuel consumption by 9 percent).[53]

"Eco-driving" is an ITS-enabled application that optimizes driving behavior to the benefit of the environment. Vehicles equipped with eco-driving features provide feedback on the most fuel-efficient speeds across all driving situations; the most sophisticated versions give visual or oral instruction on how much pressure to apply to the acceleration petal. Because autonomous vehicles will in essence be driven by computers—and thus can be programmed to drive in the most fuel-efficient manner possible—they will likely be driven in a more fuel-efficient manner (likely in addition to having a more fuel-efficient propulsion source, such as electric batteries). Morgan Stanley estimates that "an autonomous car can be 30 percent more efficient than an equivalent non-autonomous vehicle."[54] Also, as mentioned earlier, platooning promises to reduce fuel consumption and therefore emissions. A Stanford University technology spinoff, Pelaton, estimates that the rear truck in a two-truck platoon could save approximately 10 percent in fuel costs. If platooning increased average fleet mileage by 5 percent, the savings would add up to $24 billion annually.[55]

Taken together, according to the Intelligent Transportation Society of America's report *Accelerating Sustainability: Demonstrating the Benefits of Transportation Technology*, intelligent transportation systems could save approximately 650 million barrels of oil and 120 million metric tons of CO_2 emissions over a 10-year period.[56] The report finds that over 10 years vehicle technologies alone—such as adaptive cruise control and cylinder deactivation—could save 110 million barrels of oil and 20 million metric tons of CO_2. Traveler information technologies—such as eco-driving, eco-navigation, and car sharing—could contribute savings of 420 million barrels of oil and 70 million metric tons of CO_2. And, finally, infrastructure and systems operations—in the form of real-time adaptive traffic signal control and synchronization, electronic toll collection, and incident management—could save 119 million barrels of oil and 19 million metrics tons of CO_2 over a 10-year period.[57] Furthermore, the Information Technology and Innovation Foundation (ITIF) estimates that the annual economic benefits from reduction in energy by switching over to a fleet of fully autonomous vehicles across the United States could reach $24 billion.[58]

Thus, intelligent transportation systems, vehicles with driver assistance technologies, and autonomous vehicles all have a role to play in decreasing congestion, improving traffic flow, and thus significantly reducing the impact of a country's transportation system on the environment. To be sure, by decreasing congestion and enabling traffic to flow more smoothly, intelligent transportation systems may cause some degree of induced demand, encouraging more vehicles (whether with human or electronic drivers) to take to the roads due to improved traffic conditions. But while these systems may cause some induced demand, overall they are poised to deliver tremendous environmental benefits.

Boosting Productivity, Economic, and Employment Growth

Intelligent transportation systems and automated vehicles also boost productivity and expand economic and employment growth. By improving the performance of a nation's transportation system, thus ensuring that people and products reach their appointed destinations as quickly and efficiently as possible, ITS can enhance the productivity of a nation's workers and businesses and boost a nation's economic competitiveness. For example, a 2009 Reason Foundation study found that reducing congestion and increasing travel speeds enough to improve access by 10 percent to key employment, retail, education, and population centers within a region increases regional production of goods and services by 1 percent. The study reported that achieving "free-flow traffic conditions" (that is, reducing congestion) around key urban and suburban destinations in eight U.S. cities—Atlanta, Charlotte, Dallas, Denver, Detroit, Salt Lake City, the San Francisco Bay Area, and Seattle—could boost the economies in those cities by $135.7 billion and generate close to $9 billion in new tax revenues.[59] And, as noted earlier, intelligent transportation systems and automated vehicle technologies can considerably reduce the current $1 trillion annual economic impact of traffic accidents and associated injuries and loss of life.

ITS will also become an increasingly important growth industry. The U.S. Department of Transportation's Research and Innovative Technology Administration estimated in 2011 that the market for intelligent transportation systems was already worth $48 billion annually and growing rapidly.[60] Scholars predict that, over the 20-year period from 1997 to

2017, the cumulative global market for ITS-related products and services will contribute $420 billion to the global economy.[61] It is also estimated that as of 2015, the U.S. ITS end-use market will support 205,000 jobs, with total industry employment—including providers of enabling services and ITS components as well as end-use products and services—exceeding 500,000 jobs.[62] Public investment in intelligent transportation systems creates jobs: A 2009 ITIF study found that a £5 billion investment in intelligent transportation systems in the United Kingdom would support approximately 188,500 new or retained jobs for one year.[63] Nations that lead in ITS deployment are also likely to be international leaders in ITS-related job creation and to create economic, export, and competitiveness advantage for themselves. Apart from ITS, leadership in autonomous vehicle systems will be crucial for nations that wish to field automotive production industries at the forefront of global innovation.

Accordingly, the most sophisticated governments recognize the need for government to partner with its automotive sector to develop and deploy new technologies. For instance, the United Kingdom's report *Driving success—a strategy for growth and sustainability in the UK automotive sector*, recognizes that "to ensure the future health of the industry in the UK, the industry and the Government have worked together [since 2009] to strengthen the sector."[64] The report undertakes a strengths, weaknesses, opportunities, threats (SWOT) assessment of the UK automotive industry and "sets out action that will be taken by industry and by the UK Government jointly to: 1) Invest in innovation and technology; 2) Enhance supply chain competitiveness and growth; and 3) Invest in people to ensure they have the right skills for an evolving industry."[65] The United States should seriously study the UK model and identify every opportunity for government to be a productive partner with industry in both developing and deploying the underlying technologies and setting the framework conditions (e.g., regulatory, talent, and tax policies) that will maximally support the realization of intelligent transportation systems and advanced vehicular automation technologies.

INNOVATION PRINCIPLES FOR THE SURFACE TRANSPORTATION REAUTHORIZATION BILL

The following principles should guide policymakers as they assess policy, program, and financial allocation decisions in the 2015 Surface Transportation Reauthorization Bill.

Shift Focus From "Concrete" to "Chips"

Taxpayers get more value for their dollars when policymakers prioritize technology investments that bring efficiencies to and improve the performance and safety of established transportation systems. In fact, overall, the benefit-cost ratio of systems-operations measures (enabled by intelligent transportation systems) has been estimated at about 9 to 1, far above the addition of conventional highway capacity, which has a benefit-cost ratio of only 2.7 to 1.[66] In one study, researchers at Florida International University found that the $9.9 million annual cost of a traffic operations management system in Broward County, Florida, yielded a benefit of $142 million in reduced travel time, fuel consumption, emissions, and secondary accidents involving rubbernecks (a 14 to 1 ratio).[67] Another study of 26 traffic signal optimization projects in Texas found that signal optimization benefits outweighed costs by 38 to 1.[68]

Put simply, ITS delivers more bang for the buck, and with every dollar at a premium in these tight budgetary times, policymakers should focus on allocating resources to initiatives that will provide the biggest benefit to taxpayers.

Place Increased Emphasis on Deployment

From 1992 to 2012, the U.S. Department of Transportation allocated approximately $4.5 billion for intelligent transportation systems research and deployment.[69] Over the same period, the U.S. DOT allocated more than $962 billion for roads and transit.[70] In other words, less than 0.47 percent of surface transportation funding goes to ITS. Compare these statistics with U.S. business enterprises, for whom IT investments now account for at least 28 percent of total private nonresidential capital expenditures. In other words, if these relevant investment levels were applied in the case of intelligent transportation systems, industry's IT-to-total investment ratio would be nearly 60 times higher than the federal government's.[71]

The benefit-cost ratio of systems-operations measures (enabled by intelligent transportation systems) has been estimated at about 9 to 1, far above the addition of conventional highway capacity, which has a benefit-cost ratio of only 2.7 to 1.

States don't do much better. It is estimated that, as of 2010, state governments were spending approximately $1.3 billion of their combined annual federal highway funds on intelligent transportation systems investments.[72] Also, it's estimated that U.S. states were able to invest an additional $1.3 billion on smart transportation R&D from funds allocated by the American Recovery and Reinvestment Act, although those funds were of course allocated on a one-time basis.[73]

In other words, the U.S. government's investments in ITS to date represent merely a start—and while more research will certainly continue to be needed into emerging intelligent transportation systems and solutions—the reality is that many existing ITS technologies are proven and can make a real difference if applied more systemically today. While DOT's *ITS Strategic Plan 2015-2019* speaks appropriately of the need to balance research, development, and adoption, it is time for federal surface transportation policy to make a fundamental transition from its research-oriented focus to ITS deployment and adoption, so that intelligent transportation systems and technologies can reach the traveling public quicker.

Indeed, other countries are deploying ITS solutions more rapidly than the United States: For example, Japan's cooperative vehicle-highway system, called Smartway, evolved from concept development in 2004, to limited pilot stage deployment in 2007, to initial national deployment in 2010, an extremely fast development timeline.[74] The United States should invest more effort both in learning from ITS solutions already deployed by peer nations and in accelerating the widespread deployment of existing ITS technologies.

Scale Existing Solutions Nationally

A number of U.S. cities and states have developed innovative technology applications that improve the performance of transportation networks, enhance safety, and streamline infrastructure repairs. For instance, Boston created Street Bump, a smartphone application that identifies potholes from bumps a car experiences driving over them; the app automatically relays these potholes' locations to the city transportation department. As Rosabeth Moss Kanter writes, Street Bump makes "your car and your phone allies in road repairs. …The Information Superhighway reinvents the highway."[75] Another example is

SF*park*, a parking management system developed by the San Francisco Municipal Transportation Agency and deployed at 7,000 of the city's 28,800 metered spaces and 12,250 spaces in 15 of 20 city-owned parking garages; the app tracks open parking spots and sets prices dynamically according to availability and demand.[76] The California Public Parking Association named SF*park* the Public Parking Program of the Year, and in 2013 the Harvard Kennedy School awarded SF*park* one of its 25 Innovations in American Government Awards.[77] But it makes little sense for individual cities to reinvent applications developed elsewhere if platforms could be developed to scale these types of solutions nationwide; policymakers should consider strategies to broadly disseminate these applications, as detailed in the recommendations section below.

Promote National Interoperability of Intelligent Transportation Systems

While some intelligent transportation systems, such as ramp meters or computerized adaptive traffic signals, can prove effective when deployed only locally, the vast majority of ITS applications—and certainly the ones positioned to deliver the most extensive benefits to the transportation network—must operate at scale, often at a national level, and must involve adoption by the overall system and by individual users at the same time to be effective, raising a unique set of system interdependency, network effect, and system coordination challenges.[78] For example, purchasing a cooperative system such as the erstwhile-named IntelliDrive does a vehicle owner little good if it works in one state but doesn't work in other states the driver frequents. Indeed, most ITS systems work optimally at scale: For example, it makes little sense for states to independently develop a vehicle-miles traveled usage-fee system because, in addition to requiring an on-board device in vehicles (ideally part of original factory-installed equipment), VMT requires infrastructure development of a satellite system and a back-end payment system. And auto manufacturers would not want to have to make or install up to 50 different on-board devices to accommodate states' potentially differing implementations of a VMT system.[79]

In short, it is about coordination: If the United States is to achieve a truly nationwide deployment of intelligent transportation systems that are interoperable across state lines, it can't have a system where states and localities pursue their own implementations without consideration of their neighbors. The following section of the report will provide several policy recommendations to achieve greater federal-state ITS coordination.

Recognize That Emerging Transportation Solutions Will Bring Dramatic Safety Benefits

It will fall to the National Highway Traffic Safety Administration to establish safety standards for autonomous vehicles, a process it has already begun with the 2013 release of its *Preliminary Statement of Policy Concerning Automated Vehicles,* which: 1) defined a five-level schema for measuring the extent of vehicle automation; 2) announced a four-year research plan that will perform human factors research, assess electronic control systems safety, and develop systems performance requirements; and 3) offered recommendations concerning state activities related to self-driving vehicles.[80]

To its credit, the NHTSA policy statement recognizes "the enormous safety potential of these new [automated and autonomous vehicle] technologies" and acknowledges that "highly effective crash avoidance technologies can reduce fuel consumption by also eliminating the traffic congestion that crashes cause every day on our roads."[81] Indeed, the potential safety benefits of autonomous vehicles are enormous. For instance, the Eno Center for Transportation estimates that the annual economic benefits of 50 percent market penetration of driverless cars (that is, 50 percent of all vehicles on the road being fully autonomous) could include 9,600 lives saved, almost 2 million fewer traffic accidents, close to $160 billion in comprehensive cost savings, and a 35 percent reduction in daily freeway congestion.[82] ITIF has estimated that if driverless cars were widely adopted they could achieve $1.05 trillion in economic savings per year.[83] And, as noted previously, automated driver assistance technologies such as lane departure or collision indicator warnings already demonstrate significant safety benefits.

Fifty percent penetration of autonomous vehicles on U.S. roadways could result in 2 million fewer traffic accidents, a 35 percent reduction in traffic congestion, cost savings of $160 billion, and 9,600 lives saved per year.

As such, it is important that policymakers not let the perfect be the enemy of the good. It is unreasonable to imagine a future in which an autonomous vehicle is never involved in an auto accident: The comparison set should not be perfection but current statistics. A study by the National Highway Traffic Safety Administration identified human error as the "definite or probable cause of at least 93 percent of traffic accidents" while another 2001 study found that "a driver behavioral error caused or contributed" to 99 percent of the crashes investigated.[84] By contrast, autonomous vehicles analyze and predict the world 20 times a second, far faster than the human brain can. Our reflex systems and muscle movements simply are not as fast. In fact, while NHTSA has expressed concern that removing drivers from automobile control would inhibit their ability to hit the brakes before a crash, a recent study found that only 1 percent of drivers in the sample applied the brakes full force before a collision. Moreover, autonomous vehicles could dramatically reduce accident incidence because they will obey all traffic laws, including speed limits, and will not drive while distracted, exhausted, texting, or inebriated. For example, Google's driverless car has already navigated more than 1,000,000 miles without causing a traffic accident (although its cars have been involved in 11 minor accidents [light damage, no injuries] caused by other vehicles).[85] Put simply, the sooner society has autonomous vehicles, the better, and this is the broader context NHTSA should focus on, while appropriately ensuring the safety of self-driving vehicles.

NHTSA should not view its role as merely regulating and evaluating the technologies that show up on its doorstep, but should work to enable and to accelerate the development of technologies that can (and many cases have proven to) contribute to realizing the agency's stated goal: of reducing traffic accidents and fatalities. In other words, NHTSA needs to see its mission not as merely regulating technologies but as enabling the deployment of systems that help realize society's goal of dramatically reducing traffic accidents. If overly strenuous regulations on self-driving vehicle testing delay their deployment by 5 or 10 years, then potentially many lives will have been sacrificed for the goal of saving lives.

To date, four U.S. states—California, Florida, Michigan, and Nevada—as well as the District of Columbia have passed laws permitting road testing of autonomous vehicles. At least 11 additional states are considering autonomous vehicle legislation. This increased interest from states in part prompted NHTSA new recommendations concerning self-driving vehicles.[86]

Unfortunately, as Rosabeth Moss Kanter notes, "the European regulatory environment [is] more conducive to autonomous vehicles [than the United States'], already allowing automated steering up to 6.2 miles per hour, and corrective steering above that, as long as drivers can override it."[87] To be sure, Europe has room to improve, too, with a BMW representative recently noting, "The legislation is just not in place for us to be able to put these [autonomous] vehicles on the [European] market."[88] Still, an important step toward that end was taken in April 2014 with the passage of an amendment to the Vienna Convention on Road Traffic (an international treaty designed to facilitate international road traffic, which covers 72 nations, including European countries, Mexico, Chile, Brazil, and Russia, although not the United States, Japan, or China).[89] The amendment will permit vehicles to drive themselves, so long as the automation can "be overridden or switched off by the driver." The amendment still has to clear several bureaucratic hurdles and must be worked into various countries' laws, but it does pave the way for automakers to move from test drives to marketing autonomous vehicles commercially in European countries at an accelerated pace, potentially benefiting European automakers by providing a domestic marketplace in which autonomous vehicles can be sold legally.[90] By contrast, the legal status of autonomous vehicles in the United States will be determined on a state-by-state basis, for while NHTSA can set safety standards and provide a framework, under current laws individual states must determine the legality of operating autonomous and semi-autonomous vehicles on their roadways.[91]

Intelligent transportation systems and automated vehicle technologies can help significantly reduce the $1 trillion annual economic impact of traffic accidents and associated injuries and loss of life.

POLICY RECOMMENDATIONS FOR THE NEXT SURFACE TRANSPORTATION REAUTHORIZATION ACT

The U.S. Congress is poised to set the country's transportation policy for the next five years through reauthorization of the Surface Transportation Act in 2015. It is time for support for intelligent transportation systems to be a critical component of the bill's investments and reforms in order to maximize the operational performance of the transportation system and to attain the benefits enumerated throughout this report.

Since the Interstate system was completed, the surface transportation policy community has collectively struggled with defining the appropriate role of the federal government in our nation's surface transportation system. On the right, some argue for devolution of much of the system, particularly support for transit and the non-federal highway system. Some on the left wish to transform the federal system into a social policy tool, supporting much more non-vehicle transportation (e.g., transit, bike lanes and sidewalks, urban revitalization, and the like).[92] As such, like many other areas of federal policy, surface transportation policy is stuck without a unifying vision.

While this report does not presume to comprehensively define the appropriate federal role, it does suggest that as America creates a 21st-century digital economy, one key role for federal surface transportation policy is to take the lead in the development and implementation of a world-class ITS system across the country. It is incumbent on the federal government to play the leading role for a number of reasons, including the fact that most ITS systems need to be national in scale; that state DOTs have, as a rule, relatively little experience in or interest in ITS; and because, just like any other transformative change that must be coordinated centrally but carried out at the state and local level, only the federal government can be catalyst and custodian. This role need not extend indefinitely into the future. Once digital transportation systems are widely deployed, much of the responsibility for maintenance and even upgrades and innovations can be devolved to the states. But for now, federal leadership to transform our transportation system from "cement" to "chips" is critical. And finally, this can be done in a revenue neutral way, should policymakers choose. Regardless, the most important component of the next Reauthorization bill will be to significantly boost the "chips"-to-"cement" funding ratio.

The following section provides specific policy recommendations for strategy, funding, and institutional reforms that can spur the acceleration of intelligent transportation systems and advanced vehicle technologies.

Develop a Strategy to Transform America's Transportation Sector Through IT-Enabled Innovation

In its response to the Obama administration's request for input as it crafts the third iteration of its *Strategy for American Innovation*, ITIF noted that each federal agency should develop its own specific innovation strategy/agenda in which it evaluates how it can spur greater levels of innovation in the economic sectors it touches, including assessing how regulatory policy or regulations may preclude or limit innovation in each sector.[93] Such strategies are needed because federal agencies too often give short shrift to innovation and also work to advance their own particular missions rather than viewing their role more broadly.

ITS deliver more bang for the buck, and with every dollar at a premium in these tight budgetary times, policymakers should focus on allocating resources to initiatives that will provide the biggest benefit to taxpayers.

Accordingly, Congress should charge the Department of Transportation with developing a comprehensive innovation strategy articulating how it can promote the rapid deployment and adoption of proven intelligent transportation systems across the United States. Part of this strategy should include identifying innovative ways of using technology to drive high-impact, transformational change and repurposing money from concrete and steel to cost-effective solutions that increase mobility, such as computerized adaptive traffic signal lights and parking meters, real-time traffic information, and intelligent vehicles and infrastructure.[94]

Increase Federal Funding for ITS Deployment

ITS will not reach critical mass unless the Department of Transportation begins to fund large-scale demonstration and deployment projects. DOT administers a small $113 million Intelligent Transportation Systems Joint Program Office (JPO), which supports research in ITS, connected vehicles, and autonomous vehicle technologies.[95] Unfortunately, JPO's small budget allows only for small one-off projects and modest research investment, rather than the broader, more aggressive support needed to quickly advance ITS into the market.

In addition to funding levels, the character of the Joint Program Office's funding is equally as important. JPO has largely focused on research and development, rather than full-scale demonstration and deployment projects, even while many technology and automotive companies are piloting ITS-enabled vehicle technologies. For its part, JPO's new *ITS Strategic Plan 2015-2019* does propose a funding shift from research to deployment for connected vehicles and ITS-enabled infrastructure technologies.[96] This is a much needed, albeit late, switch in funding priorities.

With that said, making this switch under current funding levels would not advance ITS technologies in any meaningful way. Demonstration and deployment projects inherently cost more, and there is a critical need to conduct many projects in different geographies, climate, and metropolitan footprints, including urban settings and rural communities.

As such, the Surface Transportation Reauthorization Act should allocate a share of federal transportation infrastructure funding to deploy already available ITS technologies. **In particular, Congress should enact a new "Cement & Chips" funding approach—that directs no less than 5 percent of Highway Trust Funds allocated to states to be devoted to digital and ITS-based infrastructure projects.** Assuming that the HTF will be funded at approximately $50 billion per year, this means that at least $2.5 billion would be allocated to states for ITS deployment.[97] This should be structured as a dedicated ITS deployment fund that states have to match. Ideally, for every $1 invested through this approach, the federal contribution would be 60 percent and the state's contribution 40 percent, creating a total ITS investment pool of just over $4 billion. While states should have ample opportunities to invest these funds in ITS projects, states should be able to apply for a waiver with the Department of Transportation if they believe they really would be unable to identify enough valid projects to meet this 5 percent investment target.

It is also important for **Congress to ensure that ITS-related implementations are immediately eligible for funding under the existing highway transportation authorization.** Representative Candice Miller (R-MI) has proposed the Vehicle-to-Infrastructure Safety Technology Investment Flexibility Act of 2015 (H.R. 910), which would provide eligibility for the installation of vehicle-to-infrastructure communications equipment under the National Highway Performance Program, Surface Transportation Program, and Highway Safety Improvement Program.[98]

Incentivize States to Deploy ITS-Based Technology

While the federal government invests in ITS research, development, and pilot projects, most ITS-based infrastructure projects are currently funded by states. But ITS projects often have to compete with conventional transportation projects for funding, even though ITS technologies are poised to deliver greater long-term benefits than traditional road repair or even new road construction. But a lack of transportation funding at the state level, which tends to exacerbate focus on more immediate concerns at the expense of a longer-term vision, conspires with bureaucratic inertia or a lack of interest, technical skill, or knowledge of ITS benefits to make it more difficult for ITS projects to compete with conventional transportation projects out of the same funding pools.

Congress has an opportunity to incentivize state ITS deployment, and ultimately change the culture of state transportation agencies, through the 2015 Surface Transportation Reauthorization bill. Three policy reforms should be emphasized:

First, **Congress should create a new competition program called Race to the Digital Top that awards funding to a select group of six U.S. communities—two small, two mid-size, and two large—to build a comprehensive "smart communities" model.** Korea showcased the transformative power of ITS technologies with a "smart cities" approach that initially focused on deploying real-time traffic information, computerized adaptive traffic signals, ramp metering, and electronic tolling to four large Korean cities (Daejon, Jeonju, Jeju, and Kwa-chon City).[99] The dramatic reductions in congestion, traffic accidents (and injuries and fatalities), and greenhouse gas emissions achieved in these four model cities built a compelling case that caused other Korean cities to clamor for the immediate deployment of smart transportation technologies. The United States should consider a similar approach.

To receive funding, communities would submit their blueprints to construct and implement a comprehensive smart infrastructure plan. The communities would be encouraged to collaborate with universities, private-sector leaders, citizens, and other stakeholders in building this blueprint. The six communities with the best plans would be provided with a sizable portion of the funding necessary (ITIF suggests a 2-to-1, federal-local match) to implement this vision. Recommended prizes for each level are $150 million, $400 million, and $750 million, so the total cost of the federal contribution will be less than $1 billion (approximately $0.87 billion). The Race to the Digital Top would be managed by the Department of Transportation in concert with the Departments of Commerce, Energy, Homeland Security, and Housing and Urban Development. This consortium of executive departments would track and disseminate best practices for local and regional leaders. They will also be best positioned to develop collaborative policies to enable broader implementation of the most successful models.

There is a positive synergy between greater performance standards and ITS: performance standards will drive ITS, while ITS will enable better measurement of performance.

Second, **Congress should tie a share of federal surface transportation funding to states' actual improvements in transportation system performance.** Traditionally, the Department of Transportation allocates surface transportation funding to states on the basis of conventional needs, rather than the performance of state transportation projects. Currently, funding allocations for major programs (for example, the National Highway System, the Interstate Maintenance Program, and the Surface Transportation Program) are based largely on formulas reflecting factors such as state lane miles and amount of vehicle-miles traveled. As a result, while there is substantial process-based accountability for how federal funds are used, there is little attention paid to results. Performance measurement, evaluation, and benchmarking are notably absent from surface transportation funding. Transportation agencies at all levels of government face virtually no accountability for results.

Holding states accountable for real results would allow federal and state transportation funds to go further, achieving better results for the same funding. This would also provide stronger incentives for states to adopt innovative approaches to managing highways, including implementing intelligent transportation systems. One reason ITS has not been as widely deployed in the United States is because state DOTs continue to focus on their traditional roles of overseeing the building and maintenance of "bricks-and-mortar" infrastructure. Given that ITS can in many cases have better performance impact on mobility, safety, and emissions than building conventional highway infrastructure, holding states accountable for performance will have the effect of putting ITS on a more level playing field with concrete, asphalt, and steel. It would also send a clear message to states that the federal government values ITS and expects to see its implementation. Moreover, there is a positive synergy between greater performance standards and ITS. Performance standards will drive ITS, while ITS will enable better measurement of performance.

In order to move toward a more performance-oriented transportation financing system:

- Congress should charge DOT with developing an ITS assessment and benchmarking study that would: 1) make a rigorous assessment of the cost-benefit impacts of ITS projects that have been deployed in the United States over the past two decades, and 2) develop benchmarks for state adoption of ITS. Each year, DOT should issue a status report, holding states accountable to these ITS adoption benchmarks. As part of developing these benchmarks, DOT should develop performance goals for traffic-related fatalities, traffic congestion, and travel times.

- Congress should require each state DOT and metropolitan planning organization (MPO) to develop a performance management process to monitor progress toward meeting national goals. State DOTs and MPOs should establish short-term and long-range performance targets in areas including traffic-related fatalities, traffic congestion, travel times, and pavement quality and provide regular performance reports on their progress towards meeting established targets.

- DOT should make funding available to state DOTs, MPOs, or local agencies that lack the ability to collect necessary performance data in order to fill gaps in their data collection systems (including through the use of ITS systems).

- Data on traffic-related fatalities, congestion levels, travel times, and other performance measures should be published by DOT at least once annually as part of a National Scorecard. This data should be made publicly available in an exportable, electronic, Web-based format.

A third mechanism to incentivize states and regions to move toward deploying intelligent transportation systems would be by encouraging greater use of tolling. Tolling can play a key role in generating the funding to pay for expanded, more efficient roadway capacity. But too many states do not want to support toll-funded projects because of fear of public opposition, despite the fact that the public usually supports toll projects after introduction. To address this, Congress could require the Department of Transportation to structure the federal highway program so that it provides incentives for states to adopt tolling as a solution. **Lowering the share of federal funding for non-toll projects from the current 80 percent share to 60 percent, while funding the full 80 percent for toll projects, would provide a stronger incentive for states to establish more toll projects.**[100]

The Reauthorization could also expand the Transportation Infrastructure Financing and Innovation Act (now commonly referred to as TIFIA) to authorize incentive grants to support and encourage the development and financing of user-backed projects. As the National Surface Transportation Infrastructure Financing Commission recommended, **Congress should authorize a total of $1 billion in pre-construction Feasibility Assessment Grants designed to address a key obstacle that states and localities face in**

advancing user fee-backed projects. The program would provide funding (in the form of grants or "conditional loans" to be repaid when possible) for a portion of the costs that a state or local sponsor must incur to undertake early planning, feasibility studies, environmental clearance, and other development-stage activities. In addition, it should authorize Capital Cost Gap Funding Grants to provide incentive grants to states to complement TIFIA credit assistance. Recognizing that there are many projects for which partial (but not 100 percent) funding through user-backed revenue streams is possible, this program would provide grant funding to help close a portion of the estimated gap between the amount of capital for construction that can be derived from future user fees and the amount necessary to complete and maintain the facility for its useful life. Such a program could help spur states and localities to build more projects that rely at least in part on user-backed revenues, allowing federal funds to go farther since they would be supplemented by additional user-based revenues.

Enhancing Institutional Support to Spur Transportation Innovation

Realizing wide-scale national ITS deployment will require significant collaboration among a number of actors, including the private sector, state and federal governments and departments of transportation, and universities and research institutions.

Realizing wide-scale national deployment of intelligent transportation systems will require significant collaboration among a number of actors, including the private sector, state and federal governments and departments of transportation, and universities and research institutions, not to mention the end user. In short, realizing the future will require new public-private partnerships for transportation innovation across the automotive, transportation, and information and communications technology sectors. To encourage private investment, these partnerships should focus on enabling scale and sustainability of investments over the long term.

In particular, such a public-private partnership should engage multiple industrial sectors and government agencies to advance research and testing of advanced automotive and transportation technologies. In particular, the partnership would work on developing interoperable communications technologies to further advance V2V and V2I communication and integration, address the security challenges of connected transportation technologies, develop data protection standards, and generate data on the safety, environmental, and efficiency benefits of intelligent transportation systems.

In 2012, the United States launched a new model for public-private partnership across advanced manufacturing product and process technologies in the form of the National Network for Manufacturing Innovation (NNMI). The network brings together industry, universities, and community colleges; federal agencies; and all levels of government to accelerate manufacturing innovation in technologies with commercial applications. The NNMI, composed of individual Institutes of Manufacturing Innovation (IMIs), is poised to play a pivotal role in enhancing U.S. industrial competitiveness by supporting development of technologies that will enable U.S. enterprises to develop the cutting-edge technologies needed to compete in the global marketplace.[101]

U.S. industry and government have collaborated to launch five IMIs thus far—focused on additive manufacturing (e.g., 3-D printing), next-generation power electronics, lightweight metals, advanced composite materials, and digital manufacturing and design innovation—with four more IMIs forthcoming to focus on flexible hybrid electronics, integrated photonics, clean energy, and revolutionary fibers and textiles.[102] In some cases, such as the Digital Manufacturing and Design Innovation (DMDI) Institute in Chicago, industry has matched the federal funding to establish the IMIs on a more than $3:$1 basis, with the initial federal funding of $70 million to launch the Institute being leveraged with over $250 million in commitments from industry partners, demonstrating the tremendous interest in and value the private sector perceives in these partnerships.[103] The government partners in the IMIs launched thus far have been the Department of Defense or the Department of Energy, although forthcoming notices of proposal for new IMIs are expected from the Department of Agriculture and the National Institute of Standards and Technology (NIST). Accordingly, **Congress should direct the White House to make one of the next IMIs an industry-led intelligent vehicles and infrastructure consortium with the Department of Transportation as the supporting federal partner.** The Department of Transportation alone lacks the resources, skills, and incentives to invest in high-impact intelligent transportation systems and autonomous vehicle R&D and deployment, but the IMI framework provides a mechanism for industry and government to collaborate in research, testing, and scaling to ensure that these life-saving technologies reach America's roadways faster.

Congress should also propose a second transportation-related IMI, this one focused on materials innovation in surface transportation. U.S. states spend approximately $16.5 billion annually repairing existing roadways, but these costs could be reduced through the use of innovative surface transportation technologies such as flexible or modular concrete.[104] Likewise, concrete embedded with smart sensors can monitor stresses on bridge or road conditions on bridges (i.e., icy and slippery) and thus contribute considerably to enhancing bridge safety.[105] Driving construction materials innovation could play a significant role in achieving lower maintenance costs, improved durability, and reduced long-term maintenance costs.

Removing Barriers to Deployment

Despite the critical importance of intelligent transportation systems and autonomous vehicles, these technologies unfortunately face a number of cultural, systemic, and operational barriers to deployment. For instance, one reason intelligent transportation systems have not been deployed to the extent possible by some state departments of transportation is that the agencies have historically been populated with personnel more skilled in the civil or mechanical engineering disciplines than the electrical engineering disciplines on which intelligent transportation systems more commonly rely. General consumer resistance to new technologies also threatens to afflict the adoption of innovations such as autonomous vehicles, although this often merely reflects consumers' unfamiliarity with these technologies. For instance, Karl Benz once lamented that the global market for his invention—the automobile—would be limited only by the lack of qualified chauffeurs.[106] But just as it once seemed unimaginable that we could drive ourselves, today it seems unimaginable that anything other than a human is capable of driving. Tomorrow we are sure to find that driverless cars are capable of doing the job just fine—and quite possibly even better than we can.[107]

As noted, ITS also face a range of institutional and organizational barriers, including limited understanding of the technology and jurisdictional challenges, such as which level of government—federal, state, county, city, public authority, or interstate compact—has responsibility for or jurisdiction over ITS deployments.[108] For example, a U.S. Government Accountability Office study that assessed deployment of intelligent transportation systems found "several barriers that limit the widespread deployment" of ITS at the state, regional, and local level. The study noted that state and local transportation officials often view other transportation investment options, such as adding a new lane to a highway, more favorably than ITS when deciding how to spend limited transportation funds.[109] The GAO also found that, unfortunately, "information on benefits does not have a decisive impact on the final investment decisions made by state and local officials."[110] This challenge is amplified as elected officials often find ITS investments less appealing than highway construction. The GAO study quoted Chicago- and San Francisco-area transportation officials lamenting that since ITS applications, "do not usually offer groundbreaking ceremonies which offer positive media attention," politicians were generally not motivated to support these projects.[111]

For the vast majority of ITS solutions to be effective, they must operate at scale and involve adoption by the overall system and individual users at the same time, raising a unique set of system inter-dependency, network effect, and system coordination challenges.

As explained previously, if the United States is to achieve a truly nationwide deployment of intelligent transportation systems that are interoperable across state lines, it cannot have a system where states and localities are pursuing their own ITS implementations without consideration of the activities of their neighbors. **Therefore, the Department of Transportation should create an organization that facilitates an inter-state dialogue on ITS technologies, including vehicle-miles traveled systems and autonomous vehicle regulations so that state regulators do not create individual systems that inhibit cross-border travel.**

Yet, as the above-mentioned GAO report found, many of the barriers to deployment of intelligent transportation systems arise not from system interdependencies and network effects, but from government policies themselves. Therefore, **the GAO (or a related agency) should undertake a comprehensive review, in consultation with automotive and IT industry partners, of existing federal automotive standards, regulations, and policies that present barriers to a competitive marketplace for intelligent transportation systems and emerging vehicular technology development, along with recommendations for changes needed to remove or mitigate such barriers.** This work should further promote government engagement with international counterparts in regulatory equivalency for research, automotive safety standards, and certification processes.

With regard to autonomous vehicles, one particularly thorny issue involves product liability, particularly who is at fault if an autonomous vehicle is involved in an accident. Is it the passenger (who is no longer the driver), the automobile manufacturer, or the company that wrote the computer code operating the driverless vehicle? The product liability risk must be balanced against the societal benefits of a potentially significant overall reduction in auto accidents. One option, as noted by Alex Brown in the *National Journal,* could be to create a payout fund that would compensate victims of driverless car accidents, possibly modeled after the U.S. Health and Human Services Department's vaccine injury compensation fund, financed by a 75-cent tax on every purchased vaccine as part of a no-fault program to assist those injured by vaccine-related incidents, thus protecting the pharmaceutical industry and medical community from legal battles and expensive damage suits.[112]

Create Open Data Standards and Other Sharing Systems to Spur IT-Based Transportation Innovation

Real-time knowledge of traffic conditions allows drivers to take the most efficient route possible to their destinations. Greater public availability of traffic information and open, machine-readable transportation-related data will stimulate innovative new services and products that can enhance safety, improve fuel efficiency, and increase mobility, thereby bettering the quality of life. Accordingly, **Congress should direct the Department of Transportation to convene a meeting of representatives from state Departments of Transportation to spur the creation of high-value, dynamic traffic data sets and application program interfaces (APIs) to be hosted at data.gov**. Such an approach could mirror the success of the U.S. Department of Transportation's recently launched Data Inventory initiative, which publishes a list of the Department of Transportation's publicly available data sets on its website and at http://catalog.data.gov.[113]

The advent of ITS and autonomous vehicle technologies will transform the transportation system as thoroughly as the shift from horses to the internal combustion engines did in a prior era.

At the same time, cities throughout America have developed similarly innovative smart transportation applications such as Street Bump and SF*park*, but it makes no sense for each city to "reinvent the wheel" or for all cities not to enjoy the benefit of these already-developed applications. Any city in America could use Street Bump tomorrow if it were cloud-hosted and had a geocoded algorithm to send pothole data to the relevant municipality. But a collective action problem arises, as individual cities have no particular interest in scaling these applications for the benefit of other cities. Accordingly, **the U.S. Department of Transportation should undertake to help scale innovative local IT solutions nationally; one way they can do so is by supporting the provision of shared IT infrastructure, such as cloud storage. The White House should go further, organizing a competition to identify the 20 best such applications and getting a nonprofit such as Code for America to take applications initially developed for individual cities and code them for national use.**

CONCLUSION

Emerging innovative intelligent transportation systems and automated vehicle technologies are poised to deliver tremendous safety, personal mobility, environmental, productivity and efficiency, and economic benefits. The advent of these technologies will transform the transportation system as thoroughly as the shift from horses to internal combustion engines did in a prior era. But neither government nor the private sector can achieve this transition alone. Rather, it will take committed federal leadership to co-invest in the research, development, testing, and deployment of these advanced transportation and vehicle systems technologies and to create a permissive regulatory environment that, while always mindful of protecting public safety, permits the increasingly innovative private sector to deploy solutions that improve the performance of the country's transportation network, reduce deleterious environmental impacts, and, in fact, further the goal of enhancing driver and pedestrian safety.

ENDNOTES

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