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Infrastructure 4.0

Rebuilding America With Software

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Contents

Executive Summary

For decades, our nation's infrastructure has been the operating system that helped run our economy. Smoothly paved highways bridged the gaps between urban and rural areas; gleaming jets streamed in and out of modern airports to connect far-flung regions; and, amid it all, a network of wired links enabled ever-faster communications.

But today, in too many cases, our infrastructure is outdated and crumbling. Instead of being where we want to be, we are often stuck in traffic, backed up on potholed roads or outdated bridges, or waiting for overdue flights. And with more than 87 percent of the US population expected to be living in cities by 2050, the demand for modern infrastructure will only grow.[1]

Our analog era infrastructure undermines access to safe water, leads to power outages and safety concerns, and threatens our nation's future growth and prosperity. This aging infrastructure costs the nation nearly $1 trillion a year in lost economic growth[2] and hits the average family for about $3,400 a year in lost income.[3]

It's not just today's infrastructure that is outdated — the approach to planning, design, and construction is out-of-date as well. What's changing? Almost everything involved in the process of developing infrastructure, from the materials to the technology and the way that work is done on site.

But our lagging infrastructure also presents an enormous opportunity: the opportunity to once again harness American innovation and ingenuity to transform and radically improve our roads, bridges, airports, and more — creating millions of new jobs, boosting the economy, and advancing a more prosperous middle class.

Put most simply, our infrastructure needs a software upgrade.

What does that mean? The tools and techniques in use today were created in a time of fewer people, less urgency, and lower demands. Larger project sizes, increased complexity, and aging infrastructure in mature and growing emerging markets are driving the need to better simulate alternatives, reduce delivery schedules, maintain high quality, minimize cost, and ensure safety. It means using new computing tools to reduce costs and make projects more effective and forward-looking. It means ensuring that infrastructure projects include measures that expand broadband access so that all corners of the country can access those software tools and so that all corners of the country have access to software jobs. And it means that we invest in our most important asset — our workforce — by growing the pipeline of skilled technology workers.

The purpose of this paper is to highlight for policymakers how those fundamental steps can help upgrade our nation's infrastructure in a cost-effective and forward-looking way.

THE CHALLENGE:

40 percent of urban highways are now choked with traffic[4]

200 million trips are made across structurally deficient bridges every day[5]

Every two minutes a water main breaks, flooding streets and leaving taps dry[6]

World War II era **Air Traffic Control technology** delays air travelers, wastes fuel, and increases costs[7]

Inadequate infrastructure costs every American family **$3,400 a year** in disposable income[8]

34 million Americans lack high-speed broadband as part of our digital infrastructure[9]

Software Holds the Key to Successful Projects, Significant Savings

Many of today's infrastructure issues stem from a crumbling and outdated stock that was designed and built in an analog era[10] — long before the invention of the Internet, the cloud, connected sensors, or 3D modeling. It was built before we could integrate sensors into bridges to monitor safety, before we could build better, more cost-effective infrastructure with 3D design software, before we could even conceive of GPS-guided precision construction equipment, and before we knew there would be a time when cars might talk to the road, or drive on their own.

Our infrastructure challenges are more easily solved when we use transformative software tools to design smarter, build faster, manage better, and use our infrastructure more effectively. Software can help solve our infrastructure opportunity gap in several different ways:

- 3D design and modeling software, such as Building Information Modeling (BIM), radically reduces construction time and cost by solving complex structural design problems with the click of a mouse, boosting new forms of collaboration, making design changes less costly, and reducing expensive design errors. It is estimated that full-scale digitization in nonresidential construction will lead to annual global cost savings of $0.7 trillion to $1.2 trillion (13 to 21 percent) in the engineering and construction phases, and $0.3 trillion to $0.5 trillion (10 to 17 percent) in the operations phase.[11] Software analytics tools enable better designs by highlighting cost-reducing options, including reducing the amount of dirt that must be moved to build a highway, suggesting more affordable designs and materials, and modeling the effects of mechanical stress, water flows, and temperature to create more resilient designs.
- On the jobsite, software now powers precision construction machinery tied to 3D designs to improve the accuracy and quality of our infrastructure. Software also boosts jobsite performance by making it easier to track time, logistics, staff, and resources to keep projects on time and budget.
- We aren't just at the dawn of the connected vehicle era, but also the connected traffic light, street sign, bridge, roadway, and city. With advancing "Internet of Things" capabilities,

Today we have an enormous opportunity to harness the power of software, the cloud, and data to create a 21st century infrastructure system that reduces traffic jams, speeds air travel, strengthens our bridges, and makes our electric grid more resilient. It will enable a more seamless flow of data, electricity, water, and goods and services throughout the nation.

THE BENEFITS OF SOFTWARE

Software can turbocharge infrastructure opportunity by:

Reducing construction costs by 33 percent and cutting construction time by 50 percent with BIM software.[12]

Reducing flight delays by 35 percent by using NextGen enabled GPS navigation software.[13]

Improving traffic flow by 5 to 25 percent with adaptive traffic management software.[14]

Enjoying $2 trillion in customer benefits over the next 20 years by using SmartGrid technologies.[15]

Capitalizing on modeling by using cloud software to evaluate all possible design options.

Using our existing infrastructure much more efficiently with innovative new apps.

Reducing crashes by nearly 90 percent by using software in autonomous vehicles.[16]

Cutting millions of hours in travel time and saving billions of dollars in fuel expenses.

Seeing the United States gain nearly $1 trillion in unrealized economic potential.[17]

And so much more …

The **test of strength for tomorrow's infrastructure** isn't whether it is built with asphalt, concrete, or steel, but **whether it is built with software, the cloud, and data.**

software also makes the infrastructure itself smarter — infusing sensors and software into things never before possible, like bridges that monitor their own safety, smarter power meters to modernize the grid, traffic lights that streamline traffic flow, train control systems that avoid crashes, and GPS air traffic navigation to speed travel and reduce flight delays.

- The rapid advancement of technology and related convergence of connected devices into social-networking tools are enabling real-time public input on projects, creating new avenues for citizen engagement in infrastructure.
- Software maximizes the use of today's infrastructure. For example, we now rely upon navigation apps to route us more efficiently, ride sharing apps that get us places more effectively, and smartphone apps that can use our accelerometer to report potholes.
- Software allows us to better understand and analyze the effect of risk both in design and construction. Design and construction intelligence leveraging the use of big data and analytics could revolutionize risk management. In turn, this will equip the industry to better identify, quantify, and mitigate project risks, and thus make business judgments and margins more predictable.

It means the test of strength for tomorrow's infrastructure isn't whether it is built with asphalt, concrete, or steel, but whether it is built with software, the cloud, and data. As we make new infrastructure investments, rather than asking whether it is "shovel ready," we should instead be asking whether it is "software ready"[18] as a way of ensuring taxpayers get the biggest bang for their infrastructure buck.

If we are to meet our infrastructure challenges, we need to seize upon what may be software's greatest untapped potential — its ability to fundamentally expand what our infrastructure can achieve.

However, to maximize the opportunity we also need to ensure that the infrastructure upon which software relies is also up to 21st century standards. Software requires a robust cloud infrastructure, and fast and ubiquitous broadband — a technology the Federal Communications Commission argues should be included in any infrastructure upgrade plan because it not only plays an outsized role in economic growth, but because it also has the potential to help improve other forms of infrastructure from transportation to energy. Taking advantage of intelligent infrastructure also requires closing a looming skills gap by filling the talent pipeline with more people who know how to code.

Yet today, we are quickly falling behind. Whereas America was once the global model of progress and engineering magnificence, today we have moved from first in the world to middle of the pack. Our overall infrastructure quality has fallen to 16th in the world, behind Germany, France, and Japan — and even Iceland, Hong Kong, and Spain.[19] In fact, we spend less on infrastructure as a percentage of GDP than at any time in the past 20 years, and the results are plain to see.

Seeing an opening, countries around the globe are turning to advanced software to beat the United States in a race to 21st century infrastructure.

To cut their infrastructure costs, countries like the UK, Japan, Germany, and Russia are making 3D infrastructure design software a requirement for all infrastructure projects as part of a strategy to achieve as much as a 33 percent reduction in construction costs and a 50 percent cut in construction time.[20]

In China, they turned to software to speed construction and accelerate their high-speed train infrastructure. In just three years, China built an automated software controlled 800-mile high-speed rail network with 24 new stations, in the same time it took to fix one set of analog era escalators at a single metro station in downtown Washington, DC.[21, 22]

South Korea is building what they call the "City of the Future," where the city's infrastructure is completely infused with software and sensors that monitor and regulate everything from temperature to energy consumption and traffic.[23] By using cutting-edge technologies like 3D building design software, the country is enabling a holistic integrated software-controlled city that improves the way they live, work, and play.[24]

In Spain, after investment in fiber optic infrastructure enabled 61 percent of Spaniards to have access to 100 Mbps broadband, the country launched a national plan for smart cities that uses software to streamline city services and boost quality of life.[25] By contrast, the United States has fallen from 9th to 12th in the world on average internet speeds with 34 million Americans lacking access to fixed broadband at basic 25 Mbps speeds — limiting our smart city options.[26]

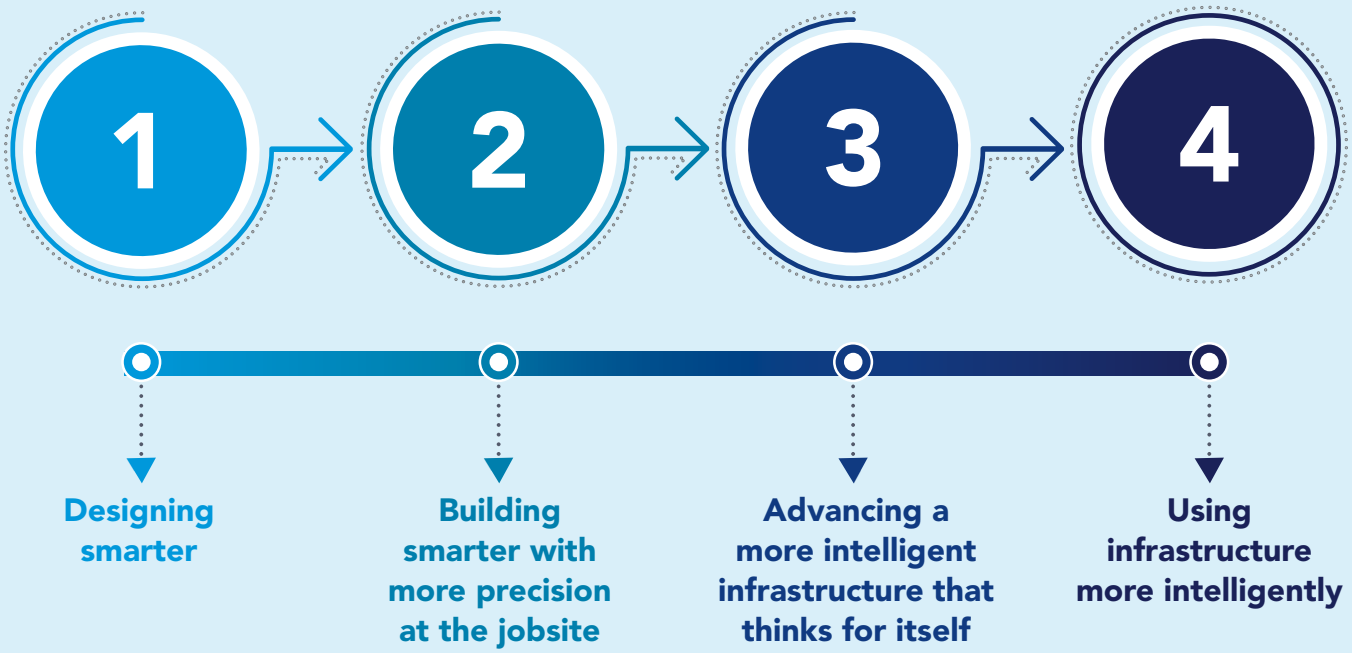
To compete and win on the global stage, the United States need a first-rate software-enabled infrastructure that can accommodate current and future needs. With enormous new opportunities on the horizon, never has it been as important as today to maximize the use of software to close America's infrastructure opportunity gap.

How Software Can Help Close America's Infrastructure Opportunity Gap

	The Infrastructure Challenge	The Software Opportunity
Roads/ Highways	Almost one-third of our nation's roads are in poor or mediocre condition,[27] and more than 40 percent of urban highways are choked with traffic[28] — leaving Americans wasting 7 billion hours a year stuck in traffic[29] and costing the economy an estimated $101 billion in wasted time and fuel annually.[30]	**Reducing highway construction costs, improving traffic flow, and saving lives.** Advanced 3D digital design and construction software can be used as part of a national strategy to reduce overall construction costs by 33 percent, and boost overall delivery time by 50 percent.[31] Connected sensors and traffic management software can enable 5 to 25 percent improvement in traffic flow.[32] Software apps can also revolutionize the way we drive using crowd-sourced real-time data to route us smarter and also advance autonomous vehicles to dramatically reduce fatalities.
Bridges	One in nine of the nation's 607,000 bridges is "structurally deficient." Americans make more than 200 million trips every day across almost 59,000 of these structurally deficient bridges.[33]	**Building better bridges.** Software now enables better bridges by design by solving complex structural analysis and leveraging generative design approaches to render dozens of options allowing for building stronger bridges while cutting costs and speeding construction time. Once built, advanced sensors can monitor structural health and identify problems before disaster strikes.[34]
Water	Most of America's drinking water and wastewater systems were built more than 50 years ago, and in some cities more than 150 years ago. It means that every two minutes, a water main breaks somewhere, flooding streets and leaving taps dry — costing us $2.6 billion a year.[35] At the same time, as many as 6 million Americans are exposed to contaminated water.[36]	**Improving water quality, control, and monitoring.** To upgrade our water infrastructure, software can help design, build, and operate water transmission, treatment, and distributions systems more effectively than ever before.[37] Software-enabled, Internet of Things (IoT) sensors combined with predictive analytics can help remotely measure and monitor water quality, and wastewater and groundwater systems, including water pressures, flows, levels, and rainfall volumes — to help prevent disasters before they happen.[38]
Railroads	While other countries race to build high speed and maglev train systems, much of our nation's passenger rail infrastructure was built during the New Deal and WWII. Freight and passenger delays on the nation's congested railroads cost the economy an estimated $200 billion a year.[39]	**Preventing collisions and saving lives.** Investments in Congressionally mandated positive train control hardware and software designed to prevent train-to-train collisions, overspeed derailments, and the movement of a train through a main line switch in the wrong position could help save lives.

	The Infrastructure Challenge	The Software Opportunity
Aviation	America uses outdated aviation technologies, based on 1940s era radar, which delays air travelers, wastes fuel, and costs the economy $24 billion in 2012.[40]	**Reducing air traffic delays with a tech upgrade.** Our cars have used GPS to navigate for years, yet the software and technology upgrade to route planes using GPS is still years away. The Federal Aviation Administration estimates that a modernized software-enabled air traffic control system will reduce flight delays by 35 percent and provide $29 billion in net benefits each year once fully deployed.[41]
Electric Grid	Our electric grid is made up of an antiquated patchwork of facilities, portions of which date to the 1880s, leaving it vulnerable to outages and cyber-attacks.[42] The World Economic Forum ranks the US electric grid at 24th in the world in terms of reliability, just behind Barbados.[43] It lacks the capacity to meet America's growing needs, lacks the sensors that tell operators when power goes out, and is unable to transform the way power is produced, stored, and sold.	**Creating a smarter grid and reducing our energy bills.** By infusing the electric grid with software and sensors and enabling it to connect to circuit breakers, meters, and appliances, the smart grid is poised to change the way electricity is generated, distributed, managed, and consumed — providing up to $2 trillion in customer benefits over the next 20 years, while creating millions of new jobs.[44] Software-enabled technologies could also yield a 10 percent reduction in home energy use,[45] and a 20 to 30 percent reduction in factory energy use.[46]
Broadband	As of January 2016, nearly 40 percent of Americans living in rural areas and 10 percent of Americans living in urban areas lacked access to quality high-speed broadband.[47] The OECD ranks the United States 16th in the world in terms of broadband access, and we are 12th in terms of average broadband speed.	**Creating new opportunity by extending digital networks that go farther and faster.** Our modern economy isn't just connected by roadways and runways, increasingly it is connected by ones and zeros. Broadband is an essential enabler for extending vital software and cloud benefits to the places where they can be used most effectively. For every $5 billion invested in broadband infrastructure, 250,000 jobs are created, and with every percentage point increase in new broadband distribution, employment expands by 300,000.[48]

Software Improves Infrastructure Throughout Its Lifecycle



BIM brings the construction industry into the digital age by creating and using a complete 3D digital representation of both the physical and functional characteristics of the infrastructure.

1. Designing smarter

The road to improving our infrastructure begins with software's ability to take good designs and make them transformatively better. At the dawn of the computing age, we turned to computer-aided design (CAD) systems to transform 2D paper drawings into 2D digital versions to speed the design process and eliminate mistakes — but it still produced a 2D drawing.

Now, a digital modeling process called Building Information Modeling, or BIM, software is replacing 2D models with data-rich 3D models to turbocharge designs using the cloud, artificial intelligence, and astonishing new collaboration features. BIM brings the construction industry into the digital age by creating and using a complete 3D digital representation of both the physical and functional characteristics of the infrastructure. It is already producing radical new improvements in the way we design and build infrastructure. The constraints and challenges these infrastructure professionals will face are no longer defined by just design rules. They will be defined by the transformative business and process outcomes they are required to solve.

Taking advantage of digital tools. Intelligent 3D BIM models allow different design teams to collaborate from anywhere in real-time on the same design to communicate and inform project decisions. The cloud-based model becomes a platform where survey, engineering, and construction data can all be more tightly integrated. Once integrated, the software can take advantage of the enormous computing power made available by the cloud to perform advanced analytics, answer "what if" scenarios, create advanced simulations, and view stunning visualizations to further improve the design. Using cloud-based analytics, BIM software can also model stress, flow, and heat — enabling designers to create more efficient designs for more resilient infrastructure. BIM enables designers to better anticipate cost and time resources, allows waste to be easily stripped out of the construction process, makes any redesigns less costly, and enables designers to reduce long-term maintenance costs. For example, by using BIM to optimize roadway alignments, corridor and route planning can be done 50 percent faster.[49]

Incorporating reality to improve designs. Reality capture, whether from drones using photogrammetry, helicopters with radars, or ground-penetrating radar, can create a 3D model of the existing physical landscape to be incorporated into BIM models. With this more-detailed physical data, designers can calculate the best earth moving options, or evaluate how the surrounding topography may affect project drainage.

Exploiting designs that can reduce the long-term maintenance costs. BIM also can help design and build infrastructure that is easier and less expensive to manage. One expert described the long-term maintenance savings that can be achieved through BIM this way: "Currently, for every dollar we spend in design, we spend $50 to $60 in maintenance … if we can spend an extra dollar in design and save $10 in maintenance costs, that's a significant savings for us."[50]

By using BIM instead of traditional tools, the San Diego International Airport saved an estimated $800 million in the largest improvement project in the airport's history.

Harnessing artificial intelligence to create better design options. BIM software can also take advantage of artificial intelligence algorithms to mathematically calculate the most effective design for meeting design objectives. These algorithms can rapidly and systematically test countless computer-generated design options that meet specific design objective (like cost, time, and energy targets) — often producing unexpected solutions. The computer-generated designs become a starting point that enables tweaking and refining for the best possible design outcome.

Unfortunately, the construction industry has long relied on outdated technologies that often lead to poor collaboration, errors, project delays, and cost overruns. These very real problems facing construction today can often be improved with BIM.

- 98 percent of megaprojects face cost overruns or delays — with an average cost increase of 80 percent, and delay of 20 months.[51]
- Poor use of data coupled with highly fragmented teams end up costing the US capital facilities industry almost $16 billion annually.[52]
- As much as 30 percent of construction cost is rework,[53] costing as much as $75 billion a year.[54]

To overcome these challenges, more and more experts are finding that the shift to cutting-edge BIM technology creates obvious advantages. For example:

- By using BIM to help rebuild a complicated highway interchange, leaders in Arizona lowered costs, boosted productivity, and enabled precision machine guidance. They estimated that for every $1 invested in creating virtual construction models of the project, they saved at least $5 in construction costs.[55]
- In a mega airport project, developers used an entirely BIM-driven approach for the design and construction of a new $3 billion midfield airport terminal. The software-driven approach enabled them to survey the site more efficiently, cut RFI time from 28 to as little as two days, save more than $1 million just by eliminating one major clash, and reduce the numbers of cranes used by five.[56]
- Similarly, by using BIM instead of traditional tools, the San Diego International Airport saved an estimated $800 million in the largest improvement project in the airport's history.[57] The project served as an economic stimulus for the region, created 1,000 jobs at peak construction, and was designed using "green" design principles leading to decreased water usage and reduced energy consumption.[58]
- In Des Moines, Iowa, to prevent raw sewage from overflowing untreated into the Des Moines River, backing up into homes, and dislodging manhole covers during large rain events, they turned to BIM to design a new sewer solids separation facility that reduced the work required by 260 to 360 hours over traditional methods.[59]

Because of these advantages, countries around the globe are moving swiftly to make BIM a basic requirement for all infrastructure projects. For

Software-controlled paving equipment can not only enable a smoother ride on the road, it can improve safety and tackle more demanding jobs like a precision runway.

example, the UK government has mandated BIM for all centrally procured government contracts, and expects to build infrastructure more quickly, more efficiently, and more cost effectively by improving information flow and collaboration.[60] By putting BIM at the heart of its national construction strategy, the UK government expects to reduce construction costs by 33 percent, reduce overall construction time by 50 percent, and cut emissions by 50 percent.[61] Not to be left behind, Spain, Germany, Japan, Norway, Finland, Denmark, the Netherlands, and Russia are all implementing national BIM strategies for public infrastructure projects in order to take advantage of these many benefits.[62] Others like Australia, Canada, and the European Parliament aren't far behind.[63] With smart strategies and ubiquitous use of BIM in all infrastructure projects, the United States could similarly catapult our infrastructure into the 21st century *and* save billions of hard-earned taxpayer dollars. But too often, US project planners have not taken full advantage of BIM opportunities.

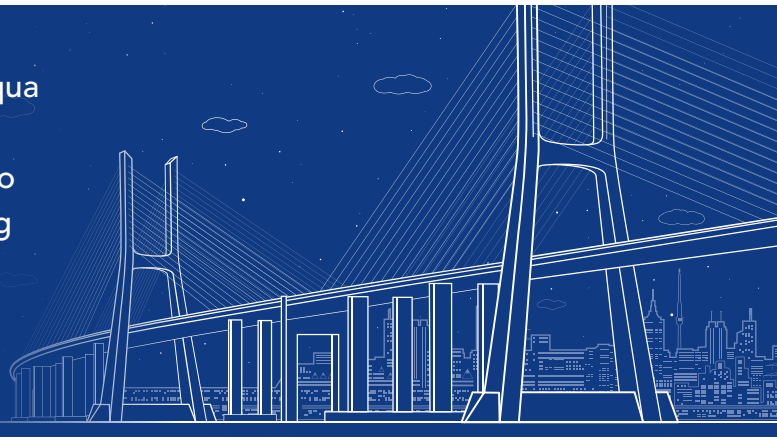
2. Building smarter with more precision at the jobsite

At the jobsite, productivity in the construction sector has unfortunately been flat or has even been falling during the past 20 years.[64] That's about to change. The construction site is about to be transformed by software, too — where cloud software is enabling tighter integration between BIM models, site logistics management, and even the construction equipment itself to boost productivity. The use of drones for rapid real-time existing data capture combined with digital BIM designs allow for up-to-date construction monitoring and quality control and the ability to transfer the designs to a digitally controlled machine. Jobsite work software enables more precise builds and a more effective workforce.

Although software-controlled vehicles have captured many people's imaginations — like autonomous vehicles, and to a lesser extent precision-controlled farm equipment — many are less aware of the software gains being made to advance digitally controlled construction equipment. Digitally engineered BIM models can be transferred to the control software contained in a new generation of connected construction machinery — infused with cutting-edge software — to perform jobs with more precision, efficiency, and safety. Using the software-designed digital BIM model, these connected machines communicate with a network of base stations that provide precise positioning data so they can perform precise grading and loading operations with the help of the GPS enabled guidance technologies. Such precision can be critical for improving the performance of all kinds of infrastructure. For example, software-controlled paving equipment can not only enable a smoother ride on the road, it can improve safety and help workers tackle more demanding jobs like a precision runway.[65] Similarly, connected bulldozers can grade higher quality surfaces 35 to 40 percent faster, while the smarter vehicle can also improve job site safety.[66]

In addition, cloud analytics help engineers eliminate construction delays before they happen by integrating real-time supply chain information. Fleet management

New Hampshire's Memorial Bridge over the Piscataqua River was transformed into a self-diagnosing, self-reporting "smart bridge" that uses a water turbine to power sensors used not just for structural monitoring and traffic management, but to measure water flow, weather, and other inputs to help inform decisions about when to raise the bridge.



software gives worksite managers a comprehensive overview of the worksite with real-time machine tracking to better manage construction logistics. Software also helps jobsite managers become more effective using construction project management software that maximizes resource allocation in a way to meet project objectives at a given schedule, budget, and quality — often while reducing energy usage and waste.

3. Advancing a more intelligent infrastructure that thinks for itself

Software drives further benefits by making the infrastructure itself more intelligent. By combining infrastructure with emerging Internet of Things technologies, you get an intelligent "Internet of Infrastructure" that can enable transformative new improvements never before thought possible.

Connected sensors and computing intelligence are being infused deeper into the very systems and processes that make our infrastructure work — into things like the power meters in a smart grid, traffic light systems in our roadways, train control systems on our railways, water pressure control in treatment facilities, and navigation in our air traffic control systems. Doing so helps enable smarter ways to make more efficient use of our infrastructure, including lowering costs, speeding traffic, improving public safety, and protecting the environment. In some cases, it can even enable self-diagnosing, self-managing, and self-improving infrastructure that is better able to adapt to real-time needs.

This software-infused intelligent infrastructure can now enable enormous gains as we transition to the smart grid, smart cities, smart lighting, and smarter everything. If policymakers and businesses get it right, linking the physical and digital worlds through the Internet of Things could generate up to $11.1 trillion a year in economic value by 2025.[67] This connected and sensor-laden infrastructure can also provide our communities with smarter options for addressing some of our most pressing needs through smart city initiatives. Cities can now connect devices to improve traffic flow, cut crime, deliver city services better, boost local economies, and improve quality of life for their residents. That's why, when the US Department of Transportation Smart City Challenge announced its finalists, they were given access to cutting-edge software to better imagine, design, and simulate what a fully integrated, forward-looking transportation network looks like, to push the boundaries of what is possible in cities across America.[68]

New kinds of connected sensors and systems are driving this future. Infrastructure can now be fitted with fiber optic strain gauges, vibration monitors, moisture sensors, computer vision, and other data management tools to advance a holistic lifecycle approach to managing, monitoring, and maintaining infrastructure. For example, real-time data from fiber optic sensors on a bridge can be incorporated and visualized in a BIM model to better monitor its structural integrity, manage maintenance, and improve future bridge design.[69]

In Ann Arbor, Michigan, where a huge but fluctuating student population can make traffic wildly unpredictable, the city supplemented its traffic signal control system with traffic corridor sensors that allow the timing of lights to be continually optimized based on real-time conditions.

For example:

- New Hampshire's Memorial Bridge over the Piscataqua River was transformed into a self-diagnosing, self-reporting "smart bridge" that uses a water turbine to power sensors used not just for structural monitoring and traffic management, but to measure water flow, weather, and other inputs to help inform decisions about when to raise the bridge.[70] The sensors are also used to calibrate a 3D analytical finite element structural model of the bridge, which is compared to a predicted structural response, to better inform future bridge design.[71]
- New York recently upgraded the world's largest train control system in the city's subways with software that provides fully automated traffic control, wayside signaling, automatic vehicle identification, and integrated voice and data communication. It enables more trains to be added to the system, and shorter wait times at the platform. These systems have been shown to increase line capacity by up to 20 percent, and cut annual energy consumption by 15 percent.[72]
- The citizens of Tyler, Texas, were frustrated with the city's congestion problem. Instead of pursuing a "bricks and mortar" solution that could have created more construction-induced traffic delays, Tyler installed traffic control software to coordinate signals in real-time. In the wake of the installation, travel times have fallen by 22 percent and delays by 49 percent. These improvements saved Tyler drivers more than $1.6 million.[73]
- In Ann Arbor, Michigan, where a huge but fluctuating student population can make traffic wildly unpredictable, the city supplemented its traffic signal control system with traffic corridor sensors that allow the timing of lights to be continually optimized based on real-time conditions. This allows the system to help smooth traffic on major arteries as well as the nearby side streets. Following the deployment of the program, weekday travel times in the city were shortened by 12 percent and weekend travel times by 21 percent.[74]
- Colorado is pursuing a bold smart infrastructure strategy called RoadX with a vision to create a crash-free, injury-free, delay-free technologically transformed transportation system in the state. By taking advantage of new software, big data, and the cloud, Colorado is working to infuse the state's infrastructure with technology that will enable opportunities like vehicle-to-infrastructure communication to create the most data-connected transportation system in the country with a goal of taking a dramatic leap toward zero deaths on the highway.[75]

4. Using infrastructure more intelligently

The ability to more effectively collect, communicate, store, and process data has led to an abundance of data, which can often be used to create new opportunities to transform and improve how we use our existing infrastructure. This growing abundance of data from our physical world creates sometimes

Using data from millions of other vehicles to help route travelers, trucks, and packages more efficiently to reduce impact on congested roads by making smarter route choices.

surprising and clever new opportunities to reduce the energy, traffic, and water usage that is overloading and congesting today's infrastructure.

Making more efficient use of our transportation infrastructure. At a time of ever-increasing congestion on the road, leaders are harnessing data innovation to reduce the hours we spend in congestion in various ways.[76] Software applications are:

- Targeting repairs by identifying the locations of potholes through apps like Street Bump that use your smartphone's accelerometer data to automatically report road conditions to the city every time your car hits a pothole.[77]
- Taking advantage of the "sharing economy," new on-demand mobility apps are reshaping how people think about transportation, transforming it into a real-time on-demand service.
- Using data from millions of other vehicles to help route travelers, trucks, and packages more efficiently to reduce impact on congested roads by making smarter route choices.
- Making the roads safer by enabling connected cars that can talk to each other to improve traffic flows, use virtual guardrails to avoid collisions, and use automated decision-making (even without becoming fully autonomous.) They can have as big an effect on safety as the introduction of seatbelts.[78]
- Enabling truck fleets to drive in wind-reducing single-file pelotons to reduce fuel and cut delivery costs. Telematic software can also perform real-time engine diagnostics to identify maintenance needs before they become a costlier problem.[79]
- Enabling railroads to stay on track with analytics that help predict derailments even weeks before they are likely to occur — reducing bearing-related derailments by 75 percent.[80]

Reducing demand on our electric infrastructure. New software innovations also are helping reduce demands on the grid by using energy smarter in buildings, homes, farms, and factories. Software applications are:

- Reducing home heating and cooling energy usage by as much as 20 percent by connecting thermostats to the cloud to let our homes turn down the thermostats when we are away.[81]
- Giving customers data about their home energy usage, as compared to their neighbors, to spur competition and energy reductions of as much as 10 percent — when even small reductions in peak electricity demand on hot days can have major economic and operational benefits for the stability of the power grid.[82]

Three Key Recommendations for Rebuilding America's Infrastructure

Our infrastructure challenges are enormous. But they are more easily solved when leaders maximize the use of transformative software, upgrade our digital infrastructure, and fill the talent pipeline.

Today's infrastructure opportunity is underpinned by three vital but nearly invisible parts of the infrastructure ecosystem — leveraging software innovation, upgrading our digital infrastructure, and improving our human capacity.

Harnessing the latest software technologies

Advancing a robust digital infrastructure

Filling the talent pipeline and upgrading our human infrastructure

1. Harnessing the latest software technologies

Rebuilding America's infrastructure requires us to maximize the use of innovative software and workflows that optimize its use and drive innovation. It can lower costs, reduce risk, speed construction, improve resiliency and sustainability, increase citizen engagement and make the most efficient use of our existing infrastructure and investment dollars by fundamentally improving the way we design, build, manage, and use our infrastructure. **As Congress turns to consideration of a major infrastructure bill, let's make sure every infrastructure dollar gets spent in the smartest way possible:**

- Let's ensure infrastructure projects are designed with cost-saving BIM tools that improve planning, design, performance, and coordination while reducing mistakes, energy needs, and time.
- Let's ensure new infrastructure can be fitted with the cutting-edge sensors and other Internet of Things technologies that maximize the use of data to extend the life and effectiveness of our infrastructure investments.
- Let's maximize software's potential by transforming our electric grid into a Smartgrid to make our grid more efficient and reliable, upgrade our air traffic control system with NextGen technologies to enable software to route our planes with GPS instead of World War II era technology, and speed the use of positive train control software to save lives.

2. Advancing a robust digital infrastructure

Today's infrastructure isn't just made of concrete and steel, it's also made of ones and zeros. To enable a smarter physical infrastructure, we also need to upgrade our digital infrastructure upon which it depends — with wired and wireless broadband networks that communicate faster, extend opportunity further, and support the cloud infrastructure upon which our infrastructure transformation depends.

Our broadband and cloud infrastructures are the backbone of the information and technology sector that is transforming the economy and expanding opportunity. They enable remote cloud computing power to be focused on solving important infrastructure challenges, enable designers to work collaboratively on the same designs at the same time, and enable a vast sea of amazing new software apps that allows us to make more effective use of the infrastructure we have.

But today our digital infrastructure isn't yet up to the task.

- Globally, America is no longer first. The United States ranks 12th in the world on average internet speeds — behind countries like Japan, South Korea, and Latvia.[83]
- 34 million Americans lack access to high-speed broadband, while nearly 40 percent of rural Americans lack access at these basic speeds.[84]
- Similarly, 11.6 million students in more than 19,000 schools throughout the country are without the minimum broadband connectivity necessary to take advantage of digital learning.[85]

For every $5 billion invested in broadband infrastructure, 250,000 jobs are created and with every percentage point increase in new broadband distribution, employment expands by 300,000.

- Likewise, too many hard-working Americans are still unable to connect on public transit, in airplanes, in public housing, in public parks, in public schools, and on public school buses — which could easily be transformed with connectivity into mobile offices.[86]

- When it comes to next generation wireless broadband, our global competitors are investing in next generation wireless broadband infrastructure to take advantage of cloud, data, and software driven benefits.[87] For example, Europe is investing $1.8 billion in an effort to become the world's leader in next generation wireless broadband infrastructure.[88]

We can and must do better. In arguing for bold new broadband infrastructure investments, a group of 48 US Senators found that for every $5 billion invested in broadband infrastructure, 250,000 jobs are created, and with every percentage point increase in new broadband distribution, employment expands by 300,000.[89] The Federal Communications Commission concluded that improving the nation's digital infrastructure should be a significant part of any national infrastructure plan because our digital infrastructure isn't just a direct engine for economic growth, it's also a catalyst for expanding opportunity across every other infrastructure sector — from transportation to energy.[90] They recommended our nation's digital infrastructure goal should be to increase and accelerate profitable, incremental, private-sector investment to achieve at least 98 percent nationwide deployment of future-proofed, fixed broadband networks.[91] Policymakers have within their reach a set of pragmatic policies to jumpstart broadband infrastructure investment to unleash these broader gains.[92]

3. Filling the talent pipeline and upgrading our human infrastructure

To maximize our infrastructure opportunity, we need to fill a growing talent gap that today prevents companies from hiring the people necessary to drive important advances. Today's infrastructure jobs aren't about having the skill to use a shovel, swing a hammer, or drive a truck — today's infrastructure jobs often require high-tech jobs skills. They require people who can design in 3D, manage a worksite, code for smart infrastructure, build an analytics engine, remotely monitor construction equipment, run a digital fabrication machine, or drive a precision-guided piece of construction machinery.

There are at least three main skill sets that are critical for enabling a 21st century infrastructure:

- **Providing infrastructure workers with the software skills they need to perform in an increasingly technology-driven workplace.** An increase in infrastructure investment will require tens of thousands of new workers at a time when there is a shortage of high-skilled construction labor with specialized knowledge.[93] A greater share of infrastructure workers use software than US workers overall. Infrastructure workers account for about 11 percent of all US workers, but they use nearly 30 percent of all the tools and technologies available in the workplace today.[94] For example, infrastructure workers today are already more likely to use inventory control software, logistics and supply chain software, CAD software, industrial control software, and map creation software than American workers overall.[95] In filling new infrastructure jobs, we need to ensure new workers gain familiarity with the sizeable number of tools and technologies that jobsites now use.[96]

- **Ensuring we can design tomorrow's infrastructure by creating 21st century classrooms and filling the 3D design skills gap.** We more people with 3D design skills.[97] To help give students more skills early on, the UK government adopted a new high-tech curriculum to give students as young as five years old 3D design and coding skills.[98] Thankfully in the US, as part of the ConnectED initiative, software leaders have stepped forward to provide every secondary school with access to cutting edge 3D design software to teach the tools of the trade; help train the next generation of designers, engineers and architects; and help students create a better world with better designs for the future.[99] For years we have been just teaching the three R's in school (reading, writing, and arithmetic). Now it's time to also start teaching the three D's — digital, design, and development. But today, 11.6 million

To advance a workforce with the skills to meet our 21st century infrastructure challenge, policymakers need to make investments in computer science education to help prepare the next generation of tech workers.

students lack sufficient broadband connectivity necessary to take full advantage of digital learning tools like 3D cloud models.[100] Because high-speed broadband has become an educational equalizer and learning accelerator, it's time we fire up the fiber, boot up our classrooms, and put America on the map as having the best classroom broadband infrastructure in the world.

- **Overcoming a looming coding skills gap is essential.** One of the most important challenges we face is in coding. As we infuse our 21st century infrastructure with more intelligence, lines and lines of code will make our infrastructure smarter. Creating this innovative infrastructure requires more workers with programming skills. However today, there are an estimated 500,000 computing jobs currently unfilled in the United States, and fewer than 50,000 computer science students graduate from US universities a year.[101] By 2020, the US Bureau of Labor Statistics predicts that there will be 1.4 million computing jobs but just 400,000 computer science students with the skills to apply for those jobs.[102] This growing gap could impede the development of the apps and software necessary to bring our infrastructure into the 21st century. And as we connect our cars, bridges, airports, railways, and runways — and every connected thing around us suddenly runs on code — we simply aren't preparing enough workers to meet these future needs. It's for this reason that parents and teachers increasingly want computer science taught in K–12 classrooms. To advance a workforce with the skills to meet our 21st century infrastructure challenge, policymakers need to make investments in computer science education to help prepare the next generation.

Looking ahead

Today we have an enormous opportunity to harness the power of software, the cloud, and data to create a 21st century infrastructure system that reduces traffic jams, speeds air travel, strengthens our bridges, and makes our electric grid more resilient. It will enable more seamless flow of data, electricity, water, and goods and services throughout the nation. By making these smarter choices today, we can close America's infrastructure opportunity gap and enable bigger opportunities tomorrow.

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instruments, devices, and software packages than the average American worker. Even while using an assortment of physical tools, various software technologies are crucial as well, including those involved in database management, operating systems, and computer aided design (CAD). Ibid.

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[100] To make America's K–12 broadband infrastructure among the best in the world, state and district leaders need to close the bandwidth, fiber, and Wi-Fi gaps that remain in our K–12 schools. Unfortunately, 3,700 schools lack the fiber-optic connections to meet current and future connectivity speeds, while 15,000 schools report insufficient Wi-Fi in their classrooms. EducationSuperHighway, *2016 State of the States: EducationSuperHighway's Second Annual Report on the State of Broadband Connectivity in America's Public Schools* (January 2017), https://s3-us-west-1.amazonaws.com/esh-sots-pdfs/2016_national_report_K12_broadband.pdf.

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