City of Norfolk, VA

Response Proposal to USDOT

Beyond Traffic: Smart City Challenge Grant

NORFOLK NAMED GOOGLE ECITY OF VA

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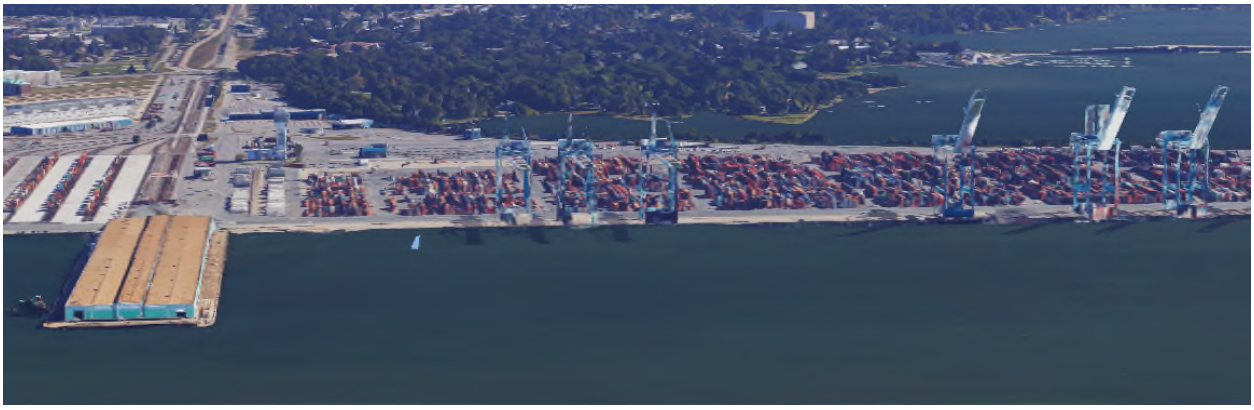
Table of Contents



1 City Challenges and Vision

The promises of the coming advances in transportation afforded by vehicle technology are astounding. Changes in vehicle technology alone will improve safety and mobility in our city. But, we have not been waiting idly – we have been on a continuous course of infrastructure, operational and design improvement, and have more on the way; changes that are going to help now, and facilitate the integration of the new. Our vision for Norfolk is innovative, yet thoughtful, targeted, and bounded by rationality, as it should be. Our vision for this project is as well, facilitating specific Norfolk-supportive outcomes, while strongly supporting national research and development. We believe we can make strides for us and for the nation.

Norfolk is a coastal city blessed with extensive waterfront, a temperate climate, beautiful historic neighborhoods, rich history, and tremendous diversity. Hampton Roads and the Elizabeth River provide the best year-round harbor on the east coast, the world-class resource that has been the driving force for this community for almost 400 years, and supports the world's largest Naval Base and several large commercial ports. Those very blessings, in addition to being the constrained, older urban core city of the region, are also the source of major challenges for the City.

Challenges

Norfolk cannot escape its relationship with the Atlantic Ocean, the Chesapeake Bay, the Hampton Roads and the Elizabeth River, with the projected sea-level rise and resiliency challenges they bring.

A Robust Test Platform

Three expressway tunnels; an interstate drawbridge; at-grade, under and overpass railroad crossings; Light-Rail Transit; local/express bus and ferry services; two interstates; and a Continuous-Flow Intersection – we have a challenging transportation system as well. More details on our city, our transportation system, and our wide range of aggressive resiliency initiatives are provided in Sections 3, 4, 5 and 8.

Almost without exception, if you ask people that live or work in Norfolk what they like least about being here, one of their top two answers would be "traffic congestion", inferring not only delay but safety concerns. We want to change that, for the better and for good. But even as we seek to change what is, issues are emerging that will dramatically impact our city and way of life.

As simple as "reducing traffic congestion" sounds, our vision requires context, and rests upon a foundation of critical principles, that are important to our city, and many others. First, we are not a rich city – in fact we are somewhat hampered with a large proportion of federal and state lands that provide no local tax revenue. Our choices for spending must be very pragmatic and targeted toward truly meaningful local benefit. Our solution will not be expensive to maintain and operate, and it will leverage private and cross-needs support to maximize benefit-to-public cost. Second, our planning focus is on "Vision 2100", a major City planning initiative. We must begin to face the 21st century challenges of being a historic, low-lying coastal city. We are

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planning for resiliency and transforming Norfolk even further toward a great live/work/play city that maintains support for the state's and nation's economy and security derived from our harbors. We know that transportation is a means for people and urban life, not an end. The city of the future addresses safety, accessibility and sustainability, with support from *all* modes of accessibility. Third, we live in a world of rapidly changing technologies, and changing demographics. We must serve an older population, while adjusting to younger generations who won't live and work in ways of past generations. We need to build tools that are adaptable and agile. **In short, we not only want our city to be smart, *we want our approach to be smart*.**

Norfolk's Vision is also influenced by a different relationship with climate change than may be typical. That of a city, and road network, that will be seriously impacted by sea level rise, and while not only learning to adapt and survive, must thrive. Our vision for planning and expenditures must focus on long-term and lasting success – not quick fixes. After population decline to the suburbs fairly typical of core cities in the latter 20th century, Norfolk's population is rebounding in this century in no small part due to an impressive array of City and private redevelopment and investment. That continues and there is substantial land ripe for mixed-use redevelopment that is pedestrian oriented, with access to bus and light-rail transit. Norfolk's approach for reducing oil reliance and carbon footprint is to incent a shift in regional population growth back to the core, to renewed reliance on pedestrian, bicycle and transit travel, resulting in reductions of annual VMT in the millions, according to a 2003 Smart Growth Analysis conducted by the Hampton Roads Transportation Planning Organization (HRTPO).

In addition, while Norfolk continues to embark on an aggressive flooding prevention and mitigation plan (see Section 3 for more details), we must deal with the reality of "managing" our system, keeping our residents and visitors safe and sufficiently mobile, particularly for essential services, during periodic flood events that are unavoidable. Coupled with other "reliability" issues faced in our region due to limited connectivity and water crossings, we have the most to gain by addressing non-recurring congestion. To wit, the HRTPO compiled national statistics of similar-sized cities and found that this region fared very poorly in travel time reliability measures, and further that this predominantly accounted for its comparatively high congestion ranking.

Our Vision for Addressing the Challenges of Mobility and Climate Change in Norfolk

Ultimately, the implementation of our Vision will have the following outcomes:

Safer Multimodal Travel – a result of actions at network/system level down to street conflicts

Facilitate Smart Growth, mode and temporal shifts, trip reduction – the overall reduction of regional Vehicle Miles of Travel and greenhouse-gas emissions

Improved travel reliability – a key for our area, addressing the majority of our congestion and barriers to synergy amongst the urban core cities, and the resiliency issues of periodic flooding.

Improved accessibility to jobs, goods, services and social life; mitigate the negative aspects of urban travel through system management, information, smart land-use and digital accessibility.

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With these critical foundational principles, and our "special" traits in mind, Norfolk proposes major "Smart City" project efforts in three areas, all supported and interrelated by a fourth, a robust information management system. This approach for the funding will address all Norfolk and USDOT Vision Elements – more information on those particulars is provided in Section 5.

Key Project Area One: Develop Norfolk "Intelligent Mobility App" and Intelligent Sensing

- Easy-to-receive-and-process, actionable information for travelers will be orders of magnitude above current practice. We will build upon the great work of our partners.
- Primary goals will include mode-shift and route/time-shift supportive information
- Advance concepts of low-cost system data acquisition from existing, leveraged resources
- Integrate intermodal and transit vehicle monitoring for traffic management functions
- Leverage the tool by integrating other public and private services to "un-waste" time. Expand to the "Intelligent Community Platform" as other service platforms evolve.

Key Project Area Two: Connected and Automated Vehicles Development and Testing Support

- Norfolk has and is actively expanding/upgrading ATMS infrastructure that allows easy installation of CV-related devices. "Real-Life-Issues" V2I testing and evaluation on urbanized arterials should be happening nationally in this time frame and the City will provide an outstanding test environment and support from local to international experts.
- City staff will bring an important perspective as traffic signal operators and maintainers that should enhance concept troubleshooting and testing design.
- We will expand the "connected" concept to all users, not just vehicles, and to a broader vehicle spectrum, through adaptations using DSRC technology in smartphones.
- Our full proposal will elaborate on a collaborative R&D support approach consistent with the current state of research. One certainty, we know that our approach must include "change management" as the state of practice will undoubtedly evolve as we proceed. More details on our system and proposed "test bed" are contained in sections 3, 4 and 5.

Key Project Area Three: Develop Active "Eco" Traffic Operations Management Tools/Systems

Fulfillment	Key Project Area		
Outcome	1	2	3
Safety	✓	✓	✓
Mode/Time Shift	✓	✓	✓
Reliability	✓	✓	✓
Accessibility	✓	✓	✓

- We will focus first on high-impact strategies at critical locations subject to extreme incident-induced stress or impassable roads.
- Innovative and flexible capacity-enhancing intersection operations including variable cycle, phasing and lane-utilization strategies, facilitated by the platforms of intelligent vehicles and sensing, and other partner systems.
- Integration of Pedestrian, Bicyclist and Transit utility and safety enhancements. Norfolk is a strong proponent and an ideal setting for Complete Streets and compact development.
- Central System rapid-action signal management tools elevating TMC performance.
- Visualization and active flow-chart based decision-support tools for operators (human operators are still the most valuable tools in the box).

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"The Heart" – A Powerful and Agile Data Acquisition and Information Management System

Figure 1 illustrates the architecture of our proposed Transportation Information and Decision-Support System. In short, the purpose of the system is to:

> Collect data – convert it to a collection of intelligence – effectively put targeted information into travelers' possession for supporting both real-time and pre-trip decisions – similarly use intelligence to take targeted real-time multimodal transportation system management actions, with and without human interaction – and monitor system performance over time for identification of potential operational and roadway improvement strategies.

The architecture could be described as having three "zones". Moving from left-to-right, first we have the Data acquisition zone – the points of data collection. They take widely varied forms and require a variety of interface modules to pass the data to the "Analytics" zone, a series of databases and processing/analyzing tools to create intelligent "use-case" information. This information is then carried through various interfaces to the "edge-users" zone, a combination of portals and applications supporting human and automated decision-support. This structure lends itself to logical compartmentalization of objects that facilitates change and adaptation. Details would include structured and documented interface mechanisms between objects.

An important note regarding the concept of "analytics" in the intelligent transportation world: there are "on-street" and "remote", or "system", analytics. On-street analytics are the subject of progressions in the connected-vehicle world and some advanced traffic controller operations. This system is addressing the "remote" side – creating abilities to influence operational actions in advance of events, as opposed to those that demand action in an immediate locale and time, often safety-related, handled by on-street systems.

Several other concepts are noteworthy. 1) The Data zone incorporates extremely important data capture from transportation partners, emergency services and the business community, as well as travelers. Much of this information is of a less technical nature than "traffic" data requiring participant input, and some will actually come into the system from the edge, e.g. smartphone app. 2) The system relies heavily on strong participation through user smartphones or similar devices. There will be concerns regarding privacy and security. We have no hesitations about achieving sufficient participation. Benefits to users and secure system design, including limiting the use of personal data in the system, will attract users. 3) There can be a tendency for large systems such as this to become "black boxes". At every level this system will include reporting, visualization and dashboard type tools to support quality assurance and human decision-making. 4) There is a huge role that Agency Operating Systems play in "end user" impacts, much of which takes place within those individual control systems. The lines between which applications do what may change, but in any event there is also a need to improve upon operational actions taken, and these will also be addressed, regardless of the side in which they reside. 5) It is crucial that the Open Data Portal doesn't simply exist. Comprehensive "user tools" will be created to facilitate the likelihood of third party interest and success.

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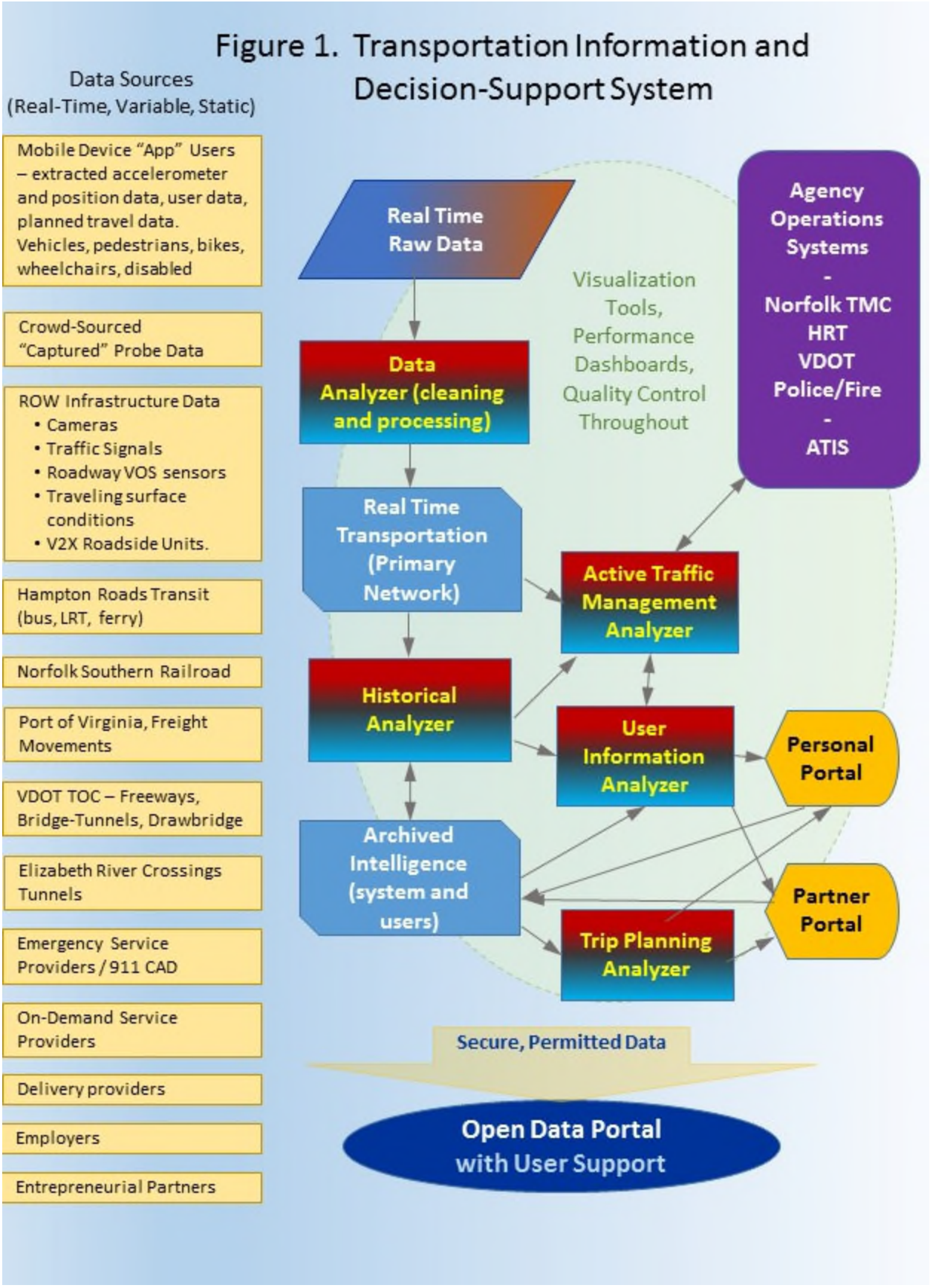
Figure 1. Transportation Information and Decision-Support System



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Implementing the Smart Cities Challenge Demonstration Project

Importantly, our vision for this leveraged grant funding is outcomes of real value, both long and short-term, and not just to Norfolk but to the entire country. Our project will be led by transportation and urban activities professionals that understand human factors and the concept of accessibility in promoting "smart" urban living.

For a project of this type a certain amount of "dividing and conquering" is a necessity as a program management technique. Our team allows for efficiently segmented resource allocation but also provides for redundant capabilities. The key project areas as we have defined them as well as the three "zones" of the information system structure, fit nicely into allocations of expertise and capacity over the entire duration of the project. It is expected that we will enhance this arrangement moving forward, and of course the project will involve engaging contractors, which the City does on a regular basis. In fact, the City's practice of having highly capable consultants and contractors "on call" with contracts will facilitate this process.

Sample Schedule and Tasks	
Year 1	Metropia installs current system, "jump starts" app development and data collection. ODU leads cooperative effort with USDOT to identify V2X research opportunities. City leads early agency partnership integration efforts, targets locations to develop new operating strategies, team partners research the top video analytics currently available. Investigate sharing services.
Year 2	Continue Data System development, particularly analytics. Develop "Eco" operating platform concepts. Install field devices and begin V2I testing. Develop test sites for autonomous shuttle. Develop plans for EV charging sites. Deploy real-time transit information systems.
Year 3	Complete Data System and app development. Continue V2I testing. Implement autonomous shuttle pilot. Develop selected Eco-traffic signal system utilities.
Year 4	Demonstration/Evaluation

The program management plan will build upon the Project Management Body of Knowledge (PMBOK). Kimley-Horn (KHA) will support the City of Norfolk in managing the proposed program based on similar experiences working on expansive technology programs including Traffic Adaptive signalization standards, the integration of KITS Mobile for Cyclists in Austin, and similarly for Connected Vehicle research planning in NCHRP 20-24. As such the Program Management plan will consist of managing scope, requirements, schedule, financial, quality, resources, communications, project change, risk, and procurement. With the nature of this multifaceted complex effort and range of team members and partners, managing resources, communications, project change, and risk will be key focus areas. In addition, the City of Norfolk and KHA will use certified Project Management Professionals (PMP) within the firm to review the project management plan throughout the project.

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2 City Characteristics

Norfolk is an independent mid-size city in the Commonwealth of Virginia, located at the core of the Hampton Roads metropolitan area consisting of nine cities and seven countries. According to the 2010 Census, Norfolk's population totaled 242,803. Norfolk is Virginia's second most populous city and serves as the historic, urban, financial, and cultural center of Hampton Roads. Norfolk has the highest population density in the region of 1.4 million - 4,363 people per square mile according to the 2010 Census - twice the population density of all other cities in the region. This represents 17% of the population of Norfolk's local urbanized area. With 191,212 jobs, and 3,533 jobs per square mile, Norfolk is the region's employment center with the highest job density in the region.

Aside from being the hub of the Hampton Roads region, Norfolk is an international city that hosts globally and nationally important assets. Norfolk and the region have a unique interdependency with the military. The region is home to the largest concentration of U.S. defense facilities in the world, and Norfolk is the home to Naval Station Norfolk, the largest naval complex in the world, which supports the readiness of the Navy's U.S. Atlantic fleet and drives the economy and employment of Norfolk and the region. Nearly a quarter of the nation's active-duty military personnel are stationed in the region, particularly in Norfolk and a third of the U.S. naval ship-building and repair capacity is housed there. The region is also home to the third-largest commercial port on the East Coast that is projected to grow. Norfolk specifically hosts the Port of Virginia's Norfolk International Terminals, one of the city's and the region's most significant economic assets, which makes Norfolk an integral node in national and global trade. These two stalwart industries provide the foundation for the region's economy. Department of Defense spending supports over 40% of total regional employment. Over 8,000 service members transition out of the military annually in the Hampton Roads region, providing the city with a highly skilled labor force. In addition, the Port of Virginia handles over 81 million tons of cargo, generates $60 billion of economic activity annually, and provides employment in port-related industries for 343,000 Virginians. Norfolk's population diversity also sets the city apart from the region. While diversity is one of Norfolk's most distinguishing attributes, it is also one of its greatest challenges. Poverty levels are highly concentrated in some communities, and the difference is even more significant by race and age. Relative to other cities in Hampton Roads, Norfolk has the highest level of income inequality. More than half of Norfolk residents have low to moderate incomes, with 19.2% living in poverty.

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3 Other City Characteristics

a) Existing public transportation system.

Through Hampton Roads Transit, Norfolk supplies a robust network of public transportation services, including local and express bus routes, para-transit, a ferry and light-rail (The Tide). The Tide opened in 2011, and will be extended into Virginia Beach, attracting additional riders. An EIS is about to begin for a transit extension to the Norfolk Naval Station. The City just opened a $7 million Downtown Transit Center greatly enhancing system efficiency, connectivity to the Tide, and access to downtown. All of these services are subsidized by the City (see Section 8).

b) Environment conducive to demonstrating proposed strategies

Norfolk is a national leader in the field of resilience and a fertile location for innovative solutions. Due to its history of resilience, its demonstrated openness to innovations and ability to transform when changing conditions require it, Norfolk was selected as one of the first resilient cities in the 100 Resilient Cities (100RC) network by The Rockefeller Foundation. The two-year 100RC grant provides a wealth of resources, including funding for Norfolk's first (and world's third) Chief Resilience Officer (CRO) – an executive post supported by a cross-disciplinary team reporting directly to the City Manager and Mayor, access to renowned international experts, and membership in a cohort of global cities with similar challenges. Through 100RC, Norfolk and other cities, such as London, Paris, and New York, are identifying, sharing, and institutionalizing innovative resilience practices which inspire and support thousands of cities around the world.

100 Resilient Cities defines resilience as the ability of individuals, communities, institutions, businesses and systems within a city to survive, adapt and grow, no matter the chronic stresses or acute shocks they face. Norfolk defined the following resilience challenges through a community engagement process—flooding and the long-term impact of sea level rise, and the need to better connect vulnerable populations, among others. Surrounded by water with 144 miles of shoreline, low-lying and flat topography Norfolk's among the nations' most vulnerable cities to coastal flooding. The city is experiencing the highest relative rate of sea level rise on the East Coast, Norfolk and the region is second only to New Orleans as the largest population at risk from sea level rise. As sea level continues to rise, severity of storm surge and extent of flooding will continue to increase, posing significant challenge to residents' mobility and mission readiness of the U.S military forces and operation of water dependent industries.

Norfolk views these challenges as opportunities to transform in a more resilient way and show the world how to thrive on the coast despite increasing risks. After two years of thorough research, analysis and stakeholder engagement, Norfolk launched an integrated Resilience Strategy to guide the city to be the successful coastal community of the future continuing its business on the water in the environment of increased risk. The city intends to use the opportunity to address environmental changes as a catalyst for diversifying the city's economic base and connecting individuals through new networks. In short, Norfolk believes that the

coastal community of the future will be a city that is more physically, socially and economically connected.

Funding for Norfolk's proposed U.S. DOT Beyond Traffic projects will support Norfolk in implementing its Resilience Strategy, as well as collaboration with other cities and private and public partners – including Naval Station Norfolk and Port of Virginia - all which have a high stake in Norfolk's success. Since Norfolk experiences these challenges earlier than others, solutions in Norfolk - a nexus of trade for the eastern third of the U.S. and a security center for the world - will help other cities on the coast to improve resilience. Finding innovative, smart city solutions focused on reducing risk and improving data-driven decisions in coastal cities (while replicable and scalable to any city) is critical because more than 80% of the nation's economy is supported in coastal states; nearly 80% of U.S. import and export freight is transported through seaports; and more than 50% of the population and U.S. economic activity are in coastal regions.

As demonstrated in the leverage section of this proposal, Norfolk has already begun to create this new city through a series of funded and leveraged initiatives. Norfolk's capacity to pilot innovative strategies was demonstrated in January 2016 when Norfolk was selected as the third highest national winner of the HUD's National Disaster Resilience Competition (NDRC), securing $120 million to continue implementing strategies to design the coastal community of the future and capture the resilience solutions in a new Resilience Accelerator discussed in Section 5 of this proposal. The USDOT project would complement/benefit and be bolstered by this project and its partnerships among many other supporting initiatives underway in the city and the region.

c) *Continuity of committed leadership and capacity to carry out the demonstration*

Norfolk has successfully implemented a variety of projects similar in scale, scope and complexity to those proposed in this application. In the past three years, the City's Public Works has managed $267 million in infrastructure projects, including construction of the flagship Slover Library and the Courts Complex. Slover Library is among the most technologically advanced public libraries in the country. The state-of-the-art Courts facility is a LEED-certifiable (Leadership in Energy and Environmental Design) green building. Phase I grand opening was in January 2015 and now houses General District Court and Circuit Court. Phase II is underway and is estimated to be completed in 2017.

Projects managed by the City of Norfolk follow a set of standards to initiate and manage individual projects. This methodology provides tools for use by the project manager containing definitions, guidelines, and templates needed to deliver successful projects. The methodology establishes common ground for all projects within the organization and the standards in this methodology serve as assets to each team member and provide a common format for evaluating progress toward project goals, objectives, and deliverables. The methodology encourages a top-down approach to project management. It ties directly to the project life cycle phases and project initiation process flow to provide a more precise definition of projects, a common

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lexicon used in project management, and a framework of activities mapped to each project class size. It enables the tracking of progress against pre-determined metrics for reporting purposes.

d) A commitment to integrating with the sharing economy

The City of Norfolk is committed to integrating with the sharing economy demonstrated by the development and support of the following initiatives:

- The City developed a Bicycle and Pedestrian Strategic Plan, dated September 2015, and initial implementation has included a Bike Sharing program.
- Uber and Lyft are ride share services that are available and in use in the city
- Hatch Accelerator, a public-private partnership startup accelerator program for technology and entrepreneur community. This program launched in 2012 and continues to be successful in growing entrepreneurial talent and retaining/ attracting that talent to Norfolk.
- Innovation Research Park, a collaboration between ODU and City of Norfolk that includes business incubation and accelerator services to help companies in any stage of development to achieve a competitive advantage.
- City of Norfolk will launch a Coastal Resiliency Laboratory and Accelerator Center that will serve as a nexus for technological, organizational and innovation around community revitalization, water management, resilience measurement, port, Naval Station, and other water-sector business related resilience challenges. Funding of $12 Million has been allocated for this initiative.

The DOT Smart City Challenges Grant enables us to leverage our current sharing economy initiatives and expand them to include: car sharing, autonomous vehicles, and data sharing. Data sharing will open opportunities for the business and entrepreneur community in the following areas: traffic management, nuisance flooding notification and avoidance, reuse and sharing of services by citizens (peer to peer services), and health platforms to address patient management. These innovations focus on the citizens rather than city process.

e) A commitment to making open, machine-readable data accessible, discoverable and usable by the public to fuel entrepreneurship and innovation.

The City of Norfolk's Chief Information Officer is developing our open data policy. Our open data policy will provide a mechanism to break down the City's departmental data silos and expose important information to the public to better facilitate community engagement, transparency, and build trust between the City and the residents it serves.

A vast variety and number of data sources are currently installed in the City, such as moving and stationary sensors, and CCTV cameras. Coupled with the user interface data, such as cell phone apps and text messages, as well as geo-location, the constantly growing data amounts may be used to optimize flooded road management, public transit plan, predict congestion and flooding impact on the road infrastructure and traffic pattern. Beyond the transportation impacts, the

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data gathered during recurring flooding may be used to validate flood-prediction models developed at the Virginia Institute of Marine Science (VIMS), help local entrepreneurs to gauge the current customer needs, to fine-tune their operation hours, and to manage supplies.

Much investigation has been done recently in applying Big Data techniques to specific data sets mentioned above. However, research into the integration of many data sets with diverse data types to infer societal and economic impacts has just begun and is being enabled by emerging public data storage and user access facilities as well as high-capacity network infrastructure. In particular, data.gov portal contains a variety of data sets in many domains of interest to the society. One possibility is to supply the transportation data being gathered by the City of Norfolk with a similar meta-data structure so that it may be combined with existing data.gov data sets using Big Data methods and---as an outcome of the data-collection activities---be housed in the data.gov repository for the open public access.

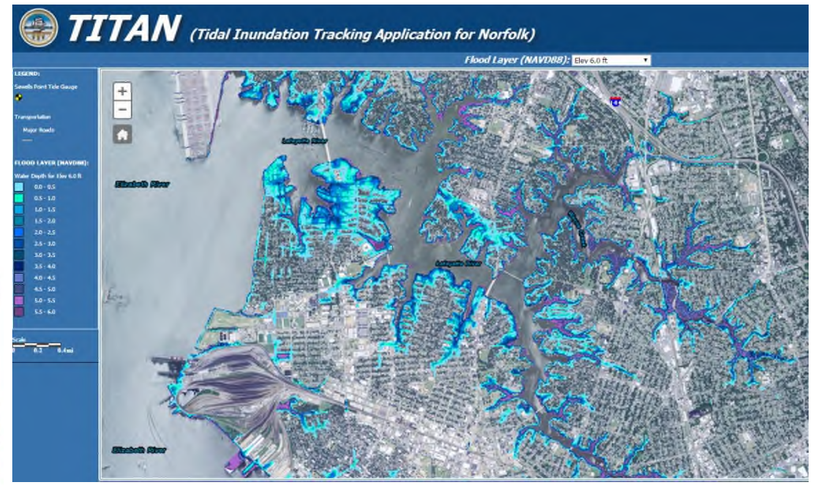
In 2015, the City of Norfolk began working with Socrata, the global leader in software solutions that is designed exclusively for a digital government. Socrata's cloud-based Software as a Service (SaaS) solutions supported by their Open Data network provide data driven innovation and transform data into actionable insights for measurable cost savings. With Socrata's Open Data API and our creative commons license, developers and entrepreneurs can programmatically access the City's data for their own consumption and application development. Some datasets we have on the Socrata open data platform are: (1) Call Center/311 requests; (2) Code Enforcement Cases; and (3) Building Permits.

Also in 2015, the City launched our ArcGIS Online Open GIS data site to share our live authoritative GIS data. The City's Open GIS platform allows anyone to explore, visualize, analyze, and share geospatial data to help solve real problems at no cost. Built using the ArcGIS REST API the City's Open GIS data site provides a simple, open web interface to our hosted map services. The allows for multiple output formats to be consumed, including html (HyperText Markup Language), json (JavaScript Object Notation), image, kmz (compressed KML, or Keyhole Markup Language), and jsapi (JavaScript) to name a few. Some dataset groups we have on the ArcGIS open data platform include: (1) Property Information layers; (2) Transportation; (3) Planning and Zoning; and (4) Public Safety.

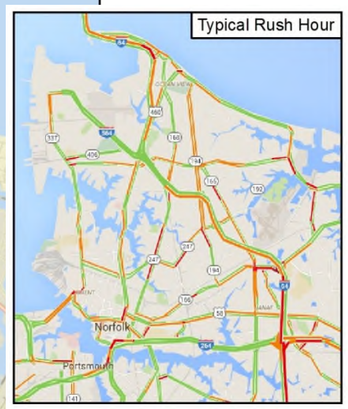
4 Preliminary Site Map

Figure 2 contains several mapping images that help describe features relevant to the suitability of Norfolk for providing an excellent site for USDOT's investment. Key features illustrated on the main map include tunnels, traffic signals, the Tide LRT line, and railroad crossings. A proposed "test bed" for Connected Vehicle V2I equipment (further description in Section 5) is located. Other sites shown include the two largest intermodal port facilities, Virginia International Terminal and Lambert's Point Coal Terminal, Naval Station Norfolk, and Old Dominion University. The intermodal terminals are served by Norfolk Southern rail lines.

With TITAN, residents can view the impacts of a predicted flooding event



Tidal Inundation Tracking Application for Norfolk (City Developed)

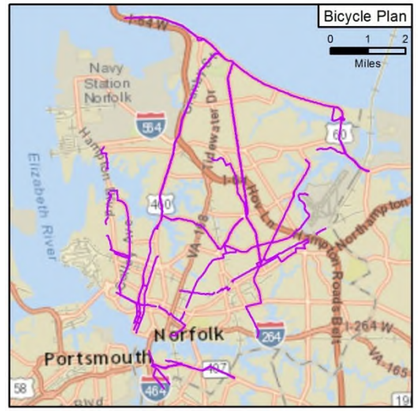


Berkley Bridge Lift Span (I-264)

Typical Railroad Underpass

LEGEND

- City Operations Facility
- Light Rail Station
- Signalized Intersection
- Tide Gauge
- Railroad Underpass
- Railroad Overpass
- Railroad Grade Crossing
- WAN Location
- I-NET Node
- Fiber Optic Network
- Light Rail Route
- Bicycle Route Plan
- Railroad



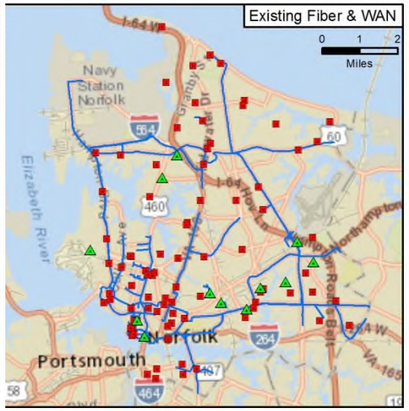


Figure 2. Preliminary Site Map

5 Holistic Approach to USDOT Vision Elements

In Section 1 we discussed a Vision for Norfolk's future, and key "project areas". That Vision reflects a very holistic approach to our City's challenges, but the next "level" must delve into more detailed objectives and strategies. This section provides elaboration, and addresses the objectives of USDOT's funding. These strategies continue to focus on achieving impact while keeping costs low, thinking "beyond traffic", and always remaining adaptable.

It is noteworthy that for every vision element there are inherent synergies with others, and in fact necessary ones to achieve impacts, but also opportunistic ones that can cumulatively increase impact. For example, data sensing alone accomplishes nothing. In keeping with our key principles, we will seek to leverage synergies to multiply benefit and keep costs low. The efficient and balanced integration of elements is critical to achieving maximum success.

The table below addresses our Vision's alignment with each of the 12 USDOT Vision Elements.

Vision Element	Alignment and Approach
ONE Urban Automation	The City has numerous locations that are sure to benefit from the introduction of "community" autonomous vehicles, in addition to general private fleet absorption. Two college campuses, a downtown with residents and visitors frequenting its attractions, the historic Ghent district, circulators for LRT and ferry patrons. Our proposed information system is highly supportive of creating the intelligence platform for autonomous vehicles in demand-based services and transit connection roles. Such services could provide improved mobility at less cost. Support for V2X infrastructure testing in support of is addressed below. Our Port and Navy partners could have ideal applications. The figure to the right illustrates a potential LRT station feeder service connecting neighborhoods that are separated from the station by highways. Norfolk's own staff or contracted resources could be utilized for the application of pavement markings or other roadway infrastructure to support pilots or testing. 
TWO Connected Vehicles (and other users)	Norfolk's team will benefit from and build on the knowledge base accumulated over the years from the USDOT's Connected Vehicle (CV) test-beds and Pilot Deployment Program around the country (e.g., Southeast Michigan, CV Pilot in NYC). Much has been learned over the years, ranging from the development of systems for privacy protection to standards for broadcasting SPaT (signal phase and timing) message from the RSU to the receiving on-board equipment (OBE). There is much more yet to develop, test, prove, and implement before these technologies, or elements thereof, are considered "roadworthy". To provide an environment for showcasing and testing Connected Vehicles concepts and technologies the Norfolk team plans to do the following: The City will provide the base infrastructure for a comprehensive real-world arterial system test-bed, that will include a continuous-flow intersection, a single-point arterial interchange, a railroad overpass with adjacent signals, three interstate interchanges

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Vision Element	Alignment and Approach
Connected Vehicles (and other users)	(one a 3-intersection tight-diamond with adjacent at-grade LRT crossing operated from a single controller), Sensys volume counters, traffic monitoring cameras, all within a contiguous 6.2 mile section of 4 to 10 lane roadways, with 36 Ethernet-connected signals using 170 Type cabinets. The fiber channels throughout emanate from a Comm field node located in our traffic maintenance building, in the corridor. The corridor is identified in Figure 2. V2I RSU devices will be installed at locations as desired to establish testing frameworks. After evaluating the literature and the lessons learned from the CV test-beds and collaborating with USDOT, the team will identify numerous CV applications that will be implemented and tested in the field (Red Light Violation Warning, Pedestrian warnings and/or detection, SPaT messaging in complex urban signal settings, etc.). Furthermore, the Norfolk team will coordinate with signal controller/system vendors (e.g., Econolite) to expedite the implementation and testing of Intelligent Traffic Signal Systems (I-SIGs) in the field where data from CV are integrated and fused with data from traditional sensors for optimizing signal timing. CV and remote data will allow predicting traffic patterns and enable proactive signal timing to reduce congestion, improve transit service, and enhance overall intersection safety. Given that DSRC-equipped vehicles are not yet common on the roads, the Norfolk team suggests working with the industry leaders in wireless communications (e.g., Qualcomm) to test and implement alternative solutions. • Working with Qualcomm, equip smartphones with the DSRC capability as well as a safety and mobility app. User interface and information provided to the user will be optimized to minimize driver distraction. • Install after-market DSRC on test vehicles with the same safety app on cell phones • Install DSRC in signal cabinets and enable communication of SPaT with vehicles and cell phones. Lastly, to have a holistic system, the Norfolk team will make relevant data from CVs available to the "cloud" to support other applications that do not necessarily rely on DSRC. For example, an emergency vehicle (EV) with a DSRC can transmit its location, route, and destination to vehicles in its path and to an RSU which then sends this information to the cloud. CVs and others with a smartphone app in the immediate area of the EV would receive a message with exact details about the EV's route, which will help vehicles and pedestrians clear paths for the safe passing of the EV. The team would expect to advance the state of R&D in the CV arena, while also creating current improvements for operations and safety in proximity to signalized intersections.
THREE Intelligent, Sensor-Based Infrastructure	Consistent with our stated Vision, our approach definitively is designed for maximum impact at reasonable life-cycle costs. In Norfolk's Vision, smartphones, or more generally mobile consumer devices, will play a central role as a sensing and communication technology. There are numerous motivating factors for this: (i) The proliferation of mobile devices with ever-increasing computing, sensing, and communication capabilities; (ii) The ability for rapid deployment and ease of software updating with the current App-store system; (iii) The ability to collect a large-amount of data at a very low cost; (iv) The ability to collect travel data across all modes of transportation;.and (v) the potential to extract rich traveler information from both GPS

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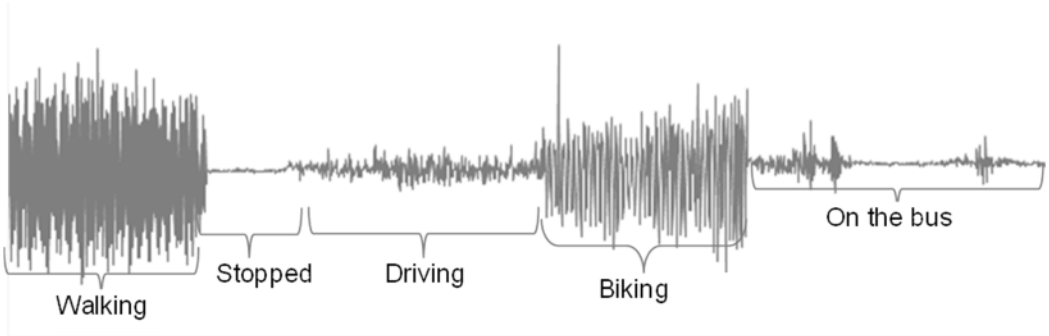
Vision Element	Alignment and Approach
Intelligent, Sensor-Based Infrastructure	and low-energy inertial sensors (i.e., accelerometers, gyroscopes, compass) within the smartphones. From the rich sensor data, beyond extracting trajectories of travelers, it is possible to detect the mode of travel (see figure), vehicle operating mode (e.g., idling,  accelerating), and the amount of time spent within each mode. Such information, which currently does not exist at a large scale, will be invaluable for accurately estimating GHG and other emissions. Furthermore, by relating such data to links and nodes of a transportation network, the system operators can determine areas with inefficient operations and higher emissions. In addition, with the recent advancements in chipsets technology provided by Qualcomm – a partner on Norfolk's team) it is now possible to have dedicated short-range communications (DSRC) technology on smartphones. This will enable smartphones to serve as a medium for communications among vehicles, pedestrians, and infrastructure to support various safety and mobility applications. Streaming video from traffic monitoring cameras (already the most powerful tool in an operator's arsenal) is currently an underutilized resource, usually providing no direct value over 90% of the time. We propose a "multi-purpose" camera system that uses visible and thermal imaging; PTZ, detection and 360 degree cameras; and powerful video analytics platforms, to leverage the already-supported systems into a data-production monster. (of note: relatively inexpensive camera systems are readily maintainable by existing traffic signal maintenance labor forces) This system could produce in addition to standard traffic data, both real-time and historical, movement data on the entire user cross-section, O-D/route data, security, road surface and weather conditions. Norfolk's efforts in establishing a system-wide high-capacity Ethernet platform can support the data transmission requirements for this approach. The nature of the system also is less "black-box" since performance can be observed at any time, enhancing troubleshooting. The City plans to develop a comprehensive set of tools to estimate water inundation levels due to flooding through crowdsourced images, video surveillance images if available, and a network of gauges or sensors. A custom smartphone app will be developed to enable citizens to collect and upload inundation image data in real-time. CV V2I sensing has been addressed.

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Vision Element	Alignment and Approach
FOUR Urban Analytics	This element involves converting captured "data" into a variety of "products". There is a distinction because we must do all three of these: take actions, provide actionable intelligence to users and our operating systems, and provide "useful" information to third-parties that will also provide benefits and help support the system. Figure 1 illustrated the need for a variety of "analyzers", having different functions, as you move from data at is source to product. Each one is unique, of a different flavor, requiring different constructs and skills. We are literally walking through the door of the data-rich environment of the future, requiring different thinking than the past. With the sheer volume of data and the complexity of the intelligence to be mined and produced, this may be one of the biggest "big data" challenges to date. The science of "big data" analytics requires cleverness in how data is housed, in computational techniques of algorithms, digital and spatial analysis, and in user delivery. This we understand and bring all of the requisite skills to the table. We've got to "meld and supplement" source data using statistical and spatial techniques to develop our total state conditions over-and-over again for our real-time moving picture., and craft the "agent" forms (an intelligent representation) of data that are easier to "mine" by the downstream analyzers. For example, a downstream analytic may compare two spatial (2 or 3 dimensional) dataset agents looking for a significant change. Agent datasets may reflect conditional variances from a norm rather than actual values. Archived libraries of historical actual and agent datasets can form the basis for models using advanced techniques such as pattern recognition and machine learning. Our private and research institute partners bring ready experience in these areas. The obvious analytic goals for traffic operations professionals are things like: predicting multimodal traffic flows, particularly in light of non-recurring events such as crashes, work zones, impassable roads and special events; identifying crashes or hazards in real time and facilitating responders; and creating tools for actionable operational adjustments, whether by automation or human operator, such as traffic signal/ intersection operations adjustments for incidents, transit or emergency responders, or on their side, transit scheduling adjustments or dynamic emergency vehicle routing. Extremely important although less complex, analytics for "app" users are a "new frontier", both on the public side and how private partners are leveraging the information. With a diverse population of users, a "one-size-fits-all" approach cannot suffice. The user analyzer should be multi-dimensional with say, a vertical spectrum of user participation level and a horizontal level of user preferences. The more participation from a user, the more benefit they can obtain. Our combined system of sensing, urban analytics and open data creates a "synergy magnet" which will induce multi-partner and service breadth, and will be scalable up to grow with opportunities and needs.

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Vision Element	Alignment and Approach
FIVE User-Focused Mobility Services and Choices	Our approach will focus on the needs of all users, regardless of age, ability, ethnicity, race and income - in particular users with disabilities, and older users, require choices and alternative services and treatments. Technology and the coming Intelligent Community Platform will revolutionize accessibility choices. The Mobility app will have ultimate power and flexibility for users to exercise choice from the entire spectrum of options, whether based on real-time or historical information, or personal vs. shared mobility options. Users will be able to set their own preferences for their level of participation. Through strategic business partnering, the mobility service provider world will have ease of successfully deploying in Norfolk at its fingertips. A current and evolving example in Norfolk is the implementation of Smart parking meters downtown. The data platform connected to the meters opens the door for parking app vendors (we are currently using Passport) that can supply a host of user utility improvements, such as simplified payment, time expiration notifications, automated validation or discounts by businesses, and the locations of open spaces. The "larger" impact of such platforms is removing some of the "disutility" associated with patronizing downtown businesses, improve downtown's vitality and success.
SIX Urban Delivery and Logistics	Trucks create a challenge for efficient traffic signal operations due to their different size and acceleration characteristics. V2I infrastructure at the south entrance to VIT could improve intermodal operations at the port. The transportation information system contains within it the network travel time information that is needed to support everyday logistics, but also would include a service coordinated through the User and Trip Planner analyzers, and the Partner Portal to support consolidated delivery services. The City's Economic Development Department would work with potential "vendors" to purchase or lease a suitably located piece of land for a storage/transfer site. We will seek to deploy logistics-driven solutions, which could include autonomous vehicles, at Virginia International Terminal to leverage all of the space available on the constrained site.
SEVEN Strategic Business Models and Partnering Opportunities	As demonstrated in Section 7 and 13, the City leverages an extensive network of partners and stakeholders in identifying and developing business opportunities.. Illustratively, the City and its partners will leverage a new $12M-funded Coastal Resiliency Laboratory and Accelerator Center to capture a portion of the new resilience market by connecting "smart city" and other resilience challenges with solutions and products. The Accelerator will also ensure that best practices and lessons learned get captured and disseminated within the region, nation and world. Business partnering opportunities leveraging the data platform will be facilitated by designing high utility and ease-of-use into the open data portal. The City has a robust and aggressive Economic Development Department constantly seeking and recruiting businesses and entrepreneurs into the City. The City offers prime downtown real estate at no cost for an entrepreneurial start-up organization called Hatch. Hatch offers a variety of tools and resources to help companies at almost any stage accomplish their goals. We create the ecosystem for entrepreneurs to thrive by building platforms, programs, events, and courses designed specifically for early stage and small businesses to pick up with ease and flourish.

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Vision Element	Alignment and Approach
EIGHT Smart Grid, and Electric Vehicles (EVs)	Dominion Virginia Power is actively deploying smartgrid technology systemwide. The City's likely contribution to this element would come in the form of EV charging stations and "park-n-charge" sites. Driving on Norfolk City streets rarely involves more than 8 miles, or 20 minutes, of travel. The City has recently collaborated with Virginia Clean Cities to install three charging stations (2 in downtown) on City property. Tesla has also recently installed a charging station in the City. With ownership of 20,000 downtown parking garage spaces, the City is extremely well-positioned to move into the "park-n-charge" business and proposes to do so. The City would also seek to facilitate similar installations at key private parking facilities and employers, and at Tide park-n-ride lots. The City would determine ways to leverage the increased power supply infrastructure needed in garages, for other uses, and use smartgrid technology to manage peak loading, perhaps even employ some form of reverse generation.
NINE Connected, Involved Citizens	As part of this proposal, the City and its partners will develop a customizable app toward an "Intelligent Community Platform", that will provide citizens, city departments, businesses, military and other organization access to targeted and actionable information that enhances their ability to make smart decisions that allow them to survive, adapt and grow in the face of the city's challenges. The app will help avoid congestion; improve safety and mobility, route around and otherwise mitigate the impacts of flooded areas; optimize business operations, and connect vulnerable residents to services in times of disruption. The City will leverage its vast network of non-profit, public and private partnerships and build upon existing community engagement campaigns and crowdsourcing efforts to make citizens active participants in the designing community of the future, asking them to be aware, involved and take a smart action in a more risky coastal environment.
TEN Architecture and Standards	Part of our Vision is to produce as much value as possible, both for Norfolk and the Country. Our approach described in Section 10, and the qualifications of our team, demonstrates our capabilities and commitment to this element.
ELEVEN Low-Cost, Efficient, Secure, and Resilient Information and Communication Technology	Our vision is to move beyond traffic to an integrated next-generation digital infrastructure that can deliver solutions and services to its residents. The City's existing fiber-optic-plant based Wide Area Network and ATMS Network, with ongoing expansions and upgrades, aligns well with this vision element and serves as the backbone of our system. The City will make its Smart City services and information accessible online at any time, from anywhere. The information will be accessed by a website or application with real-time updates from the transportation and Smart City network. Data will be presented through open web services to appropriate users in secure, PII protected manner. The City's digital infrastructure will not only connect to what resides in the City's data center, but also extended through the "internet of things" to residents' smart phones, wearable devices, cars, tablets, and PCs, etc. The City's digital infrastructure will be upgraded and expanded to increase its capacity for public Wi-Fi, internet service to residents and businesses, sensors, analytics, security, storage, and computing. Operations that were in silos will now be connected to a centralized command and

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Vision Element	Alignment and Approach
Low-Cost, Efficient, Secure, and Resilient Information and Communication Technology	control center, with communications and information flowing seamlessly across the system through a government convergence platform and robust fiber optic network. This will make possible multi-agency efforts, such as emergency notification and dispatch services via departments of health, transportation, and safety. A security plan will also be extended to fully cover all smart services used by the City, taking into account all perimeter access points to ensure proper controls and privacy are maintained. The City will also develop big data openness strategy to mine information collected to make better data driven decisions, optimize operations, ensure effective citizen engagement, and cross-government collaboration. We will develop customized traffic congestion alert services, flooded roadway warning systems, and critical infrastructure monitoring. Citizens can express preferences for specific locations and delivery methods, such as receiving flooded road and parking warnings or congestion updates for their specific frequent routes via push notifications, text, and email, etc. Agencies can prioritize users, such as emergency vehicles or critical infrastructure equipment. Targeted communications campaigns can be developed to different categories of residents, driven by their work and personal lifestyles, to increase smart services uptake and facilitate forums for continuous resident engagement in services improvement. We will conduct sophisticated data collection and analytics to enable The City to develop predictive insights for anticipatory actions. Data collection and analytics will allow the City during "blue skies" to better understand and model the impacts of sea-level rise and flooding on its transportation and critical infrastructure, and the impact it has on the citizens. This could also involve an analytics program that evaluates current road and transit patterns to predict future usage, guiding informed decisions for maintenance and expansion projects to City officials.
TWELVE Smart Land Use	Incenting, facilitating and investing in business and land development, and livability-supporting services and infrastructure, will create the future of Norfolk as a Smart City, with a focus on people and accessibility. The recent past has seen a tremendous positive upswing in attracting higher-density development in walkable and transit-oriented areas, and opportunities for continuing this trend are aggressively pursued in Norfolk's planning and economic development efforts every day (such as Vision 2100, Naval Station Norfolk Transit Extension Study, Military Circle Plan). By having a better understanding of where the worst flooding occurs, we can intelligently plan our land use strategies to make these areas green space or infrastructure. The areas can become stormwater management zones to decrease our runoff and pollution into the Chesapeake Bay and improve groundwater recharge.

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6 Risks and Mitigation

City of Norfolk's approach to assuring capacity and risk mitigations for its project relies on a rich partner network that incorporates redundancy. The City will continuously identify additional entities with capacity in critical areas and surface potential risks, and adjust as necessary.

In general, security challenges are magnified when dealing with Big Data due to its velocity, volume, and variability. Many security issues are identified, such secure computations in distributed programming frameworks, security best practices for non-relational data stores, secure data storage and transactions logs, end-point I input validation/filtering, real-time security/compliance monitoring, scalable privacy-preserving data mining and analytics ("Big Brother"), cryptographically enforced access control and secure communication, granular access control, granular audits, data provenance. Much research is being dedicated to these issues.

All of these issues are important for any Big Data collecting and processing activity but it quickly becomes overwhelming to consider all of them at once. Hence, we will apply a separation of concern principle by relying on the Cloud Services to handle security once the data are "in the cloud". However, the end-point input validation/filtering, scalable privacy-preserving data mining and analytics ("Big Brother"), cryptographically enforced access control and secure communication remain of concern and attention.

We propose to work closely with the Cloud services to define access control and data priority for the possibility of (auto) tiered storage with different security policies. In addition we will seek to partner with providers of input filtering technologies that will ensure the validity of inputs and check for untrusted inputs sources in the multi-device environments, such as driver cell phones.

7 Partners, Stakeholders and Governance Processes

The City of Norfolk has strong and long-standing relationships, that we consider partnerships, with all of the public agencies that will be key players and stakeholders on this project. We also have well-established relationships with our key university research partner, Old Dominion University's Transportation Research Institute, Norfolk Southern, Kimley-Horn, Siemens and Midnight Status. We are excited to engage Metropia and Qualcomm, rounding out a core team with an array of international expertise ideally suited for this project. Our Team:

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SIEMENS The portfolio of the Mobility Division includes signal and control technology for rail-based passenger and freight traffic. Siemens RailFusion system will soon be deployed in Norfolk improving rail/roadway operations. Electrification solutions for rail and road traffic. Road traffic control and information systems, parking space management as well as electronic payment and toll systems for urban and interurban traffic. Consulting, planning, financing, construction and operation of turnkey mobility systems. Integrated mobility solutions for intermodal networking of different traffic systems.

metropia We are a group of transportation engineers, network modelers and data scientists, all with solid academic backgrounds, practical experience, and a passion for solving urban traffic congestion problems with creative, cutting-edge solutions. We develop and integrate high-performance and mobile computing technologies to produce apps and backend analytics capabilities that help both users (commuters) and entire systems (cities) during normal operations, pre-planned special events, or unexpected, extraordinary circumstances.

QUALCOMM From reducing energy consumption, to cutting operational costs, to enhancing public safety, we're using our wireless expertise to transform infrastructure and address the complex challenges that smart cities are facing. True efficiency is the result of interoperability that allows data to flow freely across various technologies within city functions such as lighting, transportation and infrastructure – enabling intelligent communication, while maintaining security protocols. All of our citywide solutions are designed with the ability to scale — meaning entire cities can be seamlessly connected no matter their needs today, or tomorrow.

Kimley»Horn Kimley-Horn (KHA) provides the team with ITS and smart transportation from planning to design to software integration support activities. KHA's civil and electrical engineers understand the built environment coupled with software developers that can translate that infrastructure/data into an intuitive interface, and mine the databases for additional ways to enhance the way constituents get around. KHA is also apprised of recent developments in the Automated and Connected Vehicle arenas, and is developing a research roadmap on behalf of AASHTO and NCHRP related to planning and implementing Automated and Connected Vehicle technologies (NCHRP 20-24),an integral part of Smart-Cities initiatives.

Midnight Status is a Norfolk-based software development company with over 20 years of experience. Its team members have created software for The National Highway Institute, NATO, and the Marine Corps. Midnight Status has locally developed and deployed "Tunnel Traffic", providing a simple smartphone interface for Hampton Roads drivers to quickly see if any of the area's four tunnels are blocked or congested.

Tunnel Traffic

Demonstration Governance

Governance processes involving demonstration projects require the knowledge to establish proper procedures following the "rules of experimental conduct", and the ability to strategically

engage in inspection/observation throughout the process. It is desired that the "governing party" have at least some level of independency from the "demonstrating party". Our team provides numerous entities possessing this knowledge, particularly our University Research unit partners. We propose that our colleagues at the HRTPO serve as the governance lead. They will have little direct roles in the concept developments and implementation, and they are experienced in the role of operating as independent technical staff from the region's cities, to remain regionally objective. Their staff is already engaged frequently in the development of regional data collection, evaluation and reporting, for example, the annual congestion report developed from INRIX travel time data. VDOT has a somewhat similar "independency" relative to the City and can support that role.

Our team would develop demonstration plans and processes initially, and submit them for review and comment to USDOT, VDOT and HRTPO. Once the plans are finalized, any needs for additional staff, maintaining independence, could be provided through on-call consultant contracts, or by soliciting another University unit.

The main point is that given the breadth and depth of our team and partners, there will be ample opportunities for developing such processes over what could be multiple independent demonstration/testing exercises.

8 Existing Transportation Infrastructure

a) *Arterial Miles* – 189

b) *Freeway Miles* – 22 plus a 7 mile reversible HOV lane on I-64

c) *Transit Services*

Norfolk provides a robust family of transit services including 21 local routes with complete coverage of Norfolk's arterial system, 6 express routes, paratransit, a ferry service connection to Portsmouth, and the 7.4 mile "Tide" light-rail line. A new Downtown Transit Center has just opened. Most buses are equipped with AVL tracking devices.

d) *Shared Use Mobility Services*

The City is pursuing a joint effort with neighboring Portsmouth to implement a bike-share service, targeted at 30 – 40 stations. Uber and Lyft are both operating locally.

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e) Information and Communication Technology

The City, along with our shared services partner Cox Communications, has a robust 10GB Institutional Network (I-NET) fiber optic ring with 13 nodes that supports City facilities. We are also in our first year of upgrading our I-NET infrastructure to 100GB. The wide area/metro network has multiple connection methods, including owned/leased T1 services, Hybrid Fiber Copper/Transparent LAN Services (HFC/TLS), Fast Ethernet and Gigabit Ethernet services at various shaped bandwidths, and an OC-192 I-Net.

The City's Advanced Traffic Management System (ATMS) communications platform is a fiber-optic network with a topology of redundant distribution rings emanating from Sonet nodes (replaced with Packet-Optical Transport Systems this year) arranged on a redundant backbone ring (over 100 miles of fiber cabling). We are upgrading all connected signals with 8-port Cisco Ethernet switches – 40 successful installations with 120 more deployments this year.

f) Intelligent Transportation Systems

The City operates 316 signalized intersections, 275 (with continuing expansion) in its ATMS environment, which includes:, type 170 controllers, 90% Type 170 cabinets, 23 Cohu traffic monitoring cameras, 16 signals integrated with LRT operations and signaling, QuicNet central management software, several Sensys vehicle counter installations, and 20 lane-use *-blankout signs. $3 million in funding has been allocated for a complete upgrade of the control platform to ATC controllers with new local and system software.

Norfolk's Traffic Management Center (TMC) is located in City Hall adjacent to Transportation Division staff offices. The center is in the midst of upgrades to its video wall and server/switch room along with a conversion of all video to IP. Video handling and camera control will be a state-of-the-art system later this year, including the sharing of the City's camera images on VDOT's 511 website. We are connected to VDOT's regional Transportation Operations Center, and will be to Elizabeth River Crossings' new Operations Center when the tunnel upgrades and expansion project is completed in 2017.

There are several Rapid Rectangular Flashing Beacon signals, some with active pedestrian detection. The city is upgrading permissive left-turn phasing to 4-section FYA heads.

g) Smartgrid System

Three Electric Vehicle charging stations have recently been installed at City parking facilities. Tesla has installed a charging station near I-64 in the eastern part of the city.

9 Data Management and Sharing

Integrating the new level of transportation data will improve capabilities in some existing areas of fleet or emergency management, simply by providing more accurate travel time prediction. Routing first responders around an unknown road blockage could save a life. For other possibilities a potentially vast array of utilities may be realized by "cross-pollenation", replacing

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some sources of frustration associated with transportation, with comfort and convenience. The mere existence of smartphones allows people to "gain time", but improved traveler safety and predictability, plus "active" information to users, has the potential for changing behaviors, and broadening a person's "reach" to jobs, services, shopping and recreation – really anything. Imagine stopping to have a cup of coffee with a friend you haven't seen in a long time, because the two of you were randomly and coincidentally passing near each other one day, and your phone lets you know. Imagine you and your child's day care being alerted simultaneously that you're going to be late, and without doing anything you get a message from them that a neighbor with known permission has agreed to pick your child up so you don't have to pay a penalty, and the child gets to play with a friend while you are delayed. The possibilities and the potential partners seem almost endless.

Recently, crowdsourcing and constant connectivity enabled by mobile sensing and computing platforms (e.g., smartphones) spurred numerous remarkable innovations in many sectors of the economy including the transportation sector. Companies like Uber and Lyft have leveraged the mobile-phone platforms and provided new alternatives for taxi and ridesharing services that disrupted the traditional business models. Metropia (a partner on Norfolk's team) uses an app to incentivize commuters for choosing departure times, routes, and modes so that traffic congestion is reduced. All these applications and systems rely on constant communication and mobile computing technologies to deliver the intended services. In particular, they rely on smartphones which function as a key enabler and facilitate user interactions, user input, sensing, data collection, computing, and communications. In 2015, 189.7 million people in the U.S. owned smartphones (76.8 percent mobile market penetration). Given the continued increase in smartphone market-penetration, the Norfolk team plans to develop various applications reliant on mobile computing and sensing enabled by consumer electronics to address the mobility and accessibility needs in the region. The City envisions building the necessary institutional and technological components to create an environment where pervasive sensing and computing play a central role to improve mobility and accessibility.

The City currently collects, stores, and maintains a variety of data related to this Smart City Challenge. In addition to vehicle tracking of our public safety and fleet vehicles, we also have our city facilities connected to building management systems to control energy consumption in real-time. Outlined below are several key methods we currently collect data.

Verizon NetworkFleet: GPS driven fleet trafficking system on all City waste management trucks and street sweepers. Onboard vehicle diagnostics, GPS tracking, and roadside assistance are some of the features this system is used for.

Intergraph CAD: The City's computer-aided dispatch (CAD) system, we can quickly answer calls, create and update incident details, and manage multiple resources in real time. This system also gives us the ability to track and route individual responders using mobile devices allows dispatchers to view each person's location, permitting real-time risk assessment.

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Smart Parking Meter deployment will be completed by this Spring, connected to a data platform usable for vendor parking payment and wayfinding applications.

Building Management Systems: The City currently operates three building management systems developed by industry leaders including; Siemens and Johnson Controls.

311/Citizen Reporting Applications: The city currently has two in-house developed applications to manage citizen requests and storm related events. Our Norfolk Cares Center (311 Call Center) can take calls, emails, and requests submitted through a smart phone app. This data is cataloged and tracked through the life cycle of the request using a custom developed application. STORM (System to Track Organize and Map) is a custom in-house application that is also available to residents as a mobile browser-based application. This application is used to report weather related issues, for example; flooded streets, downed trees, blocked roads, and downed power lines to name a few.

The City also works closely with regional partners and stakeholders on collecting and maintaining import transportation related data and geographic information systems (GIS) data. The City is currently working with ODU, HRPDC, HRSD, and other local governments on a grant proposal to develop a regional GIS that can serve as central repository for accessing, downloading, viewing, and analyzing geospatial related data. The local Code for America brigade also has developed applications with the City, and an HRT bus/light rail finding application. This application gives real-time information about HRT routes and schedules based on the user's location information from their smartphone.

Local and remote storage and processing facilities: To store vast amounts of data being collected in the proposed activities instead of building in-house data centers, we propose to leverage data-storage facilities at ODU for the dynamic data-driven processing and, eventually, remote web storage, such as Amazon S3. Specifically, ODU has a 6-node cluster that runs Big Data processing software including Hadoop and distributed file storage format HDF5. Specifically, each node has two Intel Xeon E5-2670v2 processors (20 cores each @2.5GHz), 128GB of main memory, and three 440GB SSD disks. The nodes are interconnected with Infiniband QDR HBA.

Data management software: To support data analytics and management, iRODS, which is an open-source data management software governed by the iRODS concorsium, maybe employed. Its services run on a variety platforms and have a high degree of scalability and availability.

High-performance network facilities: ODU is a partner in the Mid-Atlantic Research Infrastructure Alliance (MARIA) which increases campus connections to the Internet2 Network to 100 gigabits per second (100G). This network infrastructure may greatly facilitate processing of the collected data since MARIA connects many Virginia university campuses and feeds into a broader interconnection network "Southern Crossroads" (SoX) a non-profit founded by Georgia Tech and partners and is recognized as one the highest-bandwidth Internet gateways in the South.

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Through Norfolk's big data platform, each stakeholder has the opportunity to use their preferred analytics tools, through open standard access methods, to glean insights from the data and suggest further operational improvements. Trusted information infuses processes bring people, process and information to bear on further insights and continuous improvement to autonomy.

10 Standards and Architectures

The City of Norfolk has been engaged in the deployment of ITS/ATMS infrastructure on a consistent basis with using Federal funding for over a decade, whereby requiring compliance with financial, environmental, and procurement guidelines. The City has been, and continues to be, intricately involved in all regional ITS planning and architecture development with local agencies and VDOT, including participation and leadership roles with the Hampton Roads Transportation Operations subcommittee of the HRTPO. The City has an existing fiber optic connection to the VDOT, and plans to integrate with a private bridge-tunnel facility in the near future, to enable further regional collaboration.

Our project teammate Kimley-Horn with whom we have a long-standing relationship, brings expertise in software development, system design, and integration support. Kimley-Horn is developing a research roadmap on behalf of AASHTO and NCHRP related to planning and implementing Automated and Connected Vehicle technologies (NCHRP 20-24), which will be an integral part of Smart-Cities initiatives. Kimley-Horn's experience includes developing Concepts of Operations (Eastern Idaho Rural IntelliDrive) and Guidebooks (TMC Connected Vehicles for the UVA Pooled Fund Study) for these upcoming technologies, developing software interfaces (Dynamic Ridesharing product development support for Axiom xCell in San Diego), software integration with Siemens and multi-vendor signal controller environment, as well as working with the USDOT connected-vehicles safety pilot where Kimley-Horn's KITS software monitors signals in Ann Arbor that broadcast SPaT data to connected vehicles. Kimley-Horn is particularly beneficial to Norfolk for the Smart-Cities program by being able to meld both hardware and software design and implementation, coupled with technical operational and maintenance support.

For a program of this kind, it will be important to document lessons learned. Under a recent effort assisting the City of Norfolk with migrating from their serial communications network to an advanced Ethernet platform, Kimley-Horn developed a testbed in the City's TOC network room, prepared a test plan, secured network hardware from multiple vendors, and implemented the test strategy and compiled a full document of the procedures, outcomes, and recommendations for subsequent deployments. The lessons learned from this testbed, and the first pilot field deployment were documented and used for conversions of subsequent field communication channels to Ethernet.

11 Measurable Goals

When we think about Norfolk's primary vision and goals, they are predominately for long-term success. In the complex world of urban activity and transportation it is very difficult to isolate

multimodal performance metrics from which one can glean success or failure over that time frame. The important concept of a "controlled experiment" is almost unachievable. Defaulting to "easy-to-collect" metrics that are not comprehensive, can't discern multivariable contributions, and only measure short-term changes, to force the issue, can actually have damaging effects. But, one of the great gains in this new data paradigm is a comprehensive data picture that has not previously existed, therefore addressing some of those issues. Our approach is going to be thoughtful, use proper experimental design techniques, and importantly, promote learning.

One of the goals of the Transportation Data System is to archive a robust recurring knowledge state in the Archived Intelligence database. The design of its structure, most importantly to serve the needs of analytics based on empirical data, will equally well serve the needs of the most robust performance monitoring system ever devised. However, we can even do one better – we can create intelligent self-monitoring tools within the analyzers, which can report on activities that would have some expectation of a possible impact, and in some cases have automated retrieval and storage of pertinent data sets following the actions.

Metrics will include: Travel Time and Reliability (all user populations), Network density, Effectiveness of information – evaluating choices, Transit ridership and service metrics, Route diversion frequency and utility, User satisfaction (app will facilitate surveys), Business/ development trends, cost-effectiveness, and crashes. With respect to crash data, it is noteworthy that our proposed systems will begin to greatly elevate data in support of safety analysis – a new paradigm of crash history assessment will be possible.

An important point project-wise is that comparable "before" data will be collected in the 2nd and 3rd years of the project so that demonstration data (and beyond) will be meaningful.

12 Capacity for Implementation

Norfolk has been in the forefront of technology implementation and is recognized as one of the national leaders in the field of resilience. Situated in the heart of the defense corridor, Norfolk has been partnering with key defense contractors and other technology leaders to transform the city into a smart city, serving its large diverse population and improving the quality of life for vulnerable residents. Norfolk has a long record of successfully implementing a variety of projects similar in scale, scope and complexity to those proposed in this application. Illustratively, in the past three years alone, Public Works has managed $267 million in infrastructure projects, including construction of the flagship Slover Library that was recognized as one of the most technologically advanced libraries in the U.S. Similarly, in the past two years alone, the City's IT department developed and launched in-house more than 10 software application, regularly supports and operates over 100 of them and scaled up its city-wide network, all in partnership and coordination with local private and non-profit partners and stakeholders. The release and implementation of our holistic Resilience Strategy, hire of Chief Resilience Officer and Chief Marketing Officer and institutionalization of a Resilience Office that serves as a connector and aligner of efforts and opportunities within the City, and between the City departments and

external partners, demonstrates Norfolk's overall capacity and executive commitment to take on the proposed project.

Importantly, the City's internal capacity to embark on projects of this magnitude, complexity and level of innovation is significantly enhanced by proven partnerships with an array of cross-disciplinary, public, private and non-profit stakeholders which will work with the City to implement the proposed projects and provide necessary redundancy to mitigate potential risks (See Section 7 Partners). Furthermore, the partnerships for this proposal will build on and will leverage a regional public-private coalition established around the HUD's National Disaster Resilience Competition application development and Norfolk's concurrent Resilience Strategy development process. Both efforts brought together nearly 100 multiple state and federal agencies (including the Navy and Commonwealth's agencies), local governments, institutions of higher education, regional planning organizations, community groups and private sector partners to develop and now implement innovative resilience projects at the local level.

13 Leverage Opportunities

While other cities benefit from the head start in the field of autonomous vehicles, electric vehicles, shared economy services or vehicles to vehicles/vehicles to infrastructure technology, Norfolk has already made significant investments in designing coastal community of the future - a city that can survive and thrive in an environment of rising sea level and uses the opportunity to address environmental changes as a catalyst for diversifying the city's economic base and connecting individuals through new networks. Because cities are systems of systems, continually interacting, influencing and impacting one another, policies and actions designed to influence one system impact, for better or worse, others. Our approach to resilience-building embraces this interaction recognizing that investments in any system creates opportunity for returns in improvements in multiple systems. To address our vulnerabilities and challenges in ways that make the city and broader region truly smart, resilient city, the work proposed in this application will simultaneously strengthen our physical, social and economic resilience while benefiting from the existing partner networks and current and committed investments in building the coastal community of the future.

For instance, in partnership with the Navy, U.S. Army Corps of Engineers, Port of Virginia, The Rockefeller Foundation, White House-sponsored Intergovernmental Pilot Project led by Old Dominion University, local community organizations and planning district commissions, Norfolk is launching a series of holistic studies and projects to redesign land use by watershed to more innovatively use green, blue and grey infrastructure to manage recurrent flooding and sea level rise to ensure that the city's and region's residents and key economic assets that rely on unimpeded access and reliable transportation networks can continue to thrive on the coast. Similarly, Norfolk has been heavily investing in live-work-play-stay placemaking, "attract and retain" projects and app tools as part of its strategy to design the economically, socially and physically more connected coastal community of the future that can adapt to and take advantage of changing conditions. These investments encourage people and businesses to move

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"beyond traffic" by living closer to where they work instead of putting pressure on the City's limited resources to invest in costly transportation infrastructure not always suitable for coastal communities facing changing conditions associated with flooding and sea level rise. Current overhaul of zoning code, investments in light rail and its future extension through flood-free areas, new bike lines, bike share program, complete street policy, investments in shared work spaces, extension of fiber network, innovation centers, and access to early stage capital for entrepreneurs to incubate new ideas are just a few examples of these efforts that will be leveraged for the proposed project.

Illustratively, the proposed project will benefit from the recently awarded $120 million National Disaster Resilience Competition grant to accelerate Norfolk's effort to design the coastal community of the future. Norfolk in partnership with the Commonwealth of Virginia and a consortium of private, public and non-profit partners, including Old Dominion University, will use $5M of these funds to establish a Resilience Lab/Accelerator to serve as a connector between "smart city" problems, solutions, and market for the region's resilience challenges – with transportation-related challenges being a major area of focus. Norfolk will also leverage connectivity-enhancing investments including, over $7M in federal funds to study corridors for the Naval Base LRT extension, $175M for the Intermodal Connector project, up to $750K to construct a bicycle loop, up to $500K to improve pedestrian crossings, over $3 million to extend broadband/fire optic, and over $55M in wealth of research in Intelligent Transportation Systems (ITSs), connected vehicles, big data, multi-modal transportation operations and planning, unmanned aerial vehicles, and other related areas to improve the safety and mobility of transportation systems provided by the partnering universities – Old Dominion's Transportation Research Institute and Virginia Tech's Transportation Institute.

14 Conclusion

Norfolk would be an excellent choice for the "Beyond Traffic: The Smart City Challenge" grant.

It is critical that the funding serve to advance the state of research, testing and practice in key technology areas such as automated and connected vehicles, and sensing. We would provide all of the resources necessary with our team, and we have ideal, challenging test bed opportunities.

Norfolk has challenges both long and short term that it intends to address with the funding. The outstanding low-cost approaches and tools that it would develop for meaningful short-term impact would be designed for easy transferability to other cities.

"Addressing climate change" takes on greater meaning in Norfolk, a city threatened by sea-level rise, a member of 100 Resilient Cities, and home to a nationally critical military presence. The benefits to be realized here are larger in magnitude and scope.

Norfolk is extremely committed to developing coastal resiliency strategies, which must involve transportation. It is not a choice, we must adapt. Our resolve will not be swayed.