INTERNET OF THINGS (IOT) PLATFORMS FOR SMART CITY IMPLEMENTATION IN RURAL AND URBAN COMMUNITIES: A COMPARATIVE REVIEW

FINAL PROJECT REPORT

by
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16. Abstract

Several transportation agencies in urban, sub-urban, and rural have started the planning or the actual implementation of their first Smart City projects. A major element of these systems includes the Internet of Things (IoT) smart city platform help manage data exchange and flows and run the analytics needed for user data and system performance monitoring. For many agencies, IoT platform selection is very challenging with the limited technical resources most these agencies experience. Several of these IoT solutions have proprietary vendor-specific attributes that lock agencies to specific vendors' solutions. IoT platforms developed by smaller vendors, while come with strong customer support and high degree of openness, face many challenges in system integration and scalability. The primary objective of this comprehensive review study is to establish an improved understanding among transportation agencies policy makers and professional regarding IoT Platform operation characteristics.

Within this report there was an in-depth evaluation of 3 smart city projects developed and funded through public-private partnership, 4 smart city implementations funded through the U.S Department of Transportation (USDOT). The study also covered 3 IoT platforms currently available from different vendors. For the 7 smart city projects (public and private, they were evaluated to the criteria of system functionalities, interoperability, integrability, usability, security, and survivability. For the 3 IoT platforms, they were evaluated by comprehensiveness, total cost, expertise and smart city focus, openness, and ease of integration. This evaluation used derived industry-based criteria to assist both rural and urban transportation agencies understand the technical opportunities, challenges, and barriers from existing smart city implementation projects. Each project and vendor evaluated in this report provided a valuable insight into the current reality of smart city projects.

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EXECUTIVE SUMMARY

As of recent, there has been an explosion in communications infrastructure speed and reliability along with Internet of Things (IoT) technologies becoming ever capable. With both technologies rapidly advancing and improving, it allows for drastic changes to be made to other domains such as city improvements. Smart city projects leverage both newly advanced technologies and existing infrastructure to create flagship implementations of smart IoT devices to improve the city operations and livability. This report aimed at providing valuable insights and evaluations of existing smart city implementation projects, focusing on the technical and operational characteristics of IoT platforms used.

Within this report there was an in-depth evaluation of 3 smart city projects developed and funded through public-private partnership, 4 smart city implementations funded through the U.S Department of Transportation (USDOT). The study also covered 3 IoT platforms currently available from different vendors. For the 7 smart city projects (public and private, they were evaluated to the criteria of system functionalities, interoperability, integrability, usability, security, and survivability. For the 3 IoT platforms, they were evaluated by comprehensiveness, total cost, expertise and smart city focus, openness, and ease of integration. This evaluation used derived industry-based criteria to assist both rural and urban transportation agencies understand the technical opportunities, challenges, and barriers from existing smart city implementation projects. Each project and vendor evaluated in this report provided a valuable insight into the current reality of smart city projects. They also allow for a primitive set of standards and goals to be established so that those that come after may learn from them.

CHAPTER 1 INTRODUCTION

1.1 Study Overview

With the recent advancement of Internet of Things (IoT) device's computational power and communications infrastructure having high reliability and speeds there has been a mass adoption of flagship projects in the smart city domain. All projects being conducted in the current infancy stage of smart city projects will provide valuable insights for future projects to learn from. Whether projects show what works or what does not work it provides a deep look into how the cities of the future will be designed and allows to start the complex process of developing standards. Within this report there was a critical evaluation done of private smart city projects, public smart city projects, and a small sample of vendors with carefully derived criteria tailored towards both rural and urban transportation agencies.

For the privately funded smart city domain the research conducted included the evaluation of three main projects including: Toyota's Woven City, Urbanova's Smart and Connected Street Lights, and Fujisawa Japan. Each of these projects involved a multilayer design that deployed IoT devices to make a smarter environment. These projects are included as they provide unique and valuable insights into the developing stages of private and public partnerships in the smart city domain. The evaluation criteria used to judge these projects included: system functionalities, interoperability, integrability, usability, security, and survivability.

For the evaluation of projects funded by the U.S Department of Transportation the report discussed the city of Columbus Ohio, Portland Oregon, Pittsburgh Pennsylvania, and the United States Department of Transportation Security Credential Management System. These projects were included as they provided transparent information on the development of these projects

includes, monetary costs, needed expertise, positive impacts, negative impacts, and many other factors hard to find in their private counterparts. These projects were also evaluated on the criteria of system functionalities, interoperability, integrability, usability, security, and survivability.

Lastly the vendors evaluated in this report included Amazon Web Services (AWS), ParkMobile, and AbleLink. Each vendor chosen for evaluation was done so for their unique products and use in the U.S Department of Transportation funded projects. Each of these vendors is also actively involved in the IoT domain, which is an emphasis throughout this report. The carefully derived criteria selected for this small sample size of vendors included: comprehensiveness, platform implementation costs, expertise, smart city focus, platform openness, and integration strategies.

Overall, the projects and vendors evaluated in this report provide a deeper dive into some ongoing development of multifaceted smart city projects that are actively using IoT devices. While some projects or vendors may not always be successful, they provide a starting point for future projects and a set of standards.

1.2 Study Goals and Objectives

The overall goal of this paper is to assist in establishing an improved understanding of IoT Platform operations in smart city developments. Being tailored to transportation agency policy makers and professionals, this paper evaluated projects on criteria tailored towards industry including interoperability, functional capabilities, integration strategies, sustainability and other criteria used by transportation agencies. The three main objectives to achieve this goal included the evaluation of private sector smart city projects, the evaluation of U.S Department of

Transportation funded smart city projects, and the evaluation of some vendors used in these projects. These evaluations are critical to understanding the current problems that smart city projects are facing both in a major metropolitan areas along with rural communities where resources such as funding are scarcer.

1.3 Study Motivation

Currently there are many negative side effects being experienced in both large metropolitan areas and rural areas which will need to be addressed by governing bodies such as the U.S department of transportation. The motivation of this paper is to assist these agencies and governing bodies in the decision-making process when developing smart city projects which attempt to solve these negative issues. The IoT technologies used in smart city projects can be used to improve the livability, quality, and sustainability of cities.

1.4 Report Organization

This report is organized into seven sections. The first section is the abstract. Following up the abstract this paper includes a section of an introduction which includes the goals and objectives of the paper, the motivation for the paper, and this section about the organization of the paper. The third section is the background of current research being conducted. For the fourth section the paper establishes the approach to evaluating projects and vendors. The fifth section is the evaluations themselves. The sixth section of this paper is the references and the seventh is the appendices.

CHAPTER 2 COMPREHENSIVE SURVEY OF THE LANDSCAPE

While there are a vast number of complexities going into the development of a smart city, having a well-planned architecture can ensure that these complexities are minimized. Therefore, many organizations both private and public are attempting to come up with a set of architectural standards to provide cities around the globe. This can only be achieved by collaboration between cross disciplinary industry experts and researchers. Given that there is currently not a standard for smart city architectures, this report aims to provide an overview of different architectures, along with the commonalities and differences found within them.

To begin, in the report titled “Smart City Architecture and its Applications based on IoT”, the authors propose an architecture that is multi-layered in design which is based upon the Dempster-Shafer uncertainty theory along with recent advancements in web technologies [64]. The research conducted in this report is targeted at designing an architecture focused on improved utilization of existing resources, improved living environments, and real time context aware customizable services.

The architecture is derived to being two levels including the high-level core components of a smart city, and a low-level multi-layer smart city architecture. For the high-level core components, they include: smart energy, smart administration, smart security, smart health, smart environment, smart buildings, smart transport and smart industries. Inside the proposed low level multi-layer architecture there is a four-layer architecture that takes data from the bottom, which is a sensor layer to the top which is the customized service layer. Beginning at the lowest sensor layer, the next layer above is the data collection unit, which works as an aggregator to collect various sensor readings such as temperature, pressure, etc. Once the data is collected at the aggregator it is then sent up to a data processing unit that takes the data and puts it in the

Resource Description Format. This format is capable of being integrated into the Resource Description Framework (RDF) that allows the exchange, encoding, and reuse of metadata [65]. Once the data has been processed it is then sent up to an interface engine which performs data integration and reasoning via semantic web technologies and the aforementioned Dempster-Shafer uncertainty theory. Finally, the derived actions such as messages, alerts, and warnings, are then sent to the device control and alert layer which then provides a fully customized service. The proposed architecture would be implemented and integrated to a cloud service for use as a software as a service (SaaS). This overall architecture, both the high and the low, are fully dependent on wireless communication infrastructure to execute their functions. The proposed communications protocols used to help execute these architectures include ZigBee, satellite communications, optical communications, Wi-Fi, cellular, and others.

The report titled “Smart City Components Architecture” [67] aims to establish a modular architecture structure for utilities, such as electricity, water, and others, that has the capability to be scaled up to the scale of a city. The suggested geographic information system (GIS) platform would be the overlapping layer of the architecture to achieve successful interoperability with infrastructure-based systems. This modular architecture suggested by the author was derived from a five-tier smart city development pyramid where subsystems near the bottom are deemed increasingly more essential. At the base of the pyramid are the most vital elements being smart infrastructure. This includes systems that are critically important to the city as they provide the most health and safety risks if something were to fail. They include electrical systems, water systems, gas systems, fire suppression systems, and telecommunication systems. One layer above that is smart database resources, including smart spatial databases, smart database servers, and smart complementary data resources. These smart databases and their stored data has

importance as it not only provides troubleshooting capabilities but the data necessary for machine learning and artificial intelligence. Which could then be later used in a centralized control fashion to improve interoperability throughout the city. Moving up an additional layer the report introduces smart building management systems including: building automation control networks, local operations control networks, and smart HVAC. The second to the top layer includes smart dashboards, a common operational platform, and integrated web services. These services are near essential for the smarter sides of the city to be functional and usable. Lastly the top layer of the architecture is a smart city which is achieved when all prior layers are properly integrated and combined to achieve a functionable whole system.

An additional report titled "Defining Smart City Architecture for Sustainability" by Leonidas Anthopoulos, attempts to define a five-layer standard smart city architecture that serves governmental purposes for sustainability and innovation [68]. This architecture was derived by utilizing experiences from prior successful cases and corresponding theoretical context. The report mentions a small set of international organizations including: International Standards Organization (ISO), British Standards Institute, International Telecommunications Union (ITU), and the US Nation Institute of Standards and Technology (NIST), that are currently looking to define a set of smart city architectural standards, which have influence on the derived architecture. The proposed design includes a multi-layer architecture consisting of five layers including the natural environment, hard infrastructure that is not based on information and communication technology (ICT), information and communication technology (ICT) based hard infrastructure, smart services, and soft infrastructure. The first layer of the suggested architecture, the natural environment, incorporates all the environmental features where the city is located. This includes typical weather patterns for the region, lakes, mountains, and other

geographical features. As it currently stands, this layer is not highly manipulable. The second layer of the architecture, which is based on non-ICT based hard infrastructure, contains all infrastructure that are safety critical including bridges, buildings, roads, electricity, wastewater, and others. These systems provide the backbone for the city and are essential for the resident's survival. For the third layer it contains all ICT based hard infrastructure with smart hardware including data centers, IoT devices, servers, and others. This layer is generally considered the backbone for the smart services that a city can provide to improve resident's daily lives. The fourth layer includes smart city services related to smart individuals, smart living, smart environment, smart governance, smart economy, smart mobility, and others that are organized according to international urban key-performance indicators. The fifth and final layer is made up of soft infrastructure which includes all software, data, and databases that make up a shared services center for individuals living there. These proposed architectural layers all need integration and coordination to provide an overarching smart city.

In the report titled "Smart City for Development: Towards a Conceptual Framework" they propose a conceptual smart city architecture titled Smart City for Development (SC4D) [69]. This architecture starts by being broken down into four high level sectors which include: city services, city goals, city resources, and city architecture. Each one of these high-level sectors gets broken down further into increasingly more specific use cases. For the city services it gets further broken down into basic services, non-basic services, and optional services. The city goals section of the architecture breaks down into livability, workability, and sustainability. As for the city resources section it gets broken down into superstructure, infrastructure, and infostructure. Lastly the city architecture gets broken down into portfolio, procedure, delivery, accountability, effectiveness, and objectives.

For the city services the report breaks down the three aforementioned service types into specifics. The basic services for a smart city include education, healthcare, public works, residential areas and housing, peace, security, social protection, and social programs. The non-basic services defined include: empowerment of women, protection of children, administration of population, population control, communications, cryptography, transportation, environment, labor, food, land, open data, capital investments, youth sports, preservation of culture, and libraries. For last city services, it defines optional services such as: tourism, agriculture, fisheries, energy and mineral resources, trade, and transmigration. This subsection of the architecture provides services not only for residents but also those who may be visiting.

To further expand on the resources needed in a smart city the report further breaks them down. The first category of resources needed by a smart city is the information and communication technology (ICT) infrastructure which includes: policy and strategy, governance and management, and human resources. The second category of suggested resources needed by a smart city includes the ICT infrastructure involving instrumentation and monitoring systems. These systems are considered intelligent or smart and are supported by sensors and actuators. The third and final set of resources needed by a smart city is the infostructure which are information systems such as websites, kiosks, and others which help citizens in their daily lives. These include city wide operating systems that assist in the management of the city by being a real time data monitoring and centralized control system.

For the city architecture subsection, it is broken down via the interaction between the responsibilities of the city and information and communication technology (ICT) resources being put into The Zachman Framework. This framework allows for the design of an architecture that

addresses numerous concerns such as portfolio, procedure, delivery, accountability, effectiveness, and objectives.

The final layer of the architecture includes the defining of goals for a smarter city including livability, workability, and sustainability. Livability is targeted at making residents' lives better through the use of information and communication technologies (ICTs). The report specifically targets increasing the ease of access to education and information, making healthcare related services more readily available, increasing recreational areas, and improving security. Workability includes enhancing economic development, creation of jobs, internet access, and higher education opportunities. Lastly sustainability allows citizens access to resources that they need, while not allowing them to consume more than what is needed.

In a report titled “Open City: An Open Architecture Testbed for Smart City” the presented smart city architecture is a real time control and monitoring system that is hosted at Virginia Commonwealth University (VCU) [70]. This system, which is primarily aimed at being an educational and research tool, is made up of data collection and processing units, distributed performance management algorithms, real time data visualization systems, and database management systems. The system architecture is made up of three core layers, with the centerpiece being a secure cloud infrastructure that works as a middle layer to facilitate control and monitoring. The highest layer which interacts with the secure cloud infrastructure includes city management systems and 3rd party systems. These high-level systems include various data analytics algorithms and databases relating to infrastructure which will provide valuable feedback to judge the successes and failures of projects, along as a scalable working model for other cities to follow. Moving to the bottom layer of the smart city architecture it includes intelligent residential and commercial buildings, intelligent traffic signals, intelligent connected

vehicles, and intelligent walkway and parking lights. The network architecture which supports communications between layers includes an IoT network which is built upon high-speed wireless gateways that use the Message Queuing Telemetry Transport (MQTT) protocol. Diving deeper the report breaks up the protocol into a MQTT server which is made up of system services and MQTT nodes which include intelligent transportation and building systems. Transportation systems use the Data Distribution Service (DDS) while building systems use the internet protocol (IP). Both these architecture and communication protocols used allow for additional flexibility and scalability to accommodate for rapidly changing urban environments like cities. The intelligent transportation system, which is interconnected to the city's core server, uses the Robot Operating System version 2 (ROS2) to achieve the management and control of traffic signals and vehicles. These systems use localized algorithms for smart autonomous operations but allow the use of MQTT communications for centralized control. For the building systems they are powered by low cost and low powered microcontrollers which collect data and make localized decisions to control actuators. In addition, they are capable of sending and receiving MQTT messages for centralized control.

Another report titled “Smart City and IoT” provides a high-level overview of some of the readily available smart technologies currently being used in smart cities along with some remaining challenges left in the realm of smart devices [66]. These smart technologies provide a baseline to establish a set of architectural standards for smart cities. Some of the developed referenced smart technologies that influence architecture designs include remote health monitors, smart waste bins, smart policing, smart parking, smart traffic lights, smart environment meters, smart home apps, and smart electricity meters. Some mentioned challenges left in the smart domain, which represent a small sample size of the encountered problems, include a smarter

grid, traffic congestion resolution, pollution and noise minimizer, open-source standards, connected health, data analytics and decision making, security, and privacy. While neither one of these lists is comprehensive, it provides valuable insight into how various project architectures are designed.

In this survey of the landscape a small sample size of architectures have been presented, along with some solved and remaining challenges, where each attempts to address the complexities of designing a smart city architecture in their own unique way. There are lots of commonalities found between architecture designs including smart buildings, smart critical infrastructure, resilient and reliable communications, heightened livability for residents, and sustainability. Many differences found between architectures reside in attempting to break down a city into various manageable subsections that can be integrated. Some of the breakdown approaches include a modular GIS system that uses critical infrastructure as a baseline, a two-layer breakdown into high- and low-level systems derived from the Dempster-Shafer uncertainty theory. A conceptual high level four section smart city known as SC4D. A smart city architecture design that pulls pieces from prior successful projects that focuses on sustainability and innovation, and finally VCUs Open City which gets broken down into three different layers where a secure cloud service is the key integrator.

CHAPTER 3 STUDY METHODOLOGY AND APPROACH

This study aimed to address the growing complexity of smart city projects that have an ever-increasing number of Internet of Things (IoT) devices being integrated into critical infrastructure. With adoption, there is a need for both large and rural transportation agencies to understand the products available to them. To achieve this, this study used carefully derived criteria tailored towards industry, to help educate those with minimal or no background.

3.1 Project Criteria

3.1.1 System Functionalities

When evaluating system functionalities this paper's goal is to show an overview of what functionalities are being adopted by both private and publicly sponsored smart city projects. There are many unique criteria to every city including geographic differences, priorities, funding, existing infrastructure, and others. These make understanding available functionalities an important evaluation criterion tailored towards industry.

3.1.2 Interoperability and Integrability:

Another carefully selected criteria this paper aimed to evaluate projects on is their interoperability and integrability. While having a smarter city to better serve its residents and tourists is a goal of every smart city project, the integration and interoperability of projects are a large deciding factor in adoption. These systems need to be able to easily integrate into existing infrastructure and be capable of communication with other systems. Gaining an understanding of the ease of integration and the openness of a project is vital to a successful project.

3.1.3 Usability:

This paper evaluates usability as a criteria of smart city platforms which helps determine the ease of use for individuals. Many times, there is a balancing act between usability and system functionalities that must be carefully evaluated when looking at smart city development projects. As system functionalities increase naturally there comes an increase in complexity which can hinder usability for those lacking background knowledge. Usability is a criteria as smart city applications must be usable by all members of the population.

3.1.4 Security and Survivability:

Security and survivability are the last evaluation criteria this paper addresses. Important for both private and publicly adopted smart city projects, these criteria are an essential part to ensuring the safety of these projects. This paper aimed to provide an insight to any available security or redundancy used in projects.

3.2 Vendor Solutions Criteria

3.2.1 Comprehensiveness:

When evaluating vendors there are various levels of comprehensiveness and specialties that each vendor offers. This paper aimed to bring attention to unique vendors of various levels of comprehensiveness to provide an overview. With each smart city application being different in a variety of ways, every project team will need to look at vendors and their comprehensiveness to ensure they align with the project's goals.

3.2.2 Total Platform Implementation Costs:

One major consideration for transportation agencies and privately funded projects is the cost overhead. Many times, both small and large transportation agencies have limited funding, so the

evaluation of the total platform implementation costs is a large deciding factor in the adoption of projects. This paper aimed to provide an overview of the costs associated with these projects when applicable. With each application being unique coming up with a estimated cost figure is a challenging task.

3.2.3 Vendor Expertise and Smart City Implementation Focus:

Vendor expertise and the vendors smart city implementation focus are considerable factors when researching vendors and their solutions to address smart city projects. These two traits could prove to be invaluable to the success of a project as most transportation agencies lack the time and resources to fully understand all aspects of a project. This paper's goal was to provide an insight into the expertise of a vendor, where that expertise resides, and if they have any expertise in the smart city domain.

3.2.4 Platform Openness and Integration Strategies:

In this paper one goal is to educate individuals about the openness and ease of integration of vendors. These two factors are important for two main reasons. With an increase of openness, a smart city platform could use multiple vendor-based solutions which would allow for flexibility in budgeting, planning, and decisions. This would also allow for ease of integration into existing infrastructure that has legacy systems that need to be updated. Transportation agencies and private projects could perform a step-by-step upgrade plan to do so rather than all at once. This would allow more rural agencies to achieve smart city projects by spreading out costs.

CHAPTER 4 LESSONS LEARNED FROM PAST EXPERIENCES

4.1 Privately Funded Smart City Projects

In order to advance the research and development of smart city platforms we must look at the current characteristics of existing smart city implementations. While these cities each may have unique applications their goals are similar by hoping to improve all aspects of life. Each one of these pioneer projects is an active learning and researching opportunity, that every other city planner, architect, engineer, government official, and citizen can learn from the successes and failures of each project.

4.1.1 Toyota's Woven City

With the concepts of smart cities becoming a near approaching reality Toyota is going all in on a fully futuristic city, in which the auto manufacturer hopes to provide the biggest learning experiment ever conducted in the realm of smart cities. Toyota's Woven City which was first released by Toyotas president Akio Toyoda at the 2020 Consumer Electronics show is a groundbreaking development that provides state of the art smart projects in all aspects of life. Designed by the famous Danish Architecture firm Bjarke Ingles Group, this 175-acre smart city is an ambitious project as it is starting from the ground up by building a city that will incorporate vast new technologies in hopes to assist its eventual estimated two thousand plus residents. Being built at the base of Mount Fuji and 60 miles from Tokyo, the groundbreaking ceremony was held February 23rd, 2021, where workers began excavations to start development of the underground utilities and streets [11].

Akio Toyoda has described the city as a living laboratory where engineers, researchers, and scientists can test in a real-life environment. This city provides valuable insights to individuals from every walk of the life and across the world as to what the future potentially

holds. With high expectations, Toyota hopes to achieve many state of the art goals to show what is possible with a successful development of a smart city project. This information can be used by governing bodies around the world such as transportation agencies to fully understand the effects that these smart projects can have. As for Toyota their overarching goal of the project is to learn what is possible along with educating the residents what life in a futuristic city could be like. Some other specific goals for the project include having positive reinforcement from citizens about autonomous systems, clean energy, equality, quality education, a prosperous economy, and many others.

These goals align with the U.S Department of Transportation's goals and allow for valuable feedback to be learned from to better serve individuals under their jurisdiction. To help achieve their goals Toyota is inviting both full time researchers and normal citizens to live in the city to gain firsthand insights from individuals with varying expertise. One emphasis of Toyota is the use of social scientists which will be monitoring the amount of technology use and how that impacts human socialization [11]. Gaining valuable insights from a variety of participants will advance the development of the city along with provide much needed data and statistics for future projects, including those outside of Toyota. As for positive reinforcement the project is aiming to have inhabitants gain trust in autonomous systems by showing that these systems can be reliable, secure, and integrate well with existing infrastructure [12].

Toyota also aims to follow the seventeen sustainable development goals set forth by the United Nations. These include no poverty, zero hunger, quality education, good health, gender equality, clean water and sanitation, affordable and clean energy, decent work and economic growth, industry, and infrastructure growth, reduced inequalities, sustainable cities and communities, responsible consumption and production, climate action, support life below water,

support life on land, peace and justice and strong institutions and partnerships for supporting the goals. There is also hope that the city will be capable of staying futuristic by making design choices that will allow for new innovative technologies to be easily integrated. For these ambitious goals to be successful, the characteristics of the city must be functional, reliable, secure, and easy to integrate.

While there are infinite ways to try and achieve their goals, Toyota is choosing innovative ways never before tested in this scale for their smart city project to be unique and functional. These systems will provide valuable insight to individuals both in positions of power, and those who are simply looking to gain an understanding of what the potential future of cities may look like. To start, they are choosing to route all utilities, power storage, and water filtration facilities underground for safety and cosmetic purposes. By putting the utilities and facilities underground, it prevents various accidents, such as lightening, car crashes, extreme weather, and other uncontrollable events from negatively affecting the resident's usage capabilities. This increases the reliability of these systems and provides the capability for maintenance without causing inconveniences throughout the main level of the city. In addition, there is a cosmetic benefit of removing utilities and other facilities cities need to support their citizens, as it allows for a less restrictive view of the local area. Along with utilities, there will be a fleet of fully autonomous vehicles underground that will deliver goods and services across the city.

Toyota plans on doing this via their e-Pallete, which is both fully autonomous and fully electric [13]. What sets this vehicle apart compared to other autonomous electric vehicles is its bus like structure, which allows the transportation of large amount of goods and or people. With the usage of these large vehicles the ability to manage a large amount of transportation of goods

with no impact on the environment, helping fighting congestion, and providing autonomous capabilities could have a major positive impact on the functionalities of a city turning smarter. While being below ground delivering goods and services is one challenge autonomous vehicles will have to face in the city, there will be many more challenges to be had above. One way Toyota is attempting to solve this complex interaction between autonomous vehicles and complex cities is by breaking down streets into three types of usage. These include fast vehicle usage, a hybrid of lower speeds and pedestrians, and then park like routes built strictly for pedestrians [12].

In conjunction with underground driving, Toyota will be using their fully autonomous zero emissions vehicles lineup as transportation throughout the city which will help align with their established goals. These were proven successful in the 2020 Summer Olympics, where Toyota transported Olympic athletes between housing and sporting venues with these vehicles [14]. Other advance features of autonomous systems could be seen during the games including various robots to assist in sporting events. Overall, these systems being designed for the city will provide valuable information as to how projects both on an individual and group basis can perform smarter actions.

As a whole, the Toyota smart city project is an advanced project that pulls in many untested technologies that are attempting to work together to perform the task of becoming a smarter city. These technologies will provide valuable information to determine what projects are successful and what projects need some refining. Considering that this city is a blank slate being from the ground up it is a unique project that will be one to watch in the future.

4.1.2 Urbanova Smart and Connected Streetlights Plot

Urbanova is a public private co-development partnership organization, based out of Spokane Washington, that focuses on solving the challenges faced by mid-sized cities, along with the growth opportunities they present. They strive to find new ways to make communities better by having healthier citizens, safer neighborhoods, smarter infrastructure, a more sustainable environment, and a stronger economy [15]. The demand for such a project was derived by the concept that people want to live in cities for jobs, education, culture, and a variety of other factors. There are also numerous downsides such as unsafe areas, unhealthier citizens due to ease of living, congestion, lack of community input, and many more which Urbanova hopes to help solve. In an article titled," Listening to Residents Voices to Build More Equitable Cities", which is sponsored by Urbanova, and written by Dalia Naguib, Justin Lall, and Justin Bibb they state 84% of citizens in the United States live in urban areas and that number is supposed to increase to 89% by 2050 [16].

As the number of people in cities increase and the number of smart city development projects by transportation departments and private companies increase in an equivalent fashion, there are many attributes that must be considered. In the article "Listening to Residents Voices to Build More Equitable Cities" there is an emphasis that the current strategies of implementing technologies into communities for the resident's benefit is poorly planned out due to not getting enough community input and trying to target ambiguous issues 2050 [16]. They hope to address this by their Neighborhood Impact Initiative, which is a multi-phase project which helps by listening to residents to help guide, evaluate, and implement interventions, along with narrowing down specific issues of any size to help the residents of Spokane.

In the first phase Urbanova partnered with Gallup, an analytics and advisory company, to gain insight into Spokane's strengths and weaknesses by conducting quantitative and qualitative studies. After the completion of the first phase, Urbanova has gained a baseline evaluation of the city from a wide array of perspectives, which can be used in further stages to increase community engagement in finding problems, potential solutions to problems, feedback on solutions, and many more insights from the residents themselves [17]. This initiative project serves as a model which could not only help the local transportation departments, but also provide a baseline for other transportation departments on how to get more community involvement, increased transparency of projects, better identify problems, and have better private public partnerships. One project Urbanova can receive community feedback and suggestions on is their Smart and Connected Street Lights Pilot program.

In the Smart and Connected Street Lights Pilot Program Urbanova is gaining valuable data for further insights, future urban projects, and the empowerment of residents along with learning about the design and development of a dynamic, unique, and living laboratory. This Urbanova program which has partnered with Avista, Itron, Washington State University, and the city of Spokane aims to help increase public safety and energy efficiency, all while monitoring a large amount of data including air quality readings. This large amount of data includes ambient temperature, ambient light, peak noise level, motion detection, pole orientation/ acceleration, particulate matter collection (PM1, PM2.5, PM10), CO2 concentration, barometric pressure, temperature, and humidity [18]. These could all be used as an example of data collection to help transportation departments figure out the amount of data that could be collected and used for processing. The peak noise level and motion detection would allow transportation departments insights to the flow of traffic on specific roads at specific times, which could prove valuable in

the design of new roads, expansion of existing roads, Using Itron's OpenWay Riva Internet of Things (IoT) solution, the control and intelligent management of streetlights is enabled which allows for the adjustment of lighting conditions remotely, energy consumption and voltage measurement, outage detection, and GPS [18]. This small project is the initial building block of the smart and connected network for the city which grow into large applications that will be used for not only smart streetlights but many other futuristic features.

Overall, this project is on the smaller size compared to other full-scale projects, such as the Toyota Woven City, however this project provides a great entry level example project for medium sized cities that are looking to start diving into smart city developmental projects. The system functionalities are vast in nature, they provide flexibility and are expandable for future development projects. These sensors also provide a baseline data set which can be later used for comparisons when new projects finish development. An example of which is an ongoing project by Urbanova titled Spokane Predictive Analytics, which is a multisector partnership that is exploring ways that data can be shared and analyzed between private and public entities for the benefit of both.

4.1.3 Fujisawa Smart City, Kanagawa, Japan

In the city of Fujisawa City, Kanagawa, Japan there is a large-scale and multifaceted project being conducted to create the ideal town for residents. This project which establishes another private and public partnership is aimed not at providing advanced technologies into modern day infrastructure, but rather a smart city where the smart aspect is based around the lifestyles of the residents. This 1,000-household town was designed with a 100-year vision at the core and then expanded out to establishing guidelines and designs [71]. For the development of these guidelines and designs the city established that a town management company will continue

to support the sustainability initiatives of the town, continuously incorporate new technologies and services, and take residents' views into their design choices.

To achieve a smart city that puts residents first the city outlined five core smart goals which include creating a smart lifestyle, setting goals, guidelines for turning goals into reality, smart and sustainable city services, and continuous development. For establishing a smart lifestyle, the city aims to bring energy into residents' lives by designing smart infrastructure and spaces that take into consideration community needs, mobility, energy, Security, and wellness. For their targeted goals they aim to have a reduction of 70% of CO2 compared to 1990, 30% water consumption reduction compared to 2006, over 30% of energy being renewable, and 3 days of lifeline maintenance in the event of a natural emergency. For turning goals into reality, the city produced three main sets of guidelines tailored towards project design, town design, and community design. For services, the city has established a committee known as the Fujisawa SST Committee to ensure the town has systems and services that support the sustainable smart lifestyles of residents and business operators. It includes over 18 different partners including Panasonic, Accenture, and others to help provide these services. For activities of individuals that are involved in the town they provide a portal to find ecofriendly activities, professional security guards, a public use committee center, rentable electric bicycles, and a stockpile of emergency supplies.

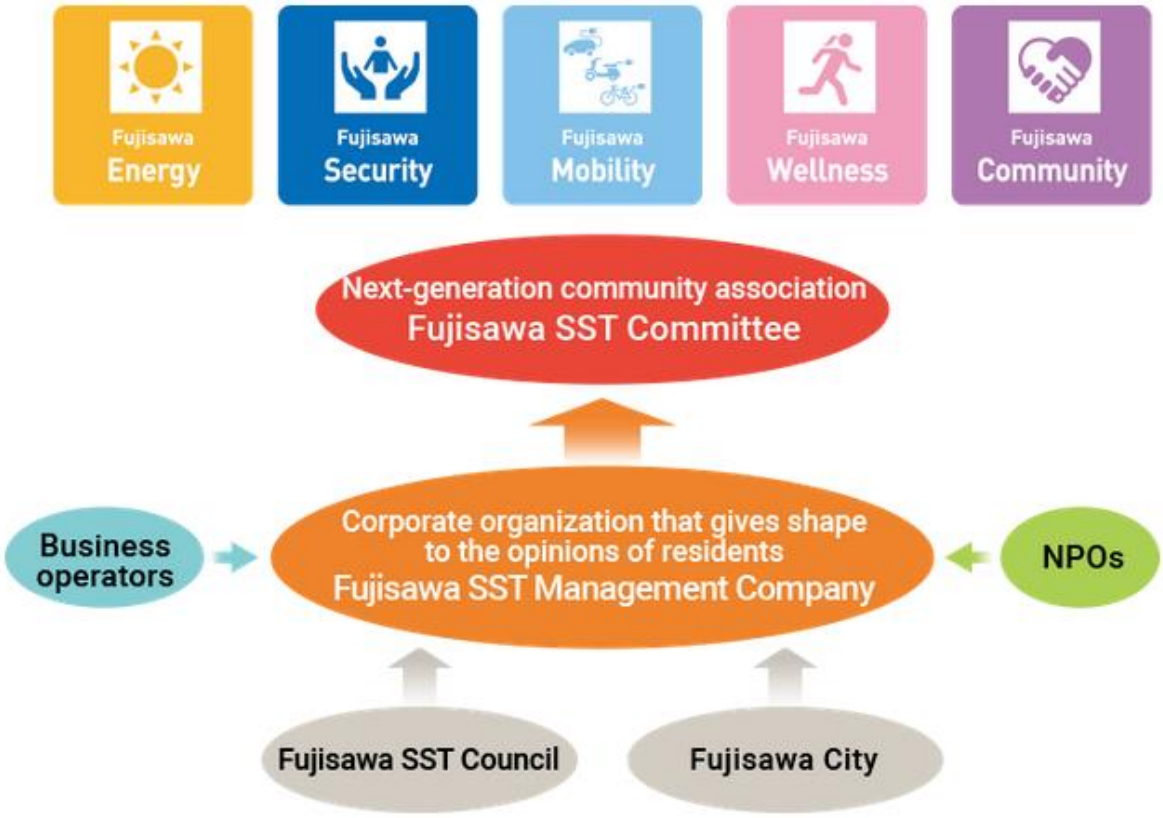

Figure 1: Fujisawa SST Smart Town Management [72]

As for the town itself it established 5 core services that are aimed at bringing energy to life for all residents. These include smart energy, smart safety and security, smart mobility, smart wellness, and a smart community [72].

For energy management the city plans to employ a plan that follows public demand by having energy solutions that are more environmentally friendly and less vulnerable in natural disasters. This has residents generating more of their own power via solar panels along with the creation of some detached houses that are capable of powering 600 other households with their solar generation systems and battery storage units [73]. This is all achieved through the SMARTHEMS (smart home energy management) system.

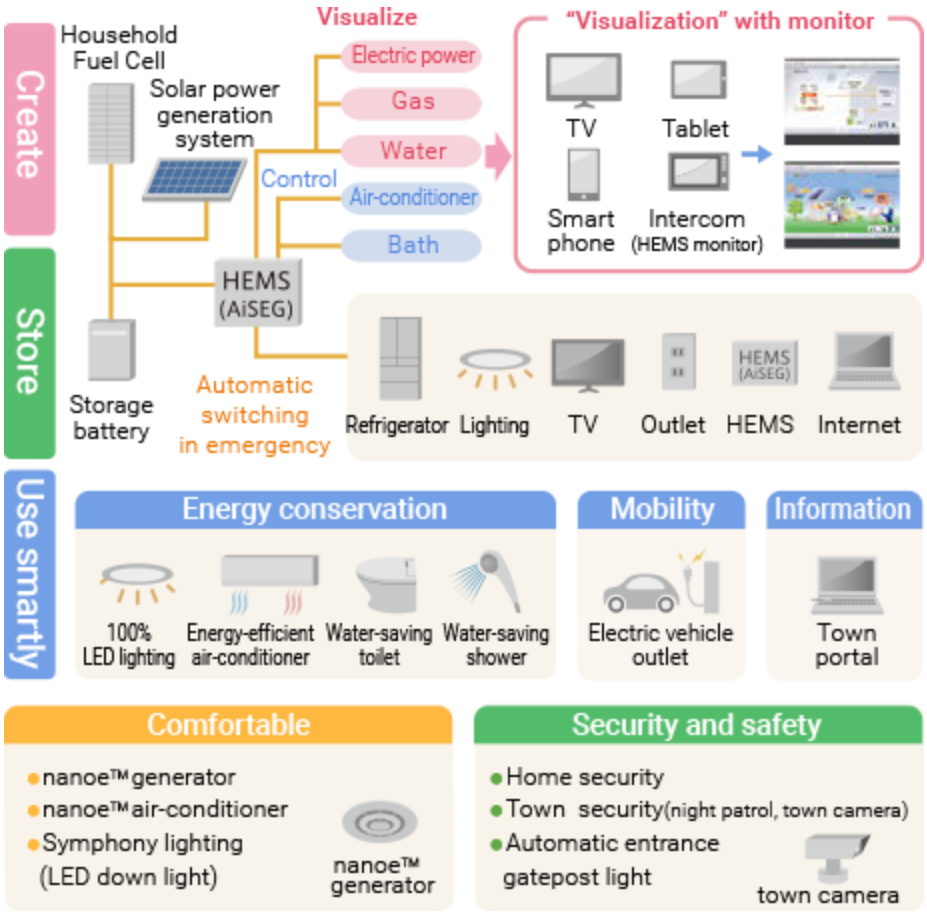

Figure 2: Fujisawa SST Smart Energy [73]

The average home IoT architecture is broken down into three main layers with the capability to visualize energy data in real time. These layers include production which includes solar panels, and a household fuel cell. Secondly, for storage there is a battery storage system which is both local and distributed in nature. The smart home energy management system is capable of automatically managing the switches between production and consumption from batteries. Lastly the final layer is the usability which includes smart EV chargers, smart toilets, and many other smart services. Overall, each home's IoT architecture is complex in nature but provides a state of the art implementation for smart energy management in a residential household.

For smart safety and security, the city has developed an IoT architecture which includes security gates and boom barriers to monitor and control the traffic coming and going from the city [74]. To be mindful of residents' psychological state the city has no physical walls on its exterior which will assist in preventing social isolation. There are also TVs installed in every household which will display real time disaster related information. These disasters include special weather warnings, power outages, typhoons, or tornados. For safety in the streets the city has installed over fifty IoT surveillance cameras and streetlights around public buildings, shady areas, and other

areas.

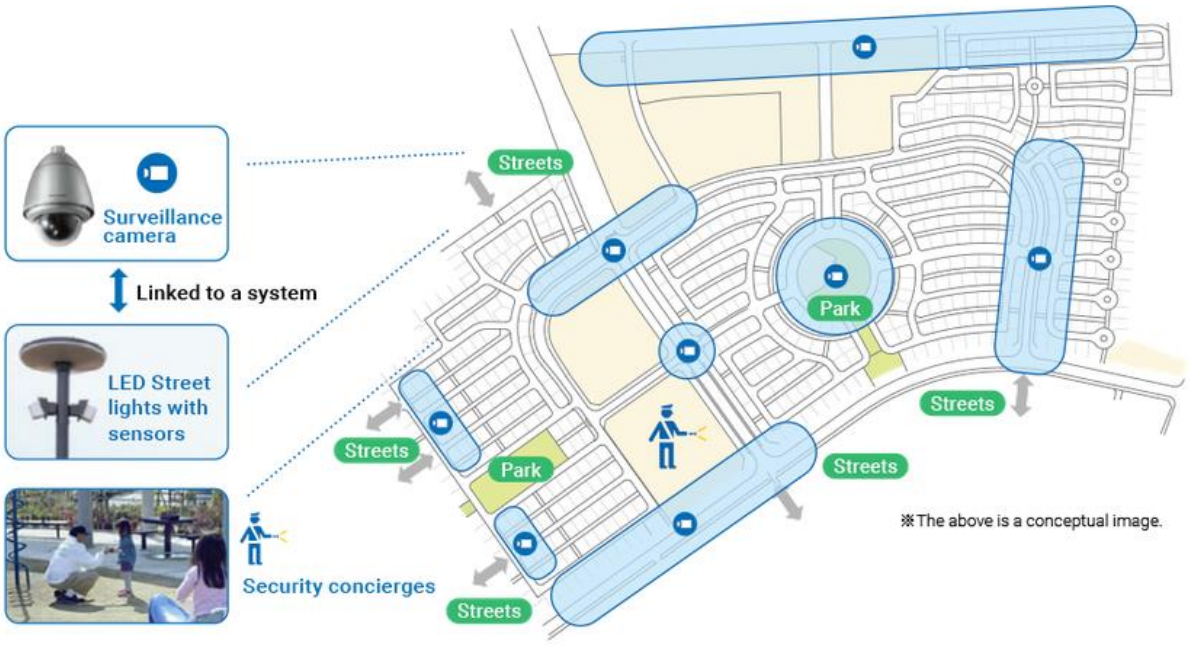

Figure 3: Fujisawa SST Smart Security [74]

The streetlights have the capability to autonomously dim when no motion is detected after a certain amount of time. This infrastructure combined with security personnel provide comprehensive security in a positive manner. The security personnel will be on patrol every day

all day to ensure the highest level of security possible. Additionally, this allows for the monitoring of places in an unobtrusive manner. This IoT security architecture is both comprehensive and well designed to align with the city's goal of putting residents first.

Smart mobility provides the needed multifaceted transportation mediums to residents in an environmentally friendly manner while remaining efficient [75]. Implementing IoT technologies The services provided by Fujisawa SST include mobility services for those with and without their own vehicle. There will be electrical vehicles and electric bicycles available for sharing throughout the city, a rental car delivery service, and battery stations for renting rechargeable batteries. Avoiding traffic gridlock with these clean and efficient solutions will benefit both the environment and residents.

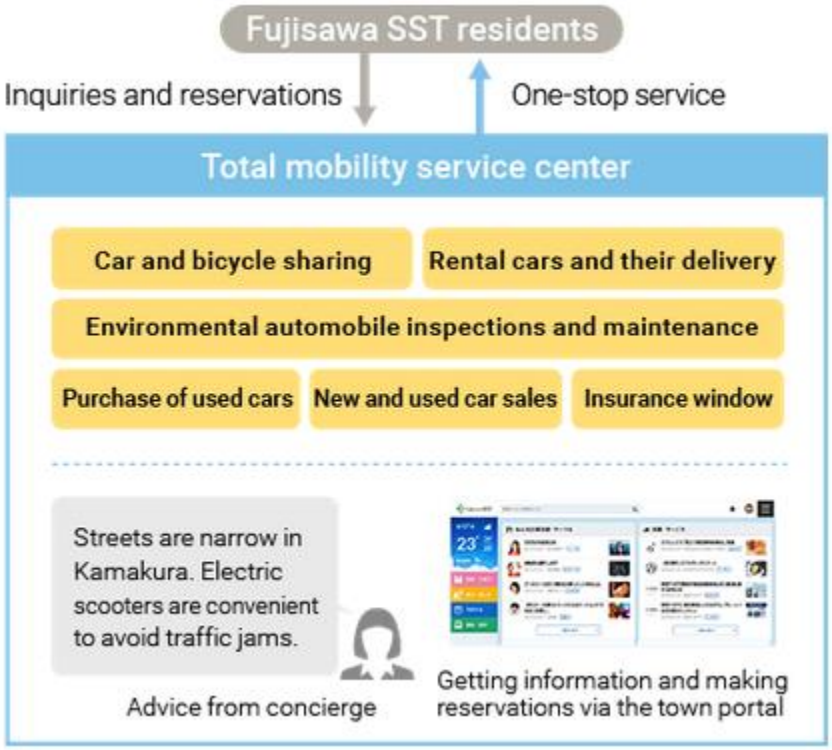

Figure 4: Fujisawa SST Smart Mobility [75]

A unique aspect regarding mobility in Fujisawa is the capability for residents to use the electric vehicle and electric bike sharing service. This service is tailored to their needs by making decisions based upon the environment, distance to their destination, and time of day. These are all incorporated into a mobility portal which allows residents to make reservations on their smart phone or TV, along with having records of car sharing and their reduction in C02. There are also emergency electric vehicle chargers at the committee center for emergencies.

The Fujisawa smart city places emphasis on the wellness of residents. The city is achieving this by allowing residents to maximize social interactions. The town provides after school care centers, nursery centers, clinics, home care services, pharmacies, elderly residential assistance, and a wellness square [76]. Inside the wellness square there are numerous opportunities for residents to interact with each other by having facilities centered around socialization. For establishing a local comprehensive care system that provides coordinated care for individuals needing nursing, the elderly, and pharmaceutical related services the city created a shared server. This shared server uses IoT and ICT to allow residents to share wellness information from a variety of services.

In addition to the use of IoT technologies in the shared server the city will use these technologies to examine the data collected from this shared server to allow the city to better serve its residents. Overall, the deployment and adoption of services using IoT devices to promote the wellness of its residents is a successful program executed by Fujisawa.

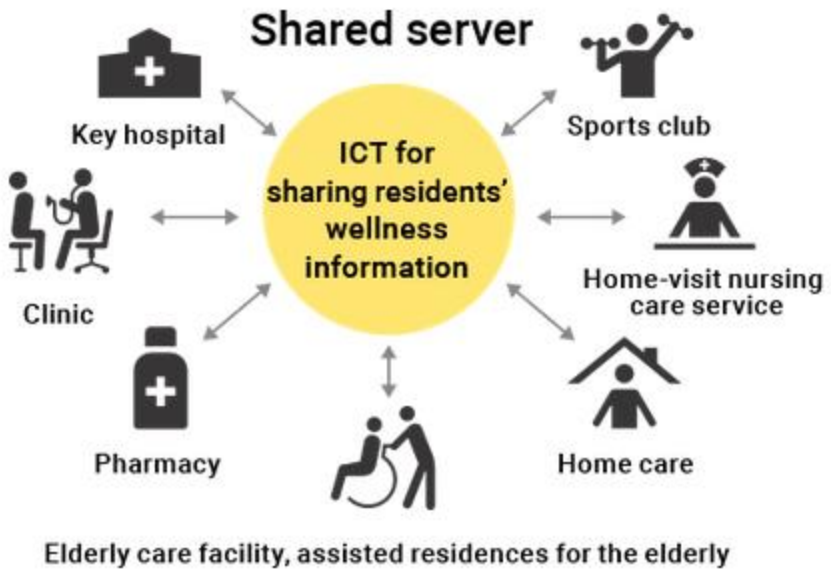

Figure 5: Fujisawa SST Smart Wellness [76]

The last goal for the city is to achieve a sense of community with residents having forward looking goals and values [77]. To achieve this the city has developed a community platform that is a single application to allow residents to monitor their energy consumption, access local restaurants, make reservations for transportation, and exchange information within the community. The portal has the capability to be intelligent and make predictions as to how it will be used so in the case of an emergency it will automatically give a resident the information they need. In another attempt to increase the community feel the cities committee will manage housing information and records to ensure houses receive the optimal maintenance and to help encourage energy savings.

Lastly, each member of the community will have a unique smart city card that will allow them to use facilities in the town, get rewards for attending community events, and rental services. Overall, this set of IoT devices will provide a strong sense of community to the residents living in the city.

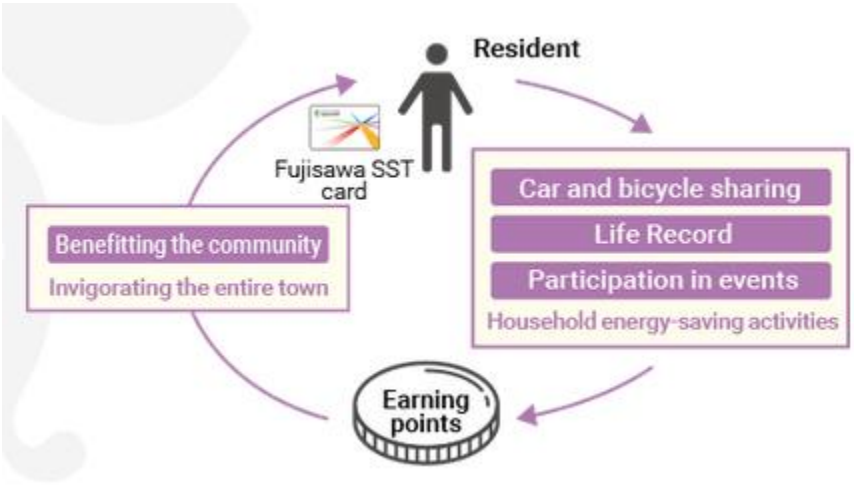

Figure 6: Fujisawa SST Smart Community [77]

Overall, the Fujisawa smart city development project leverages multiple IoT based systems to achieve their five core goals of improving energy, security, mobility, wellness, and community. This project will provide valuable information, including hard data and resident's reviews, to other cities looking to adopt aspects from this project.

4.2 Transportation Agencies Experiences with Smart City Development Projects

The United States Department of Transportation was founded on October 15th, 1966, by an act of congress, and their first day of operation was on April 1st, 1967 [19]. Currently employing nearly 55,000 individuals across the country, the U.S. Department of Transportation has its priorities set on keeping the public safe and secure, increase their mobility, and having the transportation system contributing to the nation's economic growth [20]. Their mission statement is "To ensure America has the safest, most efficient and modern transportation system in the world, which boosts our economic productivity and global competitiveness and enhances quality of life in communities both rural and urban." With such responsibilities the U.S department of

transportation is actively researching, funding, and developing smart city development projects to achieve their mission statement.

4.2.1 City of Columbus Ohio

In 2015 the U.S Department of Transportation's Smart City Challenge was created to evaluate and demonstrate a holistic approach to improving transportation performances in midsized cities, along with public services, health, safety, and energy with the incorporation of new technologies. The main winner of this challenge was the city of Columbus Ohio, which won a forty million grant from the U.S department of transportation [21]. With this, the city initially proposed fifteen projects, but it eventually narrowed down the projects into eight mobility, transportation, and data projects designed and developed to support the efficient movement of people and goods though environmentally sustainable practices, a better availability for safe and reliable transportation, economic prosperity, enhanced visitor experience, and improved access to jobs. These were launched to address the challenges criteria and help gather information about the success of various smart city project ideas.

The eight core projects of the Columbus Smart city include Connected Electric Autonomous vehicles, prenatal trip assistance, multimodal trip planning application, a connected vehicle environment, event parking management, smart mobility hubs, mobility assistance for people with cognitive disabilities, and the smart Columbus operating system.

For the connected electrical autonomous vehicle projects the city of Columbus implemented two projects with a goal to demonstrate urban automation, which is one of the U.S Department of Transportation twelve vision elements.

There was an initial proposal of multiple complex projects that had difficult to navigate routes, however the technology was not advanced enough to handle the complexity thus the city

worked with partners and stake holders to determine new routes. The two main projects included the smart circuit project and the Linden Empowers All People (LEAP) project. The smart circuit project was a shuttle route that traveled along the Scotio Mile in downtown Columbus seven days a week from six am to 10pm. The goal was to develop and document procurement protocols and steps of deployment, educate individuals about autonomous vehicles, and the linking of cultural and educational assets of downtown. The route included four stops which included the Smart Columbus Experience Center, Bicentennial Park, COSI, and National Veterans Memorial and Museum, and was chosen due to its low-speed limits, low traffic volume, low impact to riders if there was a malfunction, and low pedestrian volume.

The Linden Leap which was a project which was the nation's first daily self-driving shuttle in a residential area. It was designed to demonstrate autonomous vehicle technologies by addressing access to community services from existing transit routes via an autonomously controlled vehicle. The route included four stations, which included St. Stephens Community House, Douglas Community Recreation Center, Rosewind Estates, and the Linden Transit Center. During the Covid-19 pandemic it transported nearly 15,000 masks and 130,000 meals from St. Stephen's Community house to people in need. This highlights the capabilities of autonomous vehicles in a city like environment, both by reducing interaction between individuals during a pandemic, but also the capability of getting goods and services delivered to one's house with little to no effort involved [22, P.431].

Prior to the smart city challenge the city of Columbus had an initiative known as "CelebrateOne" which was designed to combat infant mortality which is an ever-increasing issue not only in the city of Columbus but throughout the United States. Its goal was to help ensure every baby makes it to their first birthday regardless of race, address, or family income. The city

developed this project by identifying that there is a potential correlation between reliable transportation that is safe and medical outcomes, especially when dealing with impoverished individuals. After further investigation the city narrowed down the majority of infant deaths coming from eight impoverished neighborhoods, where more than half of infant deaths were related to prematurity [22, P.335].

To add on to this initiative the city of Columbus designed and proposed the Prenatal Trip Assistance (PTA) project when they applied for the smart city challenge. This projected focused on non-emergency related medical transportation services for pregnant women on Medicare/ Medicaid, that was carried out by Ohio's Medicaid Managed Care Organizations (MCOs). The goal of the project was to lower the amount of infant mortality, which is defined as the death of an infant before the age of one, as this is considered to be the global indicator for a populations well-being. When starting the project in 2017 the infant mortality rates for Franklin County was 8.2 deaths per 1000 births and in CelebrateOne zip codes it was 11.9 deaths per 1000 births. Which when compared to the national average in 2017 of 5.8 deaths per 1000 births is a significant increase. After developing, deploying, and letting the program be adopted by citizens it decreased infant mortality rates in 2020 in Franklin County down to 6.6 deaths per 1000 births and in CelebrateOne Zip Codes down to 9.8 deaths per 1000 births. To help that happen they made sure to reach out to the community and developed focus groups with pregnant individuals to assess their concerns and satisfactions with the ideas [22, P.336]. After the focus groups of pregnant individuals developed a complex set of questions, the project team reached out to subject matter experts at The Ohio State University Wexner Medical Center, who helped develop better solutions tailored to pregnant women's needs [22, P.337].

With the help of Kaizen Health, they used an Agile methodology to develop the project and to

also help with continuous development. In the conducted study, the City of Columbus had 143 individuals with Medicaid coverage participate in the Rides4Baby program which provided access to on demand transportation and expanded the eligibility of participants to get rides covered by Medicare. To increase flexibility, the individuals had the capability of schedule appointments via a mobile application, web portal, or via a phone call to a call center. They could also choose specific times for rides, the number of passengers they had, where to pick them up from, where to drop them off at, and what vehicle would best suit their needs [22, P.342]. This resulted in the participants having a median trip count of 19 trips per individual which took them to pharmacies, grocery stores, food banks, and medical appointments during their pregnancy and 8 weeks postpartum.

After the program ended, participants were rewarded with $140 in grocery store gift cards and a large package of diapers [22, P. 347]. Overall, the project was successful with 90% of individuals being satisfied with their services and 82.8% of participants saying they would "definitely recommend" the Rides4Baby program. This project serves as an example to any governing body in transportation about how having readily available, reliable, and affordable transportation to pregnant individuals is a vital part in ensuring the success of not only a society but allowing underrepresented populations having the same opportunities as their counterparts.

Within a vast large city, such as the city of Columbus Ohio, there are many unique complexities that pose challenges not only to residents but also to tourists of that area. With tourists being unfamiliar with an area, transportation and services provided by the city can be counterintuitive, hard to discover, and allow for dangerous situations to arise by driving mistakes.

With these problems in mind, the city of Columbus attempted to make navigating the city and its services easier with the development of the Multimodal Trip Planning Application, and the Common Payment System. The goal of these two applications was to allow individuals and communities to work more effectively and efficiently, improve access to jobs, increase safety, and allow travelers and individuals from outlying communities to create trips and pay for them with a single account that is linked to various services. These services included public transportation via the Central Ohio Transit Authority and the Campus Area Bus Service, ridesharing via Gohio Commute, bike sharing via CoGo, Scooters via Bird and Lime, ride hailing via Yellow Cab, Uber and Lyft, and personal bikes and vehicles. The resulting mobile application was named Pivot, and it aimed to be the main facilitator for mobility in the city by providing one solution for all start to finish trip planning, bookings, electronic ticketing, and payments for private and public services [22, P.237].

When development began to take off, there were many challenges faced by the development team with the main one being the legal and business decisions faced by mobility providers which caused massive delays in the Common Payment System concept. With the permission of the U.S Department of Transportation in August of 2020, there was a reduction in the scope and funding of the project by removing the Common Payment System [22, P.274]. This did not stop the application from being successful, as the pivot app still offered real time mobility options including the Central Ohio Transit Authority, the Campus Area Bus Service, the Yellow Cab of Columbus, CoGo bike sharing, Lime Scooters, Bird scooters, Lyft, Uber, and the Gohio Commute services. This can all be achieved on a variety of platforms including the web, Smart Mobility Hub Kiosks, Android, and iOS, and allows for anonymous trip data to be sent to the Smart Columbus Operating System through a fast, secure, and reliable API.

Pivot was built with the U.S Department of Transportations goals in mind which led to design principles including a foundation built on open-source and proven technologies, flexible hosting options, a distributed ledger for redundancy, transparency, shared governance, and long-term viability, the ability to book trips with travel and personal information being private, machine learning, and the pivot app, website, and smart mobility hub kiosks all running on the same codebase. As for logistics in the multimodal trip planning application that the city of Columbus developed and implemented, which is formally known as the pivot multimodal transportation planning application, the application has been downloaded 1103 times in the time frame of 12/9/2020 to 03/31/2021 and had a total of 606 registered users [22, P.282. During the small data collection window during the timeframe of September 2019 to March 31st, 2021, users logged 5,820 miles which was then fed into the Operating system of the city to help improve and advance the project and city. It also supported 447 trips amidst the Covid-19 pandemic, with hopes of much more post pandemic when tourists and residents are capable and willing to explore the downtown region [22, P.283].

Overall, this project is successful both by implementing a working product that helps anyone that lives in or around Columbus along with tourists navigate the city, but also from learning the complexity of a common payment system for both public and private entities. While currently not successfully implemented, the trial and error of the development provides a large number of valuable insights for future developments of such an application.

To align with the goals of the U.S. Department of Transportation, the city proposed a project with a goal of enhancing mobility and safety for both private and public vehicle operators along with improving pedestrian safety in school zones. This project, known as the connected vehicle environment (CVE) project, was developed using secure high speed wireless

communication technologies in conjunction with software applications in vehicles and infrastructure for the exchange of critical data which is used to then alert drivers. This highspeed communications network that allows the CVE project to connect to the regions traffic signaling network is called the Columbus Traffic Signal System (CTSS) and is built using a fiber backbone that is secure and allows for transmission of large amounts of data in a short amount of time.

When connecting with the CTSS in the Use of Vehicle to Infrastructure communication there is a need for both the deployments of Roadside Units (RSU) inside traffic controller enclosures and an Onboard Unit (OBU) inside vehicles to ensure the execution of secure, fast, and reliable communications. During the time of this project, more than 1000 vehicles participated in a connected environment where vehicles could communicate with each other using Vehicle to Vehicle (V2V) communication and communicate to infrastructure with Vehicle to Infrastructure Communication (V2I). The vehicles included public transportation buses, private vehicles, fire trucks, ambulances, and many other vehicles that offer unique characteristics both physically, in their driving patterns, and their goals when using roadways. These vehicles performed Vehicle to Infrastructure (V2I) communications in 85 intersections in Columbus, where 7 intersections have the highest crash rates in central Ohio. This was done via roadside units (RSUs), which can broadcast the current state of a traffic signal or school zone. In total there was five applications developed with safety features as a primary objective in V2V communications which included Emergency Electronic Brake Light Warning (EEBL), Forward Collison Warning (FCW), Intersection Movement Assist (IMA), Blind Spot Warning (BSW), and Lane Change Warning (LCW). Each one is being used to enhance safety throughout the city. As for V2I communications there was five mobility applications and two safety applications. The

five mobility applications included Transit Signal Priority (TSP), Freight Signal Priority (FSP), Emergency Vehicle Preemption (EVP), Vehicle Data for Traffic Operations (VDTO), and Transit Vehicle Interaction Event Recording.

These systems helped increase mobility throughout the city which in return helped reduce emissions, lower cost of services, saved commuting time, and enhanced emergency vehicles mobility. For vehicle to infrastructure safety there included Red Light Violation Warning (RLVW) and Reduced Speed School Zone (RSSZ). This helped crowded intersections avoid red light collisions and helped children, their parents, and residents driving near school zones be safer. All of these systems allowed for a baseline understanding of how technology can be used to improve road safety by communications between not only vehicles to other vehicles but also vehicle to infrastructure. This also resulted in a drop of speeds surrounding school zones, and improved emergency vehicle response times. Of the 1000 participants, the majority would recommend the use of connected vehicle technologies to a family or friend [22, P.245].

With any amount of modern-day rapid urbanization the availability of parking becomes an issue for city residents, city officials, and tourists. This is notoriously notable in downtowns or popular districts where there are many activities in a small geographical area. The City of Columbus is no different as its Downtown and Short North District are both popular locations where individuals can expect to drive around for a noticeable amount of time before discovering available parking. This leads to a negative impact on the environment, extra congestion, a heightened increase for pedestrian and vehicle collisions, frustration, and a variety of other negative factors.

The cities solution was to add additional functionality to the already existing Park Columbus application. The transformation would include taking the existing simple mobile

application that allows users to pay for parking to a web and mobile based application that has parking rates, driving directions to parking, the ability to make on demand purchases and reservations, and live prediction modeling that has the ability to predict the probability of finding parking in a specific area. The specifics for parking garages and lots include the parking availability and other data from 86% of the available parking garages and private surface lots in the project area which is then sent to the Smart Columbus Operating System and the EPM Central System. For parking meters and kiosks, the system collects parking data from nine kiosk parking zones, and around 4,300 single space parking meters which is used in the Smart Columbus Operating System to predict availability. For loading zones, the city collects information about restrictions in 130 loading zones and sends it to the Smart Columbus Operating System.

Lastly the EPM Central System aspect of the project includes multiple new software models working in conjunction to produce a traveler friendly user interface on the front end, a centralized back-end system that connects, captures, stores, relates, and responds to real time parking data collected from other various services, and a connection to the Smart Columbus Operating System to store real time and archive data to give stakeholders reporting and operational access. This allows the system to provide current, projected, and complete views of parking availability and statuses to help residents and travelers plan and pay for parking to align with the cities smart parking vision and goals [22, P.401]. To help develop these systems the city first partnered with the City's Division of Parking Services, who manages all on street parking and would eventually own the Event parking management system [25. This group is vital to the success of the project as they not only are the experts of parking in Columbus, but they also agreed to allow their parking assets to be added to the application which helps ease integration

and increase development and deployment speeds. Second to join the team was Experience Columbus an organization founded by the city whose goal is to help promote the city of Columbus to visitors [23].

ParkMobile was chosen as the vendor for the project due to it being used in the existing parking application, its ability to demonstrate meeting the needs of users, and having a second parking application for the city would've caused confusion in residents and tourists [22, P.402]. Overall, the project from July 2020 to April 2021 averaged over 5,0000 new downloads every month, with 3 months gaining over 10,000 new downloads. This was also during the Covid-19 pandemic when parking downtown was not a problem due to restrictions in place [22, P.406. Despite limited interaction due to Covid-19 the project was welcomed with strong positive feedback from residents, where 87% said the new additions on the application were helpful [24]. Overall, even with a global pandemic the positive impacts of this project were felt by both residents and tourists. This sets a baseline for governing bodies to discover possibilities of improving parking in over urbanized areas where parking can be limited. It also highlights a vendor, ParkMobile, who has shown the ability to service the city of Columbus including providing flexible features to hit a variety of project goals.

With the U.S. Department of Transportation goals in mind, the Smart Mobility Hub Project was designed and developed to help improve the availability of reliable transportation for areas with limited connectivity. When researching areas to implement the project to maximize its effects, the city discovered the neighborhood of Linden where residents suffered from high infant mortality rates, many socio-economic challenges including low income, and a lack of major employers nearby. The nearest major employment opportunities for Linden residents are in the Easton area which is a high-volume retail destination. This area offers a large volume of jobs, but

it has one of the highest turns over rates in all of Ohio due to Linden residents landing jobs but being unable to sustain them. The lack of sustainability is due to the lack of reliable transportation for residents [22, P.373].

To address this the city of Ohio created a total of six smart mobility hubs in order to help with transportation gaps between popular destinations including Easton, bus stops, and other areas such as the local community college. These hubs were placed in Linden at the LindenTransit Center, the Columbus Metropolitan Library, the Northern Lights Park and Ride, and St. Stephens Community House along with two more at the Easton Transit Center, and Columbus State Community College. They contributed six new interactive kiosks, four bike sharing stations, four scooter charging stations, and one electric vehicle charging station. The Linden hub is unique due to it being the first expansion of a bike sharing project into an opportunity neighborhood [22, P.373].

Overall, this project represents a strong example of heightened mobility for underrepresented portions of the populations. It also provides more community growth and wellbeing by providing reliable transportation to jobs for residents of areas that may not have the same industry for employment opportunities.

In a private public partnership the city of Columbus designed, developed, and implemented the Mobility Assistance for People with Cognitive Disabilities (MAPCD) project. With a cognitive disability the ability to travel independently has a high degree of difficulty due to a variety of reasons including costs, reliability, availability, and many other factors. Many times, individuals with cognitive disabilities must either qualify for paratransit services or be able to independently use public transportation such as busses safely and effectively. This led to the city of Columbus proposing the project of Mobility Assistance for People with Cognitive

Disabilities for the U.S Department of Transportation's smart city challenge. The project aims to enable individuals with cognitive disabilities the ability to rely less on their caregivers and private transportation and more on a fixed route bus service for independent travel.

To achieve this goal, they used the collective experience and expertise of the staff and faculty at the University of Ohio, The Ohio State University Wexner Medical Center (OSUWMC) and the USDOT's Accessible Transportation Technologies Research Initiative (ATTRI) to help decide the best possible implementation of the project. After some time, the team decided the most viable option was a smart phone application with multimedia prompts to assist individuals with cognitive disabilities navigate public transportation. After deciding on the concept of a phone application there was also a need for a supervising body to ensure that if any mistakes happened on either the application side or the user side that there was an individual to assist in real time.

The two proposed and tested models involved an external support model, where there was support for the individual from a call center to monitor trips and make necessary changes, and the second was a caregiver response model, where a relative or caregiver provided support, real time trip monitoring, and the ability make necessary changes. The project eventually adopted the caregiver response model as when evaluating an external source such as the call center at the Central Ohio Transit Agency (COTA), there was a lack of funding, and the staff was having a hard time with having limited resources [22, P.309]. After the adoption of the model, it was decided that there would be eight core criteria where five would be focused on the individual with the cognitive disability and three would be focused on the caregiver. For the traveler the criteria included the need for a phone-based application, the knowledge of real time

transit info, voice and turn by turn directions, the ability to speak to the caregiver/ relative, to fit the WCAG 2.0AA Standard, and to be 508 Compliant.

These criteria ensured an easy-to-use product for the traveler that provided reliable transportation. For the caregiver they needed passive monitoring where the application could send alerts and updates to the caregiver, activate monitoring so the caregiver could track the traveler in real time, and a positive caregiver experience which is a qualitative measure that ensures the application meets the needs of the caregiver based upon specific criteria. Adopting these criteria ensures that the caregiver can ensure reliable transportation for the traveler and can assist in real time if any issues may arise [22, P.310].

The final solution involved the private industry vendors of AbleLink, Verizon, HNTB, and Accenture. AbleLink was chosen for the development of the mobile application due to the ability to build off their existing WayFinder Application which was and still is being funded and used by the U.S. Department of Education, and the National Institute of Health. The WayFinder application by AbleLink is currently still being maintained and is being enhanced to support the project due to the ATTRI contract with the U.S Department of Transportation. As for HNTB they took the systems engineering lead, which involved the coordination of PMO, vendors, and the research team, and the development of engineering documents including the trade study, ICD, Test plan and report, and the O&M Plan.

Lastly Verizon provided the cellular service and Accenture was responsible for implementing the interface to MAPCD to collect data for measuring performance [22, P.321]. For logistics during deployment this project resulted in a twelve-month time span where thirty-one individuals with cognitive disabilities took a total of eighty-two independent trips on public transport via the WayFinder app rather than relying on a caregiver. These individuals who

participated had a newfound sense of freedom and independence with the availability of travel without a caregiver, along with the added benefit of having a positive impact on the environment by using public transportation.

The last project implemented was the Smart Columbus Operating System (SCOS), which is an operating system for the city, which was built using largely open-source software that is an example and template for other cities by its cost effectiveness and ease of integration. This also was designed and implemented to perform as a backbone for the other seven smart city development projects developed by the city of Columbus. Throughout the planning phase and at the beginning of the development phase, there were multiple workshops held for the city of Columbus, leveraged partners, private sector individuals, academic researchers, other cities departments, consultants, and subject matter experts in order to define the initial goals for the project.

Using agile development, the minimal viable product (MVP) was first delivered in December of twenty seventeen to the U.S Department of Transportation. With continual refinements and the reorganization of the programs management office, they were able to come up with a finalized vision for the project in twenty eighteen. The six main deliverables and goals of the project included, delivering a project that supports USDOT goals and projects. Having analytic and data visualization tools that are functional, accessible, and user friendly to increase usability and accessibility. The use of open-source components to allow for migration across platforms without vendor lock ins, reduction of licensing fees, and public access to the OS technology. The resulting operating system is than scalable, portable, and sustainable and is even published to a public repository so other cities can use and contribute to its development due to its open-source nature.

The sustainability and productization where also both important so it can be maintained after the conclusion of the project and would be easily transferable to other regions looking to improve their transportation systems with the use of data. The use of DevOps, which is the simultaneous development of software while running and managing the existing software, allows for faster implementation and adoption of new features while concurrently running existing features. Lastly a goal of privacy and security by the creation and compliance of data privacy and management policies. This involves having proper security protocols and having a full administrative department to help handle personal information, payment information, health information, and other private data collections.

In April of twenty nineteen the new OS data platform was launched and included and open data portal that houses datasets from the city, state and region, real time project data from the connected vehicle environment (CVE), a live map of Central Ohio Transit Authority bus locations, and internet browser-based data visualization tools. The OS team has and still is receiving feedback from the community about the success of the project and how it can be improved to better help the citizens [27, P.189]. Overall, this project is an example that cities, transportation departments, and researchers can study and learn from in real time. As the amount of data that is collected and stored is increased there is opportunities for the data to be analyzed, visualized, applied to machine learning models and or artificial intelligence, and many other learning tools that can help better the project.

The city produced six performance measurements to ensure the city aligned with the U.S Department of transportation's twelve vision elements, helped both residents and tourists, and provided enough transparency and documentation to assist city officials and researchers. These six measurements included safety, mobility, opportunity, environment, agency efficiency, and

customer satisfaction [22, P. 26]. Following five years of design, development, and implementation Columbus had been found to successfully or be partially successful in achieving twenty-two of the twenty-nine program objectives. Of the seven objectives not in these two categories, all were decided to be inconclusive due to Covid-19, a small sample size, or a combination of both. No objectives were determined to be missed due to project or application failures.

For the connected vehicle environment (CVE) project all three objectives of safety, mobility, and environment were achieved. This included up to a 5.2% improvement in emergency response times when signal preemption was granted, with an average improvement of 1.64%. An average reduction of speed when approaching a red light by 2.3 miles per hour, and an improved school zone speed limit compliance from 18% to 56%. The environmental objective was partially inconclusive due to small sample sizes and the impact of Covid-19 on travel behavior; however, the project was shown to have a potential to reduce greenhouse emissions post pandemic. For the Multimodal Trip Planning Application, the four categories of mobility, opportunity, environment, and customer satisfaction were achieved. There was determined to be a significant increase in access to healthcare and entertainment while over 97% of users found the Pivot application very easy or easy to use. For the mobility assistance for people with cognitive disabilities project the objectives of mobility and opportunity were achieved while the agency efficiency objective was determined inconclusive due to participants not being existing paratransit users thus not allowing for a baseline to be established.

For mobility there was 82 trips that shifted from personal vehicles to public transportation and for opportunity many of the participants reported a greater sense of independence. For the prenatal trip assistance project, the objectives of mobility, opportunity,

and customer satisfaction were all achieved. This resulted in a percentage drop from 44% to 19% for individuals who did not take NEMT trips. The project also recorded 90% of participants were either satisfied, very satisfied, or extremely satisfied. For the connected electric autonomous vehicle project the objectives of mobility, opportunity, and customer satisfaction were all achieved. This resulted in over one hundred and thirty thousand meals transported to the Linden area, two hundred and sixty-five walkups at the Rosewind stop, and a 90% satisfaction rate for participants.

With the city of Columbus Ohio winning the U.S Department of Transportation's Smart City challenge, there has been significant improvements not only for the city of Columbus but also the rest of the world. The data and feedback that is being collected, processed, and displayed provides valuable insight to city officials and researcher as to the impacts that these technologies can have. Being both positive and negative in nature, the data allows for future projects to adapt, improve, and customize the projects for their geographical region which could include unique climates, population variances, and other factors. The eight flagship projects of connected electric autonomous vehicles, prenatal trip assistance, a multimodal trip planning application, a connected vehicle environment, real time event parking management, smart mobility hubs, and the backbone of the smart Columbus operating system provide flagship programs that other cities can learn from, adopt, and contribute to. This allows for rural communities to be able to achieve projects that they would have never been capable of due to staffing shortages, smaller budgets, and less expertise to ensure that not only large metropolitan areas have the newest technologies but also rural areas as well. The smart city of Columbus provides the first major step into the smart city domain, an application of the U.S Department of Transportation goals for smart cities and is an ongoing learning experience to advance the science.

4.2.2 Portland Oregon

The city of Portland Oregon, and the entire west coast offers a unique environment for smart city developments when compared to their eastern counterparts, such as Columbus Ohio, due to the development of these cities being built after the mass adoption of cars as a reliable way of transportation for the average citizen. This results in cities that are significantly more spread out geographically and offer less infill so public transportation is not as widely adopted. The city of Portland fits this narrative as with rapid growth of the Portland metropolitan area, there has been a steady increase in rent prices, which has pushed lower income residents to neighborhoods outside of the city. This puts these residents in a disconnected street grid which results in traffic congestion, negative environmental impacts, lack of public transportation due to difficulties and cost, and many other negative factors for both the city and its residents.

This can especially be seen in east Portland, where inequalities in transportation are threatening the ability to remain a city for all. To improve safety, enhance mobility, address climate change, and create opportunity for all residents the city of Portland Proposed for the United States Department of Transportation Smart City Challenge a project titled ‘Ubiquitous Mobility for Portland’ (UB Mobile PDX). Along with helping residents move around the city with heightened safety and more ease, the project will capture data and develop urban analytics to guide city investments and projects in a direction to improve mobility for all regardless of their primary transportation method [25, P. ES1].

UB Mobile PDX focused on three corridors in the city including two east Portland corridors, the Powell/Division corridor and the 122nd Avenue corridor. The third corridor is the Columbia Boulevard Corridor which is in the north side of Portland. These two areas are of interest as the east Portland area is the most diverse community in the area, and the housing is

still affordable, but the area lacks access to safe and convenient transportation services. As for the north section there lies most of Portland's manufacturing and industrial jobs, which are vital to helping residents make ends meet along with being a backbone to the Portland economy. These jobs are difficult to reach without a private vehicle, so improving the access to these jobs is vital to the health of the city [25, PP. ES2-ES4]. To address problems these problems throughout the city, the city proposed a variety of projects including, a citywide mobility marketplace, open-source data sets on a cloud service, ladders of opportunities, and information corridors. These will all be supplemented by private partnerships and public outreach along with performance measures.

As for the mobility marketplace project, the city of Portland hoped to help address their newfound changes by implementing a citywide data collection and data sharing platform along with a centralized application highlighting transportation services. This platform which is broken down into citywide and regional specific sections, can provide valuable insights on how transportation in the city works from a numbers perspective along with providing a single application to find all mobility options throughout the city. The insights involving transportation related information can provide governing bodies in the city guidance about long term investments and see the results those investments can yield. For residents of Portland, it allows a centralized application to tie together all the loose ends of mobility options throughout the city and the option for a centralized payment service.

Portland already has a large portion of mobility applications and mobility services in place, which many residents may not know of, including a variety of transit options such as RideTap, Passenger tail, Aerial Tram, Light Rail, Streetcar, and others. As for ride sourcing services and car sharing services Portland has Lyft, Uber, Zipcar, Reach Now, Getaround, and

Car2Go. Additionally, the city has peer-to-peer services, paratransit, intercity transit, biking and walking route information, bike sharing services, taxi-hailing services, and other mobility related services. The integration of all these services into a data collection and data sharing platform along with a marketplace will be an inclusive insight to the transportation methods being used throughout the city, and allow residents to discover and use new mobility options from a centralized application [25, P.1].

This will result in all travelers having a larger amount of cheaper, faster, efficient, and environmentally friendly transportation options from a single source. To assist in this project Portland is also installing chargers for electric vehicles along with implementing and testing connected vehicles on an individual and fleet wide basis. To ensure the successes of this project the city came up with four main goals including a consolidated user interface, an integration of both public and private transportation services, a pricing breakdown to make mobility more affordable along with the promotion of shared transportation, and mobility for all including individuals with a range of disabilities [25, P.2]. This project as whole provides a newfound approach between private and public transportation methods by providing a centralized application to assist residents, along with the data collection from both private and public mobility options.

This idea can foster a new private and public partnership for the benefit of all parties by connecting residents with new transportation options, having private companies have a larger marketing base, and ensuring residents are aware of their public transportation options.

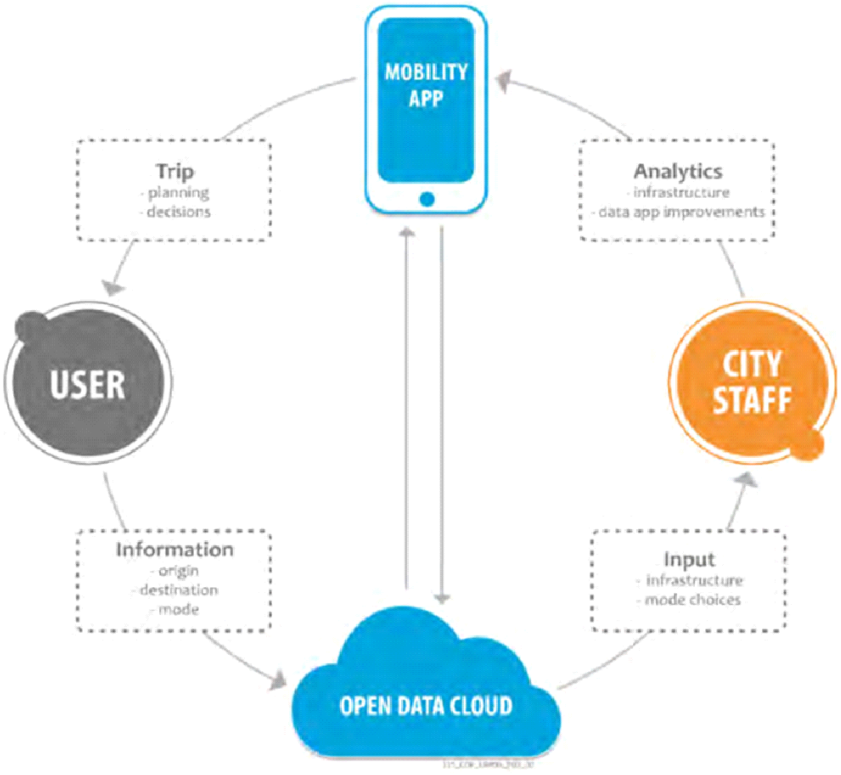

Figure 7: Smart PDX Open Data Clous [27]

An additional project funded by the city of Portland from the US. Department of Transportation's smart city challenge grant was the open data cloud project. This project is an extension on the UB Mobile PDX application by providing the application a foundation for data management. While collecting data is valuable, being able to share and present that data in relevant ways is where shared knowledge can thrive and lead to groundbreaking innovations. This data, which is being stored in the cloud will assist established private businesses and startups, which the city of Portland is known for, in solving real world problems. Portland's innovation can be partially accredited to its long-standing commitment to open data along with collaboration being used to solve problems the data presents.

Some notable prior projects that highlight the advantages of open data include PortlandMaps working in conjunction with CivicApps to accelerate innovation and increase civic

participation, the Oregon Department of Transportation's TripCheck Traveler Information Portal which provides customization real time road, weather, and traffic data, OpenStreetMap which offers a bicycle trip planning service, TriMet which maintains an developer resources website that provides schedule data in General Transit Feed Specification (GTFS) format and Portal which is open source regional transportation data hosted by Portland State University (PSU). To accommodate all this data exchange Portland created a custom fiber network known as the ITS network which allows large amounts of data to be exchanged between the city of Portland, ODOT, TriMet, and PSU. Each one of these projects has been beneficial to all parties involved and highlight the value of open-source data [25, P.11].

The Open Data Cloud project is specifically aimed at the USDOT Vision element #4 by being a platform aimed at "understanding and analyzing data to address complex urban challenges" and for "measuring the performance of the transportation network." It achieves this by strongly documented and standardized APIs that are accessible to all, which will result in a large amount of open-source urban mobility apps along with a large amount of mobility analytic. The three main principles for the Open Data Cloud Project are the use of open-source software, having an open platform, and having accessible data. With the use of open-source software, there will be a massive reduction in costs, which will increase the flexibility and mobility of the platform. As a result, this system will be able to be easily adopted by other cities by reducing the overhead and complexity.

As for being an open platform the selection of vendor chosen software and solutions is vital to allowing the Open Data Cloud to be deployed on a wide variety of platforms, thus providing a learning opportunity about private entities for other cities. For the software developed by the city, it will need to be deploy able on a variety of cloud hosting platforms to

assist in the adoption by other cities. Lastly for having easily accessible data, the city is developing standardized data formats and standardized API calls in order to allow easy access. These three main principles help align the Open Data Cloud in the city of Portland to the U.S. Department of Transportation goals. In addition to increased safety and mobility with this project there are other benefits such as more comprehensive and detailed trip information for new applications with new functionalities, the sharing of actual modal splits in the city, and data showing real time travel methods and choices. All of these will provide beneficial data on what problems are happening and potential solutions to those problems [25, P.12]. With the aligning of the U.S Department of Transportation goals and some goals of their own, the city of Portland's Open Data Cloud is setting a standard for other cities to follow.

As in many cities throughout the United States, in the Portland metropolitan area there are many underrepresented individuals that lack effective, reliable, and accessible public transportation. In the Ladders of Opportunity project proposed by the city of Portland Oregon they are aiming to assist their least fortunate residents who currently are suffering from inadequate transportation infrastructure. The city has aligned with two key elements in the USDOT goals, which are connections and revitalization. In order to keep up with a smarter city that includes open real time data analytics, electric vehicle infrastructure, autonomous vehicle infrastructure, and other smart portions of the city their needs to be the transportation infrastructure to support individuals to get to these jobs. To help ensure underrepresented individuals such as low income and minority residents have access to these jobs the city of Portland plans on partnering with Worksystems [26].

Worksystems is a nonprofit regional workforce development board that since 1998 has invested over three hundred and fifty million dollars into the Portland Oregon community to help

people find jobs. In this project the city is dedicating over four hundred thousand dollars to develop a UB Mobile PDX workforce development plan where Worksystems will coordinate with major industries in Portland to develop a collaborative plan. This plan will include 4 key elements including a new training program procurement and development, enhancements to the existing training program, group trainings for new or existing workers, and paid internships and on the job training [25, P.18]. As for the cities desired outcomes they are hoping for a workforce development program to help minority and low income residents into better paying jobs, application development and data analysis training through Portland community college, Application development competitions and support for startups, traded sector employment, help disadvantaged business enterprises, installation of connected vehicle equipment, job creations in the smart city technology sector, and access to jobs in shared mobility [25, P.19].

To achieve these outcomes they are implementing semi and fully autonomous shuttles to connect low income housing to areas in the city where better paying jobs can be found, better bus based transportation in the Powell/Division Corridor which connects several educational institutions, ADA mobility services which will cut down the time needed for individuals with disabilities to get rides, which is currently 24 hours in advance, and increased access to information by providing low cost smart phones and free WiFi to low income residents of the city [25, P.20]. Overall, this project puts an emphasis on serving areas that were left behind in prior transportation-based projects in order to connect underrepresented individuals to jobs that are better and higher paying to help the growing divide. This includes not only improved access to transportation services but also helping the growing digital divide which in return can assist individuals in finding better paying jobs.

The final project being implemented by the city of Portland from the smart city challenge funding is their Information corridors project. This project aims to enhance electric vehicle infrastructure, enhanced connected vehicle technology, the deployment of Mobileye, and the deployment of freight applications in all areas in the city to improve mobility, access, and safety for residents of the Portland metropolitan area. For electric vehicles and infrastructure enhancements UB Mobile PDX will increase access to electric vehicles and electric bikes, improve the smart power grid, expand their electric vehicle charging infrastructure, and increase the amount of electric transport vehicles the city uses. These enhancements will help reduce carbon emissions by 40% by 2030 and 80% by 2050 compared to 1990 levels. Currently Portland's carbon footprint is near zero thanks to renewables and hydro power being in use today [25, P.21].

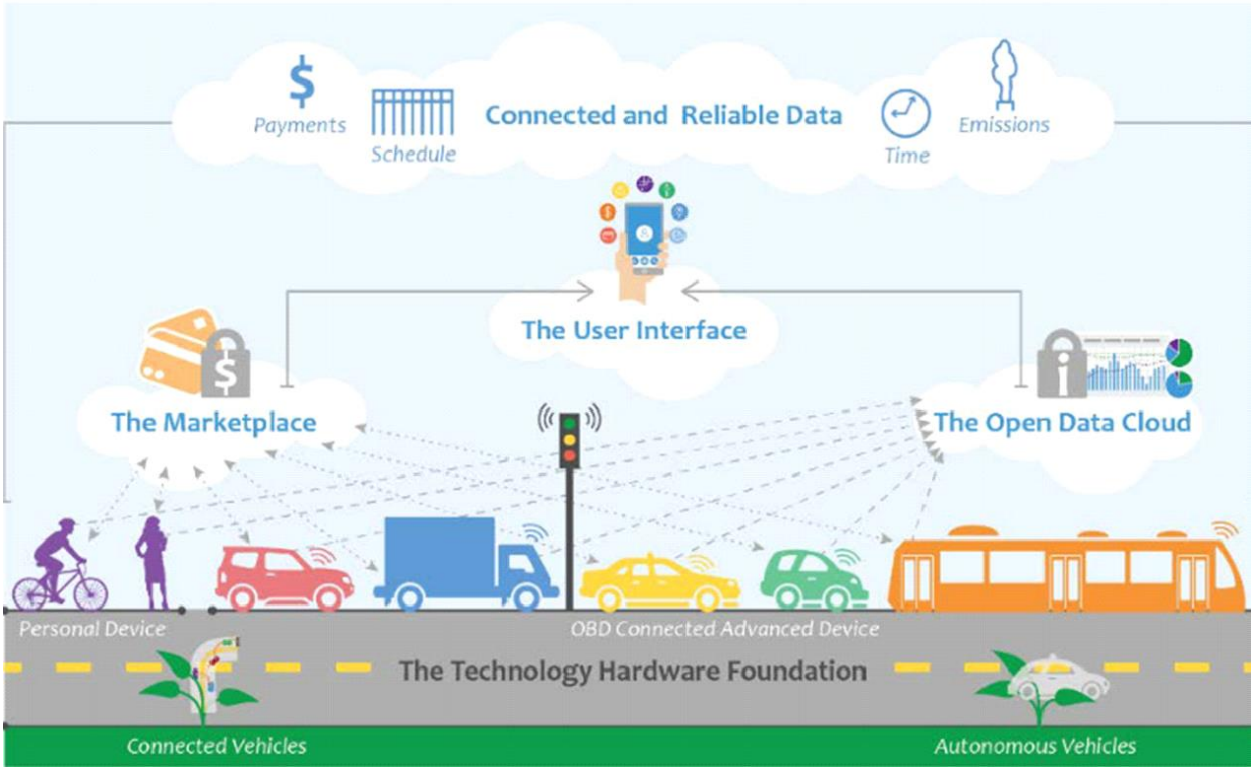

Figure 8: Smart PDX Architecture [27]

Overall, these projects being implemented by the city of Portland are vital to the success of not only having a smarter city but also having a functional city that provides opportunity for all. This includes dropping carbon emissions, decreasing traffic, increasing public transportation, and helping both residents and tourists find and pay for various private and public services through a common application. Portland provides valuable information and challenges compared to its eastern counterparts due to the majority of the city being developed around the car which leads to an increase in spacing between parts of the city. These problems are currently being addressed and will need to be continuously addressed as an increasingly number of smart city projects are being designed and implemented.

4.2.3 Pittsburgh Pennsylvania

Out of the seventy-eight city applicants for the U.S Department of Transportation Smart City Challenge one of the seven finalists included the city of Pittsburgh. Being founded on November 27th, 1758, the city quickly began to show its importance in the early 1800s as it became a gateway to the western united states. This is due to the intersection of three major waterways, two of which being the Allegheny and Monongahela, and the fact that by 1911 the city produced half of the nation's steel resulting in a major transportation hub [28]. This history has led to a city that has had many tragic up and downs based on the local industry, however with perseverance the city has become a modern-day national leader in education, healthcare, and advanced industries.

While Pittsburgh is a leader in many fields, infrastructure has been neglected for many years creating a wide array of problems for governing bodies, residents, and tourists. In a report by the American Council for an Energy Efficient Economy they reveled Pittsburgh has the

second highest energy cost burden for low-income residents. This puts an unnecessary burden on residents for a much-needed service, which could be produced in much better ways to reduce costs. Along with this, the air quality is among the worst in the county, and many residents are without sufficient transportation options.

Having a lack of availability or an unsafe route to access transportation has many residents being isolated and disconnected from prosperous opportunities. In a study conducted by the city of Pittsburg they estimated with their aging workforce they will need to fill over eighty thousand jobs by 2025, which means the infrastructure to support those jobs must be present. This resulted in the city of Pittsburg purposing to the Smart city challenge their SmartPGH initiative which has eight projects to support the U.S Department of Transportation goals and their own goals [29, P.2].

Just like many other smart city development projects the city of Pittsburgh understands that through a private public partnership they can produce positive outcomes for the region. The city has identified seven partnerships with vendors and fellow entities that can assist with technologies for safe and effective transportation, energy infrastructure, a state-of-the-art transportation learning environment, the supporting of higher education, and an open and transparent governing agency. These vendors also align themselves with the U.S Department of transportation smart city challenge goals, which allows the city to ensure they are following the projects guidelines.

One major vendor being used by the city is Autodesk, where city employees took a full day of training on the Autodesk platform to help them understand the benefits of using their product line in the development and simulations. Autodesk being the producer of various design and modeling programs including AutoCAD, supports a strong user base of over five million

users and provides valuable tools to speed up the development of projects [30]. In addition, the city of Pittsburgh has access to Impact Infrastructure and its integration with Autocase due to it being a Rockefeller 100 resilient city.

The Vulcan Foundation is also heavily involved with the city of Pittsburgh to assist in developments of decarbonization and electrification initiatives. These will assist Pittsburgh's air quality to ensure the city has a prosperous green economy. To help improve safety for drivers and pedestrians, Mobileye has donated detection devices to help increase the safety of transportation of goods and services. Due to pedestrian detection technology already being implemented on all the city busses, Pittsburgh is using Mobileye detection on heavy equipment vehicles, which helps with blind spot detection and pedestrian avoidance, as these vehicles have the potential to be the most dangerous.

Many of these trucks also travel to and from Pittsburgh from outside areas so the capability of Mobileye to work without any infrastructure hardware provides safety for the whole route. Additionally, the port authority of Allegheny County will equip their 726 buses with NXP DSRC sensors to provide transit optimization in all smart spine corridors. This allows the city to achieve vehicle to infrastructure communications for heightened mobility. Amazon Web Services is another partnership where they have been in collaboration with the city regarding the use of cloud hosting credits. The flexibility of AWS benefits the datasheets that the city is producing in various projects and is a viable hosting option for data generated by the streetlight sensors. The last private partnership is with Sidewalk Labs where they are focusing on the mobility data analytics center to support application development which in return helps heighten mobility.

As for the final partnership for the city it includes a Memorandum of Understanding with the Department of Energy's National Energy Technology Laboratory (NETL) to assist in the expansion and deployment of district energy [29, P.53]. All of these partnerships provide valuable insight to a cooperation between the city of Pittsburgh and private companies to help achieve a smarter city. As time progresses the Pittsburgh metropolitan area will be a central hub of infrastructure information that sets a standard for other cities across the nation.

To develop connected infrastructure and enhance the feedback of data provided by infrastructure to the city, SmartPGH developed a project in order to convert 36,365 city streetlights to LEDs. Pittsburg has over 40,000 streetlights to maintain which are spread out over 2400 miles of roadways. Before the project started only 12% of those streetlights were LED's which allows for the conversion to have a major positive impact.

The ongoing conversion of these streetlights has and will provide increased safety and mobility, a large amount of energy savings, and sensory data to support other projects by the city. These new lights included integrated control systems with sensory technology including air quality monitoring and pedestrian detection which allow for other future smart city projects to learn about the cities environment and foot traffic to have a strong baseline to build from. When monitoring air quality, the goal is to monitor CO, CO2, NO2, SO2, O3, and PM 2.5 to detect hotspots and determine the effect that transportation infrastructure has on these measurements. For future projects these control systems can also serve as Wi-Fi hotspots, real time traffic counters, noise monitoring, dynamic advertising capabilities and gunshot detection units which all can help foster a smarter city. Based on initial calculations this project also resulted in an expected drop of 60% of annual energy costs which saves the city around 650,000 dollars. The other advantage of converting city streetlights to LED lights is that the system will require less

maintenance which the city estimates will lower maintenance costs by 780,000 dollars [29, P.17].

Another smart city project being funded by the city of Pittsburg is their autonomous shuttle network where the city is spending over eight million dollars into autonomous EV shuttles. Partnering with 11 different entities including the University of Pittsburgh, Carnegie Mellon University, the Urban Redevelopment Authority and many others, the city aims to demonstrate safe and convenient transportation via autonomous EV shuttles [29, P.18]. Carnegie Mellon, who is a primary partner of this project is generally considered the birthplace of autonomous vehicles based on their research in the 1980s. They also participated and won the DARPA Urban Grand Challenge, which is a popular autonomous vehicle competition, in 2007. Carnegie Mellon University has also worked with General Motors since 2000 where in that time they have received over twenty-five million research dollars, and they have received over fourteen million dollars from the USDOT's National University Transportation Center on Safety and the National Science Foundation's Cyber-Physical Systems program. This provided SmartPGH a high expertise partner which has been involved in the field since the beginning.

The route taken by the shuttle includes ALMONO, Hazelwood Ave and 2nd Ave, Carnegie Mellon University and Boundary St, 4 Mile Run and Boundary Street, and the Pittsburgh Technology Center. This route was chosen not only due to the population, the population characteristics, and its driving situations but also due to the hopes of linking the new and existing bus routes together. The current bus route has stops in Hazelwood and Oakland, which are two neighborhoods in the Pittsburg metropolitan area, and aims to connect the two neighborhoods and to allow residents the ability to access jobs. With the new route and busses the average commute time commuting from Hazelwood to Oakland via public transportation has

dropped by twenty-five minutes which takes the average trip time of forty-five minutes down to just twenty minutes.

While this route drops travel times for residents and provides public transportation that was once not there or not nearly as good, the most noticeable difference can be the time savings from ALMONO to Hazelwood to Oakland [29, P.21]. This new project can be attributed to a drop in seventy-five minutes of travel time along the route compared to the prior public transportation options. This project was welcomed with open arms by residents and had over two thousand unique riders during the weekdays during 2017 [29, P.22].

While cities in the past may strictly rely on feedback from residents and tourists about projects and various aspects of the city, to move a step in the next direction cities need to become smarter by collecting data to see quantifiable values. SmartPGH aims to do this by their deployment of projects creating vast new sets of data that can provide valuable insight into how the city of Pittsburg works on an underlying level. This publicly available data will be machine readable to align with the Smart City Challenge goal of collecting and distributing more data with the benefits of open data being seen in other public agencies, actively engaged citizens, businesses, and researchers.

This project provides a framework to recognize economies of scale, collective decision making, and four standards of interoperability in city wide data transmissions. These interoperability standards apply from a variety of data collection sources to the network, from the network to a storage location that organizes, anonymizes, and archives the data, and from storage to the public internet. The last interoperability standard is used for the development of public sector applications both for public accessible applications and governmental decision-making tools [29, P.24].

What helps make this possible is the Western Pennsylvania Regional Data Center (WPRDC), which is a data driven entity that is operated by the University of Pittsburgh and a world leader in open data. Being founded by the City of Pittsburgh and Allegheny County in 2015 they currently host over one hundred and twenty data sets and provide the ability for public and private entities to share and explore open data through their platform. Included in the one hundred and twenty data sets are transportation related data sets provided by several different consortium partners. Some of the transportation datasets include bicycle lane usage counts, paving schedules, scheduled closings, parking garages and lot capacity, parking garage real time usage, permit parking areas and schedules, real time bus locations, rideshare statistics, traffic counts, traffic models and outputs, recommended bike routes, and many more which all provide valuable insight as to a quantifiable measurement of the city. Besides their data sets being open to the public the Western Pennsylvania Regional Data Center provides support to users which includes but is not limited to technical assistance, special events, data user guides, data portal training, visualization tools and many others to ensure that the data is being used to its best ability [29, P.25].

These open data sets provide a newfound direction in the realm of smart cities by providing open-source data that will be accessible by all. This data will play a key part in the decision-making progress not only for city and state projects but also for private companies to have a better understanding of where and who to market their potential solutions too. With this comes cybersecurity concerns which will need to be addressed to prevent data being used in a harmful way. However, overall the open source data will be a net gain for its citizens by taking a step to achieving a smarter city by providing entities with the data they need to design a better and more targeted product.

When looking at the history of the city of Pittsburgh, power has always been a core element of their city. The city was the first with a drive through gas station which has currently set the standard for modern day society. Along with providing the first drive through gas station, Pittsburgh was one of the fossil fueled giants of the nation's industrial economy for multiple decades, which resulted in infrastructure to support the consumption and generation of massive amount of power. The city aims to repeat history by changing their infrastructure to support a cleaner and more resilient electric grid with more renewables to support EV charging infrastructure. To achieve this the city has signed a historical agreement with the United States Department of Energy, and the National Energy Technology Lab to research, develop, and deploy microgrids throughout the city while the University of Pittsburgh's Center for Energy will be evaluating and researching the microgrid system. For the electric avenue project, the city of Pittsburgh aims to charge into a fossil free future by reducing greenhouse gas admissions from transportation related sources by 50% by the year 2030.

To achieve this goal the city derived they need to implement dramatic changes in land use and development practices, the use of fossil fuels, traffic management, and other aspects of city lives. The electric avenue project is the first steppingstone in a much larger goal for the city of having a completely fossil fuel fleet by 2030. The Monongahela River Valley will be reinvented as the hub of 21st century smart city technology, through the creation of a clean energy transportation corridor. This corridor will run along Second Avenue ranging from the Downtown Business District, alongside the Pittsburgh Technology Center, to the Almono site in the underrepresented neighborhood Hazelwood [29, P.28]. To support this corridor the city is purchasing a new electric vehicle fleet which will be parked and charged at a city owned parking lot on second avenue that has solar canopies that are tied into a local microgrid. This allows the

grid to charge the vehicles along with the vehicles being capable of providing energy to the grid [29, P.29].

As for the implementation of this project the city has and will continue maintaining a five-year vehicle acquisition plan that prioritizes the retirement of high mileage and high emissions vehicles for retirement. Recently the city completed a three year, five-million-dollar, electric vehicle acquisition plan that started in 2017 where the city purchased one hundred and seven level two charging stations, fourteen electric SUVs, eighty-one electric sedans and ten electric motorcycles. The city councils fleet currently consists of twenty-four diesel trucks with biodiesel tanks, five heavy duty compressed natural gas trucks, and seven hybrids. To support their new corridor project, they will be installing twenty-five new level two charging stations on a DC microgrid which is powered by a 100-kW photovoltaic array and supported by a 900 kWh battery bank in their second avenue lot.

These stations will be available to the public during the day and then will be used to charge the cities fleets at night to ensure they are getting maximum usage. With usage from the public, Pittsburgh parking Authority will be able to generate revenue from both the parking and charging through the Go Mobile PGH app. They also provide the capability of providing some backup power in case the power grid goes down. To help integrate this project and reduce proprietary networks to monitor information SmartPGH is building and establishing an IPV6 based communications protocol with Duquesne Light to support the charging stations, smart meters, and led lighting [29, P.30]. Overall, this project provides a plan to move in the right direction of converting fossil fuel powered vehicles to electric or hybrid vehicles along with a strengthening of the power grid by diversity. By diversifying the power grid by developing

multiple microgrids Pittsburgh will be contributing to the study of more reliable power through the collaboration between federal government agencies and university researchers.

In the Mobility through technology project the city of Pittsburgh is expanding off of President Obama's Ladders of Opportunity agenda by addressing a need for better mobility. The city decided rather than taking the traditional route of funding projects related to public transportation and pedestrian projects related to bikes and walking, they chose to pursue three normally unaddressed services. In addition to improving mobility the city also aims to help health and human related outcomes. The first emphasis is to address mobility limitations for those with impairments. Secondly the city aims to enhance mobility for the homeless community, and third the city is looking to help those seeking preventative healthcare have better mobility. This helps address the U.S. Department of Transportation goals by providing mobility for all, including the underrepresented individuals with impairments, homeless individuals, and people needing healthcare.

To implement projects for individuals with impairments the city is implementing low energy Bluetooth beacons and transceivers in specific regions to make the physical environment aware of individuals capabilities and limitations. This information will be funneled through an easy-to-use smart phone app that allows users to create profiles about themselves. This design has many benefits including being modular by being able to expand to other sections of the city with relative ease and low overhead, and the last benefit being ease of access with smart phones being the primary method of interaction. As for projects related to mobility of homeless individuals the city has conducted research which has demonstrated over sixty percent of the homeless population has access to a smartphone, which provides a large technological advantage [29, P.31].

To use this advantage the city partnered with the Homeless Children's Foundation to design and develop a web-based application for smartphones and computers called BigBurgh, which provides geographically specified services for homeless individuals. To help advance this application the city is planning on eventually integrating the application in with their MovePGH app. For the final section of the project the city is aiming to increase transportation services to those needing transportation to healthcare. As it stands today lack of transportation is one of the largest factors in preventing people from getting the healthcare they need, and the lack of clear information on transportation services increases the number of missed appointments. To address this the city is partnering with the Allgeheny County Department of Human Services and Access, which will provide a two-step transportation model to ensure better attendance. This model allows for when an individual needs transportation to a healthcare related trip they will be assigned a transport coordinator which ensures they get provided a paratransit vehicle or are well informed of the existing services near them to get them to their destination [29, P.32].

Within the smart city challenge the city of Pittsburgh not only sees the opportunity to design and deploy state of the art transportation technologies, but also an opportunity to create new advanced jobs in Cybersecurity and advanced manufacturing. To achieve this the city came up with a multifaceted project for the smart city challenge aimed at workforce training. As for the details behind the workforce training program the city of Pittsburgh hopes to forge new pathways for individuals by providing technical and advanced workforce training solutions to connect employers to skilled employees. In the city of Pittsburgh currently ninety-five thousand workers are employed in various advanced fields, which when the Three Rivers Workforce Investment Board researched this, they determined it as a major opportunity sector for the city [29, P.33]. With a partnership of higher education institutions in the area, the city has three main

implementation steps. First, they are looking to develop both a cybersecurity certificate and an advanced manufacturing certificate with local higher education institutions. This will allow individuals to gain access to the training they need without traveling to a faraway location. Secondly, they will send out an RFP in cyber security and advanced manufacturing training to promote and improve existing programs, and third they will create advisory groups for Cybersecurity and advanced manufacturing to engage employers, monitor trends, and examine best practices for the betterment of the community [29, P.34].

As with many other projects receiving feedback from your userbase is vital in understanding the successes of projects along with their shortcomings. Pittsburgh aims to do this with their SmartPGH Community Census project where they are collaborating with Jackson/Clark partners to gather quantitative and qualitative data to measure the performance of projects and to provide valuable insights to other cities on how to replicate projects while also improving on them. When collecting information, the community input gathered will include a statistically valid random sample group that conforms with the key University Center for Social and Urban Research (UCSUR) regional quality of life survey indicators and the census methodology. This will enhance the cities system engineering approach and will allow for the use of a new approach of sustainable returns on investments to evaluate, monetize, and prioritize the environment and social changes to ensure the putting of people first along with a smarter community design.

Overall this project is the backbone to determining the affect these projects have on residents of the city and to ensure that all are being represented equally.

As for the city of Pittsburgh there is many multifaceted projects that will be beneficial for all parties involved ranging from the average resident of the city to any governing body that is in a

position of power to fund projects for the betterment of the community such as a department of transportation. This can be extrapolated out with the added private vendor partnerships and added higher education institutions to create a more thorough and targeted projects along with active research into the success of those projects.

4.2.4 United States Department of transportation Security Credential Management System

With an ever-increasing number of devices connecting to localized networks, cyber security is becoming an important aspect for any agency including cities, states, and transportation departments. Some of these devices include Dedicated Short-Range Communication (DSRC) devices that can be found in infrastructure and vehicles to allow for Vehicle to Vehicle (V2V) communication and Vehicle to infrastructure (V2I) communication. Both of which are being adopted by transportation departments across the United States to enhance the safety, mobility, and intelligence of roadways and intersections. This creates a need for a secure communications protocol to allow the exchange of data between devices to ensure safety, security, and privacy protection. The resulting system developed by the U.S department of transportation, automotive manufacturers, and security experts is known as the Security Credential Management System (SCMS) [31].

The Security Credential Management System (SCMS) is a proof of concept (POC) message security system that allows for the secure communication of Vehicles to Vehicle (V2V) and Vehicle to Infrastructure (V2I). It uses a highly innovative and unique Public Key Infrastructure (PKI) approach to ensure proper encryption of data and certificate management which allows for secure transmission of data between devices. It works by allowing authorized system participants having digital certificates issued by the system to validate and authenticate messages sent by vehicles and infrastructure to ensure safety and mobility. These certificates

contain no personal information or equipment identifying information to protect the privacy of vehicle owners. They also serve as system credentials to ensure that both parties can be trusted, along with actively manages devices by removing misbehaving devices, which allows for the content of messages to be accurate, all while maintaining privacy. This project has security benefits by ensuring integrity so users can trust that messages sent back and forth have not been modified, ensuring authenticity so users can ensure the messages they are receiving originate from a legitimate and trustworthy source, and ensuring privacy so users can be reassured their messages are anonymous and contain no personal data [32]. There is also a financial and logistical benefit of helping to achieve interoperability by allowing various makes and models of vehicles to communicate without pre-existing agreements or the altering of vehicle designs. This allows for an easy user experience with no vendor lock-ins along with setting a standard protocol to ensure proper confidentiality, integrity, and accessibility [31].

Being a state-of-the-art project by the U.S. Department of Transportation, the project is being divided up into various sections for research to be able to be further developed and advanced. Some research currently being funded includes operations of the SCMS, National SCMS development, misbehavior detection development and implementation, government management of the SCMS, and the technical management of the SCMS. Moving forward the U.S Department of Transportation plans to integrate SCMS with other projects such as smart cities, a connected vehicle pilot program and others to ensure messages are being delivered securely, have accurate information, and contain accurate non identifiable information while avoiding vendor lock ins. In September of 2017 was the first application of the SCMS system where the SCMS Operational Environment was able to coincide with the full-scale deployment of devices in the Connected Vehicles Pilot Series. This project included over forty-five million

dollars in funding to New York City, Wyoming, and Tampa Florida to provide an evaluation of the system and technologies involved [33].

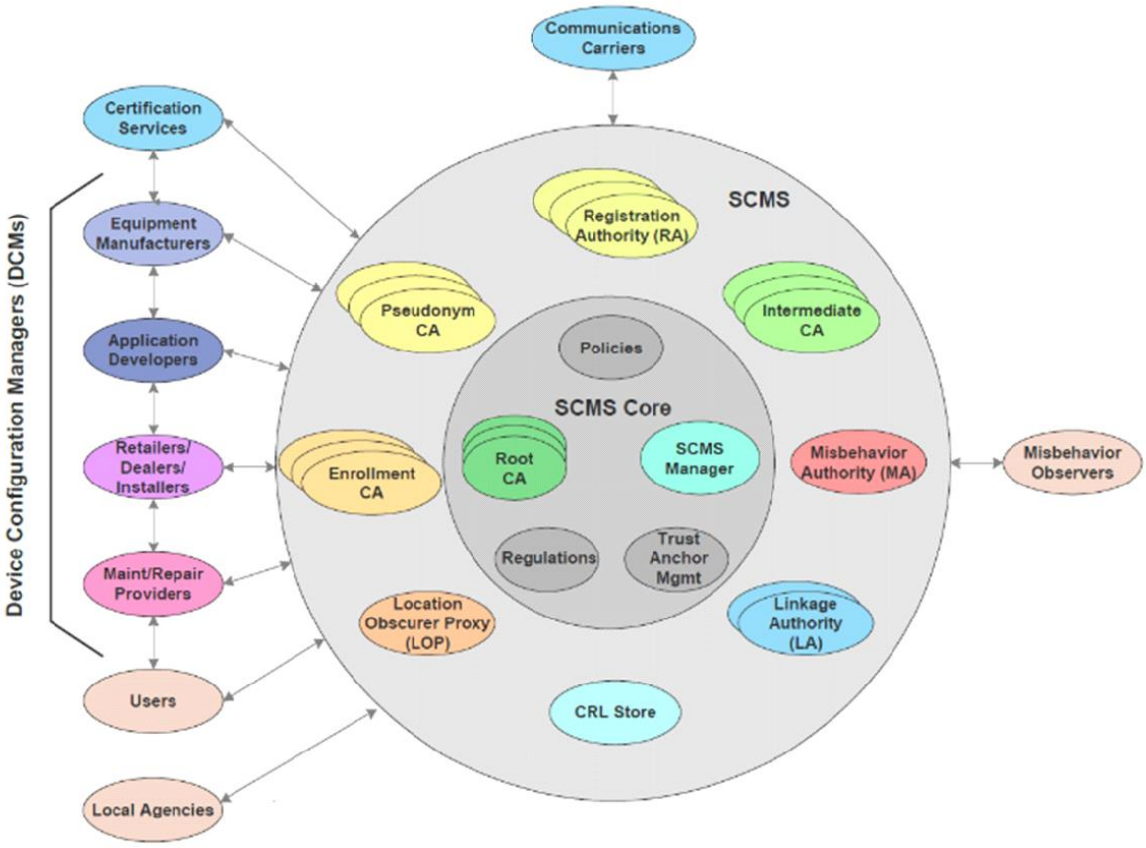

Figure 9: National Security Credential Management System (SCMS) Deployment [31]

Overall, the project is setting a standard for cybersecurity of dedicated short range communication devices in the transportation and automotive industries. With the SCMS project, other advance projects around the world for transportation agencies, cities, and researchers will be possible by the ability to establish an industry standard for Vehicle to Vehicle and Vehicle to infrastructure communications that allows for the secure transmission of accurate data. This project provides a much-needed security protocol to establish secure messaging between entities such as vehicles and infrastructure which will play a pivotal role in the development of a smarter

city. Without the establishment of a secure protocol the valuable information gathered from vehicles and infrastructure would never have the capability of performing dynamic controls to make a city smarter for the benefit of all.

Overall, the documentation and evaluation of smart city development projects funded by the U.S Department of Transportation allows for a layer of transparency not found in the private sector. This transparency allows the public to offer feedback, understand what is happening behind the scenes and determine where their taxes are going. It also can be allowed for rural areas with less funding than their larger counterparts to adopt, learn from, and contribute to flagship projects by large metropolitan areas.

CHAPTER 5 VENDORS AND THEIR SOLUTIONS

Vendors and their potential solutions are essential in the development of smart cities, as they attempt to solve problems surrounding complex systems subjected to use by the public. This leads to a need for a high standard of reliability, security, and functionality at the lowest possible cost and complexity to the user. This leads to vendors and their solutions to be subject to a high level of scrutiny to ensure their products are sufficient for integration into a smart city development project.

5.1 Amazon Web services

As an increasing number of devices connect to the internet to become a part of the internet of things (IoT), there is an increased demand for hardware and software to deal with the data these devices are producing. With large urban areas such as cities like Portland, Pittsburgh, Columbus, and many others being vast in size and complex in nature, cloud services are becoming an increasingly popular choice to assist cities in their data collection data storage and data processing. Amazon Web Services, more commonly known just as AWS, is the worlds most adopted and all-inclusive cloud platform which allows its millions of users to access advanced services to help them become more innovative, lower their costs, develop large scale projects faster and many other states of the art features.

AWS states on their homepage that they have the largest number of available services and features than any other cloud provider by a large margin [34]. These features could be proven to be invaluable to Transportation agencies and governing bodies as they provide readily available proven solutions that have vast documentation and trainings available to individuals. Some current notable users of AWS include Netflix which spends over nineteen million, twitch

at fifteen million, LinkedIn at thirteen million, and many others ranging from free tiers of pricing to budgets in the millions [35].

In terms of comprehensiveness Amazon Web Services could be considered an all-inclusive cloud and software vendor for any size project. This cannot be true of many other vendors who focus on one niche area, so Amazon Web Services is extensively comprehensive. Having over 200 fully featured services, all cloud and software aspects of a smart city could be controlled and integrated into AWS. This provides value with having an single area where agencies can perform all their cloud actions rather than performing on separate platforms. Additionally, if in their vast number of services, they don't offer a needed feature, they also include 3rd party solutions that are preconfigured to integrate seamlessly with their services in the AWS Marketplace.

The cloud services provided by AWS are vast and comprehensive which allow for endless flexibility to support smart city development projects. Some of these notable features that would be helpful in a smart city environment include autonomous systems which use artificial intelligence and machine learning, along with data collection and data processing.

In the realm of autonomous systems artificial intelligence and machine learning provide advanced capabilities for these systems that can be intricate parts of a smart city. For services involving AI and machine learning AWS has many solutions including SageMaker, the Alexa Skills Kit, Lex, Polly, Transcribe, Rekognition, and training for each one in their Skills Kit. These could provide valuable services to transportation departments with projects of any size and of any discipline. SageMaker is a cloud-based service that allows the training, deployment, and management of machine learning models [36].

This service could be beneficial for a smart city development project to apply machine learning to traffic signal timings, to increase the speed and safety of goods, services, and resident's commutes. This could especially prove helpful for morning and evening rush hour traffic when certain routes will be overly populated, as it could manage the timing of traffic signals. The Alexa Skills Kit is used for the development of intelligent bots that can connect to interact with users using texting, Skype, Slack, Teams, Twitter, and many other popular services [37]. While intelligent interacting bots could fill a variety of positions, one of which doing what they are doing currently in being virtual home assistants, they could be revamped to step up to a bigger role and start to perform administrative and logistical duties for governing bodies. This would allow mass communication throughout the city in case of natural disasters, traffic jams, and other things of significance. This would also lead to an increase of efficiency as well as an opportunity for transportation agencies to inform residents of upcoming road closures and detours.

As for AWS services Lex, Polly and Transcribe, they all perform speech to text and text to speech actions, but each contribute their own unique attributes. Polly is unique by using deep learning to turn text into life like speech, where there is added emotion and feeling embedded into the conversation. This is capable of being done in numerous different languages with both female and male preconfigured voices. A company also has the capability to add their own voice to the service to increase customization [38]. This could be helpful for automated services to have more emotions and express them in a variety of languages, which in return will help with users gaining trust and experience with autonomous systems. For the governing body it would help automate systems to reduce the cost of running city services while keeping a human-like feeling.

Additionally having a more human like feeling communications agent would allow for residents of a city to call in to check development statuses of projects to help cut costs of traditional employees. Transcribe is specifically designed for high accuracy automatic speech recognition (ASR) that is fast enough for live phone calls. Amazon states it can be used for generating metadata for media assets to create a searchable archive, automating subtitling, and transcribing customer service calls. In addition, there is Amazon Transcribe Medical which allows accurate and fast medical speech to text capabilities [39]. This could be used to help automate a variety of services such as bill payments for residents, and automated Teladoc technologies to help those that are in non-emergency situations. This would reduce the amount of traffic for residents while keeping the same functionality as an actual person.

In addition, this could help a governing body and department of transportation agencies keep records of automated calls for record keeping purposes, and to run machine learning algorithms on the data to better help its citizens. Where Lex stands out is the additional ability to understand intents and the context of conversations along with the automation of simple tasks in a variety of languages [40]. This would allow automated systems to be able to perform tasks rather than just understanding such as scheduling appointments, prescribing medications, and other various simple tasks. As on par with the other autonomous services, transportation departments could use these to increase transparency, reduce traffic, better time signals, achieve heightened safety, and less traffic for day-to-day residents. All of these are programmable through the Skills Kit that amazon offers through a self-service Application Programming Interface (API) which allows for advancement of skills for the system or customization for developers depending on the application.

There is also a design guide which helps users develop applications that suite their needs by laying out the best practices and the building blocks needed to implement each system. Both organizations and individuals are capable of publishing skills, for added functionality of these services, which allow for other users or organizations to use and add onto existing skills to fit their desired application [37]. This flexibility would allow the United States Department of Transportation to be able to define a standard for all cities to follow to achieve communications between agencies and provide a high level of security, reliability, and resilience. All of these services can contribute to a smarter city that benefits residents, governing bodies including transportation agencies, and tourists by aligning with and helping achieve the U.S. Department of Transportation's goals.

As for the processing, sorting, interconnecting, and storage of big data, AWS has many solutions that could be helpful in the development of smart city development projects. The services provided by AWS include Redshift, Lake Formation, Timestream, EMR, and Dynamo DB. Redshift allows organizations to quickly analyze data with the most widely used cloud data warehouse all while using standard SQL to run queries and the option to deploy machine learning models. It can be used with all data types in an organizations data warehouse, operational warehouse, and data lake [41]. This would allow transportation departments the ability to improve machine learning models by the capability of analyzing different types of data with according to Amazon three times better price performance than competitors and ten times the speed with Amazons Advanced Query Accelerator (AQUA). Alongside increased performance, redshift allows for the sharing of live data both inside and outside your organization to help with transparency.

A noticeable customer of this service is Nasdaq which scales over 70 billion records per day, which is comparable to a large transportation departments data records. Lake Formation is a service that allows for the creation of a secure data lake in a short amount of time. A data lake is a data storage repository that is centralized, curated, and secure. This allows for the combination of different types of data that are either modified or unmodified for analysis [42] Data lakes could provide valuable data storage options for various sensors and measurement equipment data after going through processing needed in a smart city. Having a centralized hub such as a SCADA system writing to a data lake after processing and scaling the data would allow all data collected to be stored in a centralized place which would decrease complexity and overhead. Another option for smart city development projects to use for sensor data includes Amazons Timestream which is a fast, scalable and serverless time series database. This is a unique service as according to Amazon it allows for trillions of events to take place per day at a tenth of the cost of a relational database with the capability of performing a thousand times faster.

To help lower these costs Timestamp lets you choose a threshold of when collected data can be transferred to a cost optimized storage option rather than timestamp itself all while allowing querying of all collected data through one API. There is also no need for the management of the infrastructure of the software as this is automatically programmed in to scale up or down depending on the applications needs [43]. This application would be a great option for transportation agencies or governing bodies who are integrating smart city projects focused on data collection and data processing to make decisions as it is flexible, fast, affordable, and extremely capable.

Amazon EMR is another tool that would be beneficial for smart city development projects due to it being a big data platform that can run large scale distributed data processing

jobs. It has capabilities of performing petabyte scale data analytics at a low cost, ease of integration, customizability by supporting open-source frameworks, and support for machine learning [44]. These features allow it to be able to run what-if analysis on data using statistical algorithms that can help discover hidden patterns in data. This feature could be a baseline as to what projects should have priority in a city by discovering newfound patterns of how the city works on an underlying level and how to address those current problems with the newly provided insights.

Lastly Amazon DynamoDB is a fast and flexible NoSQL database service that provides single digit millisecond performance with 25GB of free storage and 200 million read and write requests per month. Just like Amazons EMR service DynamoDB also scales up and down based upon your needs to help lower costs. In addition to lower costs and extremely fast speeds DynamoDB also offers built in security, data exporting tools, in-memory caching, continuous backups, and automated multi-region replication. Some notable customers include Dropbox, Disney, Snapchat, zoom video communications and many others [45]. This service provided by AWS could provide valuable features to smart city projects looking to perform data storage and queries on large complex data sets that would be accumulated with a city.

While autonomous systems and databases only scratch the surface of Amazon Web Services available products, they provide valuable insights as to what functionality these services have that could be essential to the backbone of a smart city. The comprehensiveness of AWS is vast for cloud services which could prove vital to developing a backbone of a smarter city.
As for total cost Amazon Web Services has flexible pricing which includes a free option for over 100 different services including artificial intelligence, machine learning, cloud computing, cloud database development, web applications, IoT applications, intelligent threat services, community

engagement services, and many others [34]. This allows for smaller rural communities to entertain free options without the overhead of committing to a major platform. In addition to a free tier their services also have a pay for only what you need model by having users pay as they go rather than paying a lump sum every month and not using all their features. This allows cities to automatically accommodate for tourists, weather, and other events that may impact the amount of use certain services receive. With entities such as Netflix, Zoom, Snapchat and others using AWS for their services, AWS has a strong user base and a proven track record to ensure confidence and help deliver a low-priced quality product.

In regard to their vendor expertise and smart city focus Amazon Web Services is one of the strongest candidates. They have a large user base which includes both private and public entities which has allowed them to expand their expertise as with more clients more services are needed. They currently have over seventy-five hundred government agencies using their government focused cloud services [46]. They can do this by their vendor expertise and understanding that for governing bodies there needs to be high cybersecurity, compliance with regulations, and reliability in services. There are also four levels of confidentiality with their government branch including unclassified, sensitive, secret, and top secret to add to their expertise and smart city focus. With four levels of security there is also a breakdown of where these services will be used including the intelligence community, the defense community, the federal government, and state and local governments. This breakdown allows for a smarter focus at the target client which could range from a large metropolitan area such as Columbus Ohio to more rural communities just starting cloud service projects.

Realizing how important openness and integration with other companies is, Amazon Web Services has a full marketplace of automatically configured third party applications that are easy

to deploy and integrate with their systems [47]. AWS's marketplace includes over sixteen hundred independent software vendors, with over ten thousand potential products that are preconfigured for seamless integration. This large selection ensures that their platform is easier to integrate along with providing an openness platform to integrate with other vendors. In addition to the marketplace Amazon Web services also has breakdowns for specific governing bodies on how to integrate their services into their specific application. The API's used by AWS also provide the functionalities of building a specific application on top of AWS's systems to ensure your application or project suites the governing body's needs.

Overall Amazon Web Services is a large provider of cloud related services which can assist governing bodies in the design, development, implementation, and maintenance of their projects that involve the cloud. These services can help achieve a smarter city for the betterment of all. Their flexible pricing along with their large number of supported applications that help with ease of integration provide an excellent cloud service for any sized project including those with no budget.

5.2 ParkMobile

While parking may not be an initial thought when thinking of smart cities, a shortage of parking spots in areas that are having rapid urbanization are presenting the need for a smarter approach to parking. This is where ParkMobile excels and provides a solution that is easy to integrate, has low overhead, and has strong examples of where their product has helped. Used in the Event Parking Management Project for the city of Columbus Ohio, the ParkMobile Parking Application allows for cities that are facing parking problems from rapid urbanization or large venues to be able to help residents and tourists be capable of finding and paying for parking which helps limit congestion, heightens mobility, helps limit carbon emissions, and a variety of

other positive factors for residents, tourists, and governing bodies. It has parking in over 557 venues in 42 states, which helps allow states, cities and private entities simplify the process of paying for and reserving parking [48]. It is capable of servicing millions of individuals by removing kiosks and meters for simplicity and allowing all transactions to take place via a mobile phone application.

To help governing bodies understand the companies' values, they have 8 core company values which include providing a great customer experience, acting with integrity, paying attention to the small details, an ease of integration, a strong team dynamic, and supporting of the community [9]. After implementing the park mobile application towns and cities have benefited from a 31% increase in parking payments, event venues have seen a 90% increase in pre-paid parking, parking garages have seen an average drop of 50% in staffing costs, colleges are capable of having smart class scheduling as many average over a student per parking space with numbers as high as 17.2 students per spot, and airports can make parking revenue with minimal effort, which accounts for on average 41% of their non-aeronautical revenue [48].
As for the comprehensiveness, ParkMobile may have a narrow scope in terms of looking at a city as a whole, however what they lack in scope they make up with an all-inclusive product centered around addressing parking.

ParkMobile not only can service both high and low traffic areas, but they also have the capability to handle parking as a whole for a city. They offer solutions to handle zone parking, payments, reservations, white labeling, event reservations, parking help, reporting, parking availability, integrations, and policy management for towns, cities, event venues, private garages, college campuses, airports, and other entities contained within a city. This provides a

comprehensive centralized solution for governing bodies through a private public partnership which benefits the governing body, private organization, residents, and tourists.

As with many services provided by vendors the cost is not always readily available knowledge due to various complexities in the systems. This is no different for cities looking to get ParkMobile established for their parking services. However, what can be found is the transaction fee put on the user side by ParkMobile. According to the City of Sacramento the cost to the user is approximately thirty-five cents per transaction, with this sometimes being waived depending on the location [49].

In order to extrapolate this out to a yearly cost for an individual working in a busy area, we take the number of working days in 2021, which was 249, and multiply that by thirty-five cents per day to get a total of eighty-seven dollars and fifteen cents for fees charged by ParkMobile for one individual. Overall, the projects costs are inconclusive due to a lack of information available without a consultation.

As for ParkMobile they are experts in the area of implementation of smart parking. With over 557 venues ranging from cities to private entities choosing to use the service they provide, they have developed and expanded their expertise in the field. To help ensure that cities can provide services in a smart fashion, they have a focus on a minimal hardware-based approach where they allow the option of all transactions to take place via a mobile application. This cuts down on human intervention and allows the city to focus their efforts elsewhere. Overall ParkMobile are experts when dealing with smart parking due to their prior experiences of their product being successfully mass adopted throughout the United States, core values that help align it with the U.S Department of Transportation’s goals, and the capability to provide a product that is easy to integrate, easy to use, and helpful for cities to manage parking.

For the criteria of openness and integration of the ParkMobile application, there are many benefits to this system. One beneficial aspect for ParkMobile is the option of having little to no physical hardware, such as kiosks or meters, for each application. It provides the options of having all transactions take place through a mobile application, or a custom combination of the mobile application and kiosks is possible to fit each individual applications needs. This allows for a lower cost to implement and maintain, a faster adoption of the service, and ease of expansion. The company also supports a core value of being a team player by understanding that they are only a small portion of the solution so they must be capable of integrating easily with other vendors and the customer to help support openness.

Between strong core values, a large existing user base with numerous success stories, and an easy to use and integrate product, ParkMobile is a leader in the domain of smart parking. This private company highlights how a partnership between public and private entities can provide services to a society while maintaining a standard that aligns with various governing bodies goals. Overall, the ParkMobile application provides a smart solution to parking in areas where parking is hard to come by for both residents and tourists.

5.3 AbleLink

Being founded in 1997 AbleLink Smart Living Technologies aims to help address the need for cognitive support technologies founded in research for individuals suffering from cognitive decline and cognitive disabilities. They employ a diverse multi-faceted team consisting of members in the disciplines of human services, clinical psychology, experimental psychology, human factors, rehab technologies, software engineering, and occupational therapy. With this diversity they have done over eighty research and development projects to research, investigate,

and develop technological applications for seniors utilizing technology and individuals with cognitive disabilities. These projects assist individuals in their daily lives and provide services and solutions to individuals who would normally be fully reliant on a caregiver or a governing body for.

They have ongoing collaborations with the Beach Center of Disability at the University of Kansas, the Joseph P Kennedy Jr. Foundation, the National Institute of Disability and Rehabilitation Research, the National Institute of Aging, and the Westchester Institute for human development. Along with their current work, their prior work has also been published in numerous peer-reviewed journals such as the Intellectual and Developed Disability, Journal of Special Education Technology, Journal of Developmental and Physical Disabilities, and many others [50]. Their life changing smart solutions help align them with the U.S. Department of Transportation goals by providing safe, reliable, and effective mobility for all. Used in the cognitive disability project for the smart city of Columbus, the AbleLink WayFinder application provides an example of a private public partnership which can be used to help individuals that are underrepresented achieve a sense of self mobility and independence which at one point was not possible.

While AbleLink doesn't provide as many commonly derived smart city solutions as other vendors, they do provide a comprehensive series of products that allow individuals with cognitive disabilities a large amount of fully functional services. These services provide a lifestyle that allows individuals to perform daily tasks independently and have a newfound sense of normality. These solutions include WayFinder, Smart Living Mobile Suite, ATLAS, and Smart Living Desktop Suite. Used in the city of Columbus, the WayFinder application is a solution which aims to unlock independent travel for individuals with cognitive disabilities. By

using GPS the WayFinder application is capable of guiding travelers independently with bus and foot navigation [51]. Overall AbleLink may be small in terms of overall scope, however their products help underrepresented individuals achieve a sense of normality and independence. These achievements align with the U.S. Department of Transportation goals and can provide essential services in a smart city.

As for total cost, there is not a large amount of publicly available information as AbleLink is a diverse company that has dynamic services, however when looking at the apple store online the AbleLink WayFinder phone application and similar applications are sold at one hundred and fifty U.S. dollars [52]. While this number may initially seem high, the application offers a newfound sense of independence and freedom to individuals in need.
AbleLink may not have as much of a direct smart city focus as other vendors, they do provide a smarter city for their target audience. However, integration into publicly funded transportation services such as public transportation to inform their users does provide a baseline for smart city development projects. What they lack in terms of smart city focus they make up for in terms of expertise when dealing with projects involving individuals with cognitive disabilities. With a large amount of research conducted by the company, along with their current projects they provide a strong product to those in need.

In terms of integration their products are easily to integrate into existing cities and future projects as they are dependent on those projects to be able to get their projects working and out to their target audience. Many times, as long as individuals have access to a cellular device, they are capable of accessing projects by AbleLink.

With the U.S Department of Transportation's goals of being capable of providing mobility for all, Able Link is a company that provides valuable solutions for underrepresented

individuals who normally would have limited transportation options. In addition to providing much needed transportation to people with cognitive disabilities, they also provide the ability for these individuals to gain a newfound sense of independence by having easy to access and reliable transportation. A public private partnership between governing bodies and able link provides invaluable solutions to residents and tourists who may have never been able to independently travel without these solutions.

With many vendors developing more solutions in the smart city domain, the importance of understanding their services along with the evaluation of those services are vital to a functional smart city. Transportation agencies, city officials, and other individuals or organizations in charge will need to be able to soft through large amounts of information to understand which vendors and their solutions will work for them.

CHAPTER 6 RESULTS OF FINDINGS

6.1 Introduction to Results

The results of these flagship smart city projects help establish a basis for new projects and standard to be developed. Each project and vendor will be evaluated against the aforementioned criteria to get comparable results.

6.2 Smart City Projects Funded through Public-Private Partnership

Table 1 Summary Results - Smart City Projects Funded through Public-Private Partnership

Criteria	**Project: Toyota Woven City**	**Project: Urbanova Connected Streetlights**
Integration/ Interoperability	-No integration into existing infrastructure -Starting from scratch	-Large amount of integration and collaboration including Avista, Itron, Washington State University, and the City of Spokane. -Integrating smart functionalities into existing lighting infrastructure.
Functionality	-Full blown city -Fully underground utilities -Self-driving vehicles -Autonomous package delivering -Green energy -Home artificial intelligence systems	-Limited to light controls and air quality monitoring
Usability	-Usable by all to test and learn. -Active monitoring to ensure users are comfortable with systems. -Professional mental health monitoring to ensure AI systems aren't overwhelming.	-Usable by city of Spokane. -Average citizens have no control over system.
Security	-Large security concerns due to large number of features. -More personable data. Controls based upon user input need added security. -Fully Autonomous vehicles add to security concerns.	-Generic data. -Only controlling lights.

6.3 Smart City Projects Funded through USDOT

Table 2 Summary Results - Smart City Projects Funded through USDOT

Projects Criteria	City of Columbus Ohio	City of Pittsburgh Pennsylvania	City of Portland Oregon
Functionality	-Urban automation via connected electrical autonomous vehicles. Use of autonomous electric vehicles for public transportation in low-income neighborhoods -Prenatal trip assistance to lower infante mortality rates in low income neighborhoods -Multimodal trip planning application to centralize transportation methods -Connected vehicle environment for V2I and V2V capabilities. -Smart Parking -Assistance for individuals with cognitive disabilities -Smart Columbus Operating System for managing the city	-Large LED street light program for smart lighting and air quality monitoring -Autonomous EV shuttles connecting residents to jobs -Generation of large data sets for quantifiable feedback -Installing new EV charges -Replace city vehicles with EVs -Focused mobility enhancements on access to healthcare -Create workforce training in cybersecurity and advanced manufacturing -Data driven community feedback	-Citywide data collection and sharing application that highlights available transportation services -Open data cloud project with fully documented and supported API for data sharing. -Increased public transportation for underrepresented individuals -Advanced work force training -Improved electrical infrastructure for electric vehicles -Improved mobility for those that are disabled
Integration/ Openness	-Open-source operating system for high openness -Integration into existing infrastructure -Partner with vendors and local colleges	-Open-source data sets -Integration into existing infrastructure -Partner with vendors and local colleges	-Open-source data sets -Partnership with vendors for solutions -Integration into existing infrastructure
Usability/ Capabilities	-Transportation for all, including individuals in low-income neighborhoods and those with cognitive disabilities -Single navigation-based application -Reserve, find, and pay for parking -Safer school zones for drivers and pedestrians	- Data sets to be used by all -EV chargers available to residents during the day -Better transportation to healthcare -Offer feedback via application	-Improved public transportation for all. -Data collection, storage, and analysis. -API available to all
Security	-No mention of any security built into the system -Fully dedicated city operating system is a primary attack target	-Open-source data sets help reduce security concerns -Integration into infrastructure which deems for increased security	-Anonymous data -API security necessary

6.4 Result of vendor evaluations

Table 3 IoT Vendor Solutions Evaluation Results

Vendor Criteria	**Amazon Webservices**	**Park Mobile**	**AbleLink**
Comprehensiveness	-Most comprehensive vendor evaluated -Hundreds of amazons and 3rd party services	-Simple and niche market	- Simple product with a narrow use case
Total Costs	-Pay as you use plan -Minimal to no new infrastructure needed	-Low overhead as there is minimal infrastructure -Cost passed on to consumer	- Low initial cost -Cost passed on to consumer
Expertise and smart city focus	-Specific smart city and government branches -Large amount of expertise in house	-Highly smart city focused -Parking experts	-Not specifically focused on smart cities -Expertise in cognitive disabilities
Openness and Integration Strategies	-Many ways to integrate into existing systems -Open to working with additional vendors	-Easy to integrate with web portal and mobile application -Open to work on multidiscipline projects	-Open to work on multidiscipline projects -No mention of integration capabilities

CHAPTER 7 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

7.1 Summary and Conclusions:

Throughout the breadth of this paper there have been three main sections dedicated to the evaluation of smart city projects using IoT devices. The first section was an evaluation of some private smart city projects which varied in their system architectures, implementation, and goals. Secondly this report looked at publicly funded smart city projects which were a part of the U.S Department of Transportation's Smart City Challenge. These projects provide a transparent view into how smart cities will be built in the future, by highlighting both mistakes and achievements. Lastly there was the evaluation of a small sample of vendors used by the projects. Each one of these vendors provided a different service which would be integrated into an overall smart city. Overall, each project and vendor evaluated a valuable baseline to build from for future smart city projects using IoT devices.

7.2 Recommendations

With all the information inside this report considered there are three recommendations this report aims to provide. The three main recommendations are an increase in cybersecurity education and implementation, heightened redundancy in systems, and better resilience. The first recommendations being that the cybersecurity of these systems should be of the utmost importance. When dealing with the controls of critical infrastructure that residents of cities count on, having the highest possible level of cybersecurity is vital. One such reason why security should be the main emphasis is that with critical infrastructure systems there is the potential of physically harming individuals. One such example would be the loss of power during the peak winter months could result in the deaths of individuals in colder areas. If these projects cannot be

proven to be secure, then proceeding with the projects provides a large target for attackers. With getting both private and public entities educated on cybersecurity there can be seamless deployments of safety critical projects with strong security.

Vendors need to also be held to a high standard of cybersecurity when looking at being integrated into a project. Commonly vendor specific devices are a target for attacks due to the lack of security built into the system. To compound on this, most vendor solutions lack the capability to do over the air updates, so it is up to the municipality or private purchaser to install security patches.

Secondly, adopting redundancy will allow these systems to suffer failures while still being capable of providing the services they are expected to perform. Between the private and public smart city projects covered in this report, none had mentioned redundancy being built into a system. Besides the increased reliability of using redundancy, it also allows safety critical systems to have maintenance performed while maintaining their services by having two or more systems in place. While vendors mostly deal with the manufacturing and technical support of their products, having built in redundancy in products would increase the reliability of their products.

Lastly there is a need for better resiliency to be built into these systems, as in the projects covered there was not much consideration given to what would happen when a system fails. Preplanning for a system to fail will allow for systems to have better reliability, by minimizing the effect a failed device has.

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