ACKNOWLEDGEMENTS

This technical report is a supporting document to the Virginia Avenue Smart Corridor Study, led by the Aerotropolis Atlanta Community Improvement Districts (AACIDs).

The funding for the overall study was provided by the Atlanta Regional Commission’s (ARC) Livable Communities Initiative (LCI) grant program with a local match provided by the AACIDs.

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1. OVERVIEW

1.1 Study Purpose

The purpose of the Virginia Avenue Smart Corridor Study, led by the Aerotropolis Atlanta Community Improvement Districts (AACIDs), is to evaluate emerging technology strategies that address safety, walkability, and mobility. The Virginia Avenue Smart Corridor spans 2 miles from U.S. 29/Main Street to South Central Avenue. As illustrated in Figure 1, it traverses the Cities of College Park, East Point, and Hapeville and is located just north of the Hartsfield-Jackson Atlanta International Airport.

Figure 1: Virginia Ave. Smart Corridor Study Limits
1.2 Context

The *Virginia Avenue Smart Corridor Study* consists of four stages, as illustrated in Figure 2. The study is currently in the second stage with this *Best Practices and Trends in Emerging Technologies Technical Report*. The *Existing Conditions & Needs Inventory Technical Report* was completed earlier in the second stage. Now that needs and opportunities have been developed, this targeted research scan was conducted to identify potential technology solutions. These technology strategies will then be evaluated and input into the project prioritization framework. Technology projects and/or strategies will be scored, ranked, and prioritized. An implementation plan will then be developed, along with the final report, that will include an action plan going forward, including a funding strategy. The entire study will be completed in September 2019.

**Figure 2: Four Stages of the VA Ave. Smart Corridor Study**

- **Final Recommendations**
  - Finalize recommendations; funding strategy; implementation and action plan

- **Preliminary Recommendations**
  - Finalize project prioritization framework; score, rank and prioritize projects

- **Existing Conditions & Needs Assessment**
  - Existing conditions; needs and opportunities; best practices

- **Project Initiation**
  - Data collection; update project prioritization framework; initial project types
This *Best Practices and Trends in Emerging Technologies Technical Report* includes the following:

- An overview of communication concepts and technologies required for the various strategies to be implemented;

- Menu of technology strategies, including a brief description of the strategy, benefits, where it has been implemented, if applicable, any lessons learned, relative cost, and ease of implementation; and

- Conclusions related to which strategies are recommended to proceed further with evaluating as part of the preliminary recommendations.
2. TELECOMMUNICATIONS AND INTEROPERABILITY

Prior to elaborating on various technology applications that could be considered along the Virginia Avenue Smart Corridor, we must first explain the various communication concepts and technologies that serve as the backbone of technology implementation. Without the appropriate communications, the technology applications simply will not work.

Given the number of industry terms used throughout this document, many of which may be new to the reader, definitions of each have been included in the margins for the reader’s convenience.

2.1 Vehicle Telecommunication Concepts

Figure 3 defines a variety of communication concepts, all of which fall under the umbrella of **Vehicle-to-Everything (V2X)**. V2X is where “everything” is anything relevant to the vehicle’s safe and efficient operation.

*Figure 3: Overview of V2X*

![Vehicle-to-Everything (V2X) Diagram]

1. **Vehicle-to-Vehicle (V2V)**
   - Exchange of data and messages between vehicles using wireless communications (Ex. emergency vehicle approaching).

2. **Vehicle-to-Infrastructure (V2I)**
   - Exchange of critical safety and operational data between vehicles and a roadside unit using wireless technology (Ex. traffic signal ahead turning red).

3. **Vehicle-to-Pedestrian (V2P)**
   - Wireless exchange of critical safety and operational data between vehicles and a pedestrian through their smartphones (Ex. pedestrian in walkway ahead).

4. **Vehicle-to-Network (V2N)**
   - Exchange of operational data between vehicles and the back-end/mangement center through the backhaul (wireless or fiber) network (Ex. traffic queue 3 miles ahead).

5. **Vehicle-to-Device (V2D)**
   - Exchange of information between a vehicle and any electronic device that may be connected to the vehicle itself.
V2X systems can convey important information to the driver in regards to dangerous activities of nearby vehicles (V2V, vehicle-to-vehicle), presence of pedestrians and cyclists crossing the road (V2P, vehicle-to-pedestrian), traffic signal ahead is about to change to red (V2I, vehicle-to-infrastructure), and inclement weather, nearby accidents and road conditions ahead (V2N, vehicle-to-network).

V2X communications types, as shown in Figure 4, consists of two components: 1) direct (time-critical safety) communications and 2) indirect or broadcast (non-time-critical) communications.

Direct communications consist of V2V, V2P, and V2I, with no network involvement that enables better handling of latency (time) sensitive safety services, such as collision avoidance, blind spot warning, and others. As illustrated in Figure 4, vehicles communicate directly (exchanging safety related messages) with each other (V2V), through On-Board Units (OBUs) mounted on the vehicles; with the infrastructure (V2I), through direct communications between the OBU and a Roadside Unit (RSU) typically located on signal mast arms, traffic signal poles and other locations along the roadway; and with pedestrians (V2P) via their smartphones. Specific technologies, such as Dedicated Short-Range Communications (DSRC) or Cellular Vehicle-to-Everything (C-V2X) have been or are being developed and tested to address these types of safety applications and needs.¹

Vehicles can also communicate indirectly with the network (V2N) or cloud to obtain more regional-based information. The broadcast component of V2X supports wide area communications, by leveraging the existing 4G-LTE (or near-future 5G) cellular network as well as satellite systems. Latency-tolerant communications, such as the notification that an accident occurred a few miles ahead, can be broadcasted by a V2X server located at a Smart Data Center and/or Traffic Management Center (TMC) to vehicles, pedestrians, and infrastructure. The vehicles, pedestrians, and infrastructure send

2.2 Telecommunication Technologies

Various communication technologies as mentioned earlier are available and ready to support the Virginia Avenue Smart Corridor as described below.

2.2.1 DSRC - Based V2X

What is it?

DSRC (Dedicated Short-Range Communications) is a wireless technology (variant of Wi-Fi) defined by the Institute of Electrical and Electronics Engineers (IEEE) 802.11p standard which is part of the Wireless LAN (WLAN) IEEE 802.11 family of standards referred to as WAVE (Wireless Access in Vehicular Environments). In the U.S., DSRC also relies on the IEEE 1609 suite of communications
middleware and security standards, and uses a data dictionary developed by SAE International (SAE J2735).²

DSRC can achieve a data rate ranging up to 27 Mbps³ in the 5.9GHz Intelligent Transportation Systems (ITS) spectrum with a range of about 1,000 ft. (0.2 miles), although range may be greater in roadside to vehicle communications environments.

DSRC, is an incumbent and mature technology conceptualized nearly two decades ago. It has undergone continuous development, extensive standardization, and field trials by many stakeholders.

What are the benefits?

It is a two-way wireless communication characterized by low data transfer latency (the amount of time it takes for data to travel from one point to another, i.e. delay), high data transmission rates (how much data can be sent per unit of time), and dependability in extreme weather conditions. All equipment on the roadside are connected by a local connection, such as Ethernet or other data transfer cables (with standardized external interfaces).

Where is it currently in place?

GDOT is actively building upon its current connected vehicle program to increase deployments within the Metro Atlanta area and throughout the state. They are in the process of deploying up to 1,700 Roadside Units (RSUs) utilizing DSRC communications to complement the RSUs already deployed.4

Figure 4: GDOT Deployment Plan

A few other cities and/or states moving forward with DSRC include:

- Tampa, FL (Tampa-Hillsborough Expressway Authority)
- New York city (NYC) DOT
- Wyoming DOT – I-80 Corridor
- Columbus, OH – Smart City Challenge

Are there any lessons learned?
Lessons learned to date include:

- Keeping stakeholders and the public informed;
- Working together with local agencies and stakeholders;
- Promoting interoperability and standards-based solutions; and
- Providing open-source CV applications and sharing data.

How much does it cost?
Roadside equipment, including the DSRC radio (RSU) and antenna, upgrades to traffic signal controller (as required), V2I Hub hardware and software, wiring, design, installation and integration, averages in from $2,500 to $8,000 per DSRC site.

Backhaul communications, which provides the connection between the DSRC site and the backend servers at the TMC or Smart Data Center, ranges from $4,000 to $48,000 per site for the corridor depending on existing services or infrastructure. Ongoing operations and maintenance costs for the corridor could be approximately $2,000 to $3,000 a year per intersection, depending on backhaul communications costs.5

How difficult is it to implement?
Vehicle-based equipment, including an OBU/DSRC radio, antenna, telematics control unit (TCU), sensors, displays, and wiring, is better off being installed by the automotive manufacturer or an automotive professional. Roadside equipment and software installation, configuration, and integration should be provided an experienced system contractor and integrator. Roadside-based equipment includes the RSU/DSRC radio and antenna, GPS, upgrades to the traffic signal controller, as required, for supporting SPaT messaging, V2I Hub hardware and software to support broadcasting of SPaT messages, as well as generating intersection geometry information (MAP data) and real-time GPS correction data.

5 SPaT Challenge Folio, National Operations Center of Excellence (NOCOE) partnered with AASHTO, ITSA, ITE & FHWA, 2019
https://transportationops.org/spatchallenge/resources
Is it interoperable?

DSRC communications is based on industry standards. Devices and applications based on these standards can communicate with each other exchanging basic safety and mobility messages and information. A standards-based system and open architecture solution should be installed to support interoperability.

2.2.2 Cellular C-V2X

What is it?

Cellular V2X (C-V2X) is like DSRC-based V2X, except it uses cellular technology. The “C” refers to both 4G LTE and 5G NR (new radio) releases of specifications, whereas X refers to multiple things’ vehicles may connect with. 5G-NR C-V2X is expected to achieve up to 5 Gbps with an expected range of over 1.2 miles, lower latency and provide more efficient use of the electromagnetic spectrum.²

C-V2X includes both network-based communications that have been in use for decades, such as vehicle-to-network (V2N), as well as direct communications using a ProSe Sidelink (PC5) interface, first defined in the 3rd Generation Partnership Project (3GPP) Release 14 specifications and approved in June 2017. This allows for direct communications between vehicles (V2V), as well as between vehicle and roadside infrastructure (V2I) without requiring any cellular network coverage or subscription. It can further support vehicle-to-pedestrian (V2P) by integrating the direct communications technology into mobile and other devices.

4GLTE V2X is the 3GPP nomenclature for direct communications as specified in releases 14 and 15, whereas 5G NR-V2X is from Release 16 (anticipated to be commercially available in vehicles in late 2020 to 2021) onward. V2N involves indirect

communications where a vehicle communicates with network infrastructure over licensed spectrum, whereas V2V/V2I/V2P is supported by direct communications that would operate in the ITS spectrum (e.g. 5.9GHz) and is known technically as PC5.7

Based on preliminary standards development efforts within SAE, PC5 will be integrated with the same communications middleware, security (IEEE 1609), and V2V application data as DSRC. Since PC5 reuses much of the V2X security and applications technology already developed by IEEE 1609 and SAE, it is being rapidly developed and like DSRC, it can be deployed without the presence of infrastructure.8

3GPP Release 14 C-V2X is a key step to the next generation of cellular technology. 5G-NR C-V2X is being developed with evolution in mind, with improvements and enhancements coming in new releases; implementation of the specifications supports backwards compatibility. This means that vehicles deployed now based on Release 14 will continue to operate with future vehicles that will leverage emerging 3GPP specifications, including Release 16.9

Between 2018 and 2022 it is expected that more than 125 million connected vehicles that use V2N are forecasted to ship globally.10 Because the C-V2X direct communications functionality is being included as part of new cellular chipsets that will be embedded into vehicles for V2N communications, newer vehicles will be able to benefit from the higher level of traffic safety enabled by supporting the direct communication.

8 Ibid
What are the benefits?

5G NR C-V2X is a rapidly emerging integrated communications technology that is expected to leverage and enhance current 4G-LTE C-V2X systems to facilitate the exchange of V2X messages between vehicles and between the infrastructure and vehicles (and/or pedestrians). The attractiveness of this emerging technology is that it is well suited for an evolution path to support more complex safety use cases with stringent delay, reliability and bandwidth requirements. Plus, it can leverage the proliferation of cellular devices throughout our communities and already built into many automobiles as part of on-board navigation systems.

Where is it currently in place?

The following locations have deployed C-V2X based networks:

- Colorado – CityNow Smart City initiative and RoadX smart road project (uses both C-V2X and DSRC);[^12]

[^12]: C-V2X Nets Its First US Deployment, CCS Insight, [https://www.ccsinsight.com/blog/c-v2x-nets-its-first-us-deployment/](https://www.ccsinsight.com/blog/c-v2x-nets-its-first-us-deployment/)
Las Vegas (uses both C-V2X and DSRC);\(^{13}\)
Washington DC, Michigan and California – pilot testing to compare C-V2X versus DSRC\(^ {14}\)
Asia – China in multiple locations. According to Deloitte, since 2015, China has deployed nearly 12 C-V2X sites for every one deployed in the U.S.\(^ {15}\)
Europe – Spain, France, Germany and the UK\(^ {16}\)

Are there any lessons learned?

- Solidify standards earlier in the process.
- Early sourcing of suppliers (roadside and radio equipment, RSUs, OBUs, etc.) to create a collaborative environment.
- Early real-life testing with infrastructure in place to verify end-to-end system/application performance including low and high (dense) vehicle volumes and security issues.
- Determine potential wireless interference sources and potential solutions to mitigate impacts early in the development process.
- Hire auto professionals to manage OBU installs.

How much does it cost?

Vehicle-based equipment including the OBU/C-V2X radio, antenna, etc. and roadside equipment including C-V2X radio


(RSU) and antenna, upgrades to traffic signal controller (as required), V2I Hub hardware and software, wiring, design, installation and integration costs is expected to cost on average higher than an equivalent DSRC site early on until the technology becomes more stable and mature. As 5G NR C-V2X continues to develop and begins to scale, the cost differential with DSRC will begin to narrow.  

Backhaul communications for 5G NR C-V2X should also essentially be the same as DSRC-based deployments.

How difficult is it to implement?

It is expected that the overall deployment effort for 5G NR C-V2X will be similar to DSRC deployments, with the exception that integration may be more involved early on until the C-V2X technology and equipment becomes more of a commodity product and fully tested.

Is it interoperable?

5G-NR C-V2X communications will be based on industry standards. Any devices or application that is based on these standards should be able to communicate with each other exchanging basic safety and mobility messages and information.

2.2.3 Satellite

Global Navigation Satellite System (GNSS) communications will play an important role in the connectivity and autonomy of intelligent cars with software updates and providing back-up communications capability through V2N applications. The challenge is to create a totally reliable and ubiquitous communication system that is both highly secure and economically viable.  

Vehicle functions that need less time-sensitive information can rely on satellites as a medium of communications due to the inherent

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18 Satellites to Provide Vital Link to Connected Cars, Mohamed Juwad, Spectrum Strategy, Intelsat, November 7, 2016, https://telecomworld.itu.int/blog/satellites-to-provide-vital-link-to-connected-cars/
attributes of satellite technology. For example, satellites can multicast updates to cars concerning road conditions ahead, local imaging of city streets and mapping of selected routes. Such information is necessary to enable the intelligent cars to “make decisions” autonomously as they move from place to place.

However, for time-sensitive functions, satellite is not a viable telecommunications solution. Since most technology strategies being evaluated along the Virginia Avenue Smart Corridor are indeed time sensitive, DSRC and/or cellular telecommunication solutions are recommended.

2.2.4 Industry Technology Debate

In January 2017, the National Highway Traffic Safety Administration (NHTSA) and United States Department of Transportation (U.S.DOT) released a notice of proposed rulemaking (titled Federal Motor Vehicle Safety Standard (FMVSS), No. 150) that would mandate all passenger vehicles to be equipped with V2V technology with a focus on DSRC. A phase-in period was to begin in 2021.

On November 1, 2017, the Associated Press (AP) reported that the Trump Administration no longer intends to proceed with the DSRC mandate while the FCC continued to drag out their study on sharing the spectrum.

Since the FCC set aside the 5.9GHz band over two decades ago for this purpose, Mercedes-Benz E-Class and GM’s Cadillac CTS were two of the first automobile manufacturers that equipped their new cars with DSRC technology. Other major automotive manufacturers including Nissan, Honda and Subaru are planning to implement DSRC technology on their new vehicles starting in

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2021. However, the Ford Motor Company announced in January of this year that their plans have changed, and they will start installing C-V2X, in all its cars, starting in 2022.21

While there continues to be a lot of pressure being put on the FCC to complete their study of the possibility of sharing the 5.9GHz band and mandate that DSRC to be deployed as originally called for, the 5G Automotive Association (“5GAA”) on November 21, 2018 requested that the Commission grant a waiver22 to allow for the deployment of C-V2X technology, in a 20MHz channel located in the upper edge of the 5.9GHz. band. The 5GAA is a rapidly growing global association consisting of many of the world’s major automotive companies (i.e., Ford, Audi, BMW, Volkswagen and others), as well as technology and telecommunications companies. They state that widespread implementation of C-V2X technology in the United States is not feasible today since the Commission’s current rules for the 5.9GHz band, adopted well before the development of C-V2X, restrict ITS operations to those that use the DSRC standard.

Since Ford’s announcement, Toyota came out and announced changes in April of this year that it will not deploy its V2X communications technology on vehicles in the U.S. in 2021 as previously planned. The company said in a statement that is reasoning to suspend the program is based on a “need for greater automotive industry commitment as well as federal government support to preserve the 5.9GHz spectrum band for DSRC. They also indicated that they will “continue to reevaluate the deployment environment” going forward.23

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2.3 Interoperability

DSRC (IEEE 802.11p) and C-V2X use different physical layers and medium access control protocols and are not interoperable. Both cannot simultaneously operate at the same time; co-exist on the same channels in the same geographic location since this would result in mutually harmful co-channel interference.

Possible solutions include:

- Consider using either DSRC or C-V2X communications (not both at the same time in same location) along Virginia Avenue; or
- Use both if a band sharing plan has been developed within the industry and FCC has opened up the band spectrum for both. This band sharing plan would need to allow for both to co-exist / share the 5.9GHz band by operating within different parts of the 5GHz band with some sort of mutual detect-and-vacate protocol to enable access to the remaining parts of the band.24

At some point in the future, the FCC will make a final decision on whether the use of the 5.9GHz band will be reserved for one technology use only (DSRC or C-V2X) or it will be shared with possible provisions indicated above.25 26

2.4 Development and Deployment Considerations

For now, given the uncertainty within the industry on which technology and solution will prevail, especially in the near future;

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increasing numbers have suggested that DSRC and 5G-NR C-V2X solutions would be complementary rather than competitive, offering multiple sensor inputs for different levels of tasks, addressing different use cases, and ultimately leading to a safer driving experience. There are some chip manufacturers starting to produce chips with both DSRC and C-V2X capabilities available so that one can select.

ABI Research\(^{27}\) estimates that in the initial years of deployment, C-V2X will cost more to deploy than DSRC. DSRC, being the longer established and incumbent technology, has cost advantages typically associated with multiple deployments in the field and with a competitive ecosystem.

Figure 7 provides a comparison of the technology candidates by communications scenarios and readiness, based on the current state of the technologies and on-line research conducted.\(^{28}\)

**Figure 6: V2X Technology Readiness**

<table>
<thead>
<tr>
<th></th>
<th>DSRC</th>
<th>Current C-V2X (4G LTE Cellular)</th>
<th>Current C-V2X (PC5)</th>
<th>Near Future C-V2X (5G and Beyond)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Time Critical Communications</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Time-Critical Safety Communications</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes(^4)</td>
</tr>
<tr>
<td>Standards Complete</td>
<td>Yes</td>
<td>Yes</td>
<td>Partial(^1)</td>
<td>In Progress(^3)</td>
</tr>
<tr>
<td>Ready for Deployment</td>
<td>Yes</td>
<td>Yes</td>
<td>Soon(^2)</td>
<td>No(^5)</td>
</tr>
</tbody>
</table>

Notes:
1. SAE J3161 is currently in development for V2V over PC5
2. Testing is currently underway – expected late 2019 / 2020
3. Continue development – expected in late 2020 / 2021
4. Full compliance to specifications
5. Expected by late 2020 / 2021

Figure 8 illustrates a relative comparison of DSRC v. Cellular based on the anticipated full benefits of 5G Rel-16, once it has been fully commercialized.


It should be noted that DSRC is already tested whereas the assessment for cellular is based on anticipated results based on release 16 which is not out yet. As a result, once 5G cellular (Rel-16) has been deployed, the following should be evaluated:

- Speed
- Latency (delay)
- Transmission range
- Reliability
- Ease of implementation

Some development and deployment considerations include:

1. **DSRC/C-V2X**: When deploying V2X radios along a corridor, radios should be required to be fully tested, including interoperability testing, field testing and certification testing based on industry standards. To minimize the risks associated with inadequate testing and to ensure the integrity and performance of a product, engineers will need interoperability and device certification tests. Line of
sight challenges should also be considered as it relates to hills, curves, and buildings.

2. **System Interoperability and Compatibility**: The U.S.DOT has developed a Connected Vehicle Reference Implementation Architecture (CVRIA)\(^{29}\) to facilitate and guide the design and implementation of connected vehicle and Smart City systems. To ensure maximum usage of systems and infrastructure, the Virginia Avenue Smart Corridor project should be compliant with the CVRIA Architecture and utilize an open-architecture and standards-based components during deployment to provide and promote interoperability with other Atlanta region Smart City initiatives.

3. **Project Coordination**: The development of the Virginia Avenue Smart Corridor should coordinate with on-going City of Atlanta Smart City Initiatives, including the North Avenue Smart Corridor, as well as the Peachtree Industrial Boulevard Smart Corridor project, to leverage lessons learned and to possibly utilize developed resources.

4. **GDOT Deployment Plans**: GDOT is also actively deploying connected vehicle technologies and upgrades to over 1,700 additional traffic signals and ramps throughout the Atlanta region using DSRC communications.

3. TECHNOLOGY STRATEGIES

3.1 Industry Roles

In addition to the auto industry, as illustrated in Figure 8, there are other players that make up the pieces of the puzzle as it relates to deploying technology solutions in transportation. As evidenced by the previous section, the telecommunications and automotive industry plays a key role in how the technologies communicate with one another. Another piece of the puzzle includes the transportation technology manufacturers and distributors. All three of these private groups have a stake in the advancement of emerging technologies in transportation and are moving forward at a rapid pace.

The technology strategies discussed in the following sections are not an endorsement of specific technology vendors. Instead, it consists of research based on readily available information online and from meetings with technology vendors to learn more about the technological capabilities currently available on the market. Any strategies that are recommended for further evaluation will focus on the desired outcomes of the technology, anticipated return on investment, and ultimately, how they meet the goals of the Virginia Avenue Smart Corridor Study based on feedback from the public on what they value.
3.2 Menu of Technology Strategies

The existing conditions and needs inventory analysis of the Virginia Avenue Smart Corridor, as well as public input from the online survey, indicated that technology strategies that address the following goals should be considered:

- Improve safety for vehicles, transit, pedestrians, cyclists, and the neighborhood
- Provide mobility options
- Improve transit rider experience
- Improve and maintain pavement conditions
- Attract economic development opportunities

As a result, 34 strategies were evaluated that fall into the following 13 categories, as illustrated in Figures 10 and 11.

Figure 9: Categories of Technology Strategies

Further detail on technology strategies within each category is provided below.
## Figure 10: Menu of Technology Strategies

<table>
<thead>
<tr>
<th>No.</th>
<th>Project Types</th>
<th>Goals of Corridor Project</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Safety</td>
</tr>
<tr>
<td>1</td>
<td>Signal priority (transit, bikes, peds)</td>
<td>■</td>
</tr>
<tr>
<td>2</td>
<td>Signal Pre-emption (emergency vehicles)</td>
<td>■</td>
</tr>
<tr>
<td>3</td>
<td>Signal countdown digital signage</td>
<td>■</td>
</tr>
<tr>
<td>4</td>
<td>Adaptive traffic control</td>
<td>■</td>
</tr>
<tr>
<td>5</td>
<td>Cross alert systems for bike/pedestrians (motion sensor triggers light at crossing)</td>
<td>■</td>
</tr>
<tr>
<td>6</td>
<td>Flashing pedestrian beacons (along with refuge islands)</td>
<td>■</td>
</tr>
<tr>
<td>7</td>
<td>Bike traffic signal</td>
<td>■</td>
</tr>
<tr>
<td>8</td>
<td>Solar/smart street light poles</td>
<td>■</td>
</tr>
<tr>
<td>9</td>
<td>Solar/smart pavement/sidewalks (ice, WiFi, maintenance, power, striping, EV)</td>
<td>■</td>
</tr>
<tr>
<td>10</td>
<td>Roadside sensors to communicate roadway conditions (weather and maintenance)</td>
<td>■</td>
</tr>
<tr>
<td>11</td>
<td>Smart dots in street centerlines (communicate maintenance issues)</td>
<td>■</td>
</tr>
<tr>
<td>12</td>
<td>Technologies for extreme weather conditions</td>
<td>■</td>
</tr>
<tr>
<td>13</td>
<td>Digital wayfinding signs/kiosks</td>
<td>■</td>
</tr>
<tr>
<td>14</td>
<td>Navigation assistance sensors for visually impaired (bus shelters, buses, crosswalks)</td>
<td>■</td>
</tr>
<tr>
<td>15</td>
<td>Solar bus shelters (lighting, cooling/heating, WiFi, digital kiosk, etc.)</td>
<td>■</td>
</tr>
<tr>
<td>16</td>
<td>Autonomous shuttle (6-12 passenger – first/last mile)</td>
<td>■</td>
</tr>
<tr>
<td>17</td>
<td>Mobility as a Service (Plan, ticket, and pay for all modes in one app)</td>
<td>■</td>
</tr>
<tr>
<td>18</td>
<td>Real-time transit data and systems coordination</td>
<td>■</td>
</tr>
<tr>
<td>19</td>
<td>Transit-Vehicle/Pedestrian Warning Applications (in transit vehicle)</td>
<td>■</td>
</tr>
<tr>
<td>20</td>
<td>Bus Stop Warning Applications (alerts nearby vehicles or pedestrians)</td>
<td>■</td>
</tr>
<tr>
<td>21</td>
<td>Automated Parking Systems (garage or outdoor system)</td>
<td>■</td>
</tr>
<tr>
<td>22</td>
<td>Parking availability app (including preferred parking for carshare)</td>
<td>■</td>
</tr>
<tr>
<td>23</td>
<td>Smart parking meters and other parking management systems</td>
<td>■</td>
</tr>
<tr>
<td>24</td>
<td>Electric Vehicle (EV) charging stations</td>
<td>■</td>
</tr>
<tr>
<td>25</td>
<td>EV charging outlets in light polls along curb (EV driver pays for kw usage with app)</td>
<td>■</td>
</tr>
<tr>
<td>26</td>
<td>Automated traffic monitoring/detection (vehicle class, traffic flow, incidents)</td>
<td>■</td>
</tr>
<tr>
<td>27</td>
<td>Camera/ultrasound plate readers (monitor traffic, parking enforcement and crime)</td>
<td>■</td>
</tr>
<tr>
<td>28</td>
<td>Gunshot detection technology</td>
<td>■</td>
</tr>
<tr>
<td>29</td>
<td>Network connectivity and wireless communications opportunities (public wi-fi)</td>
<td>■</td>
</tr>
<tr>
<td>30</td>
<td>Flexible curbside management and associated technologies (loading vehicles, Lyft/Uber/TNC pick-up &amp; drop offs, on-street parking, EV charging, etc.)</td>
<td>■</td>
</tr>
<tr>
<td>31</td>
<td>Construction related applications to ease impacts on neighborhoods/businesses, reroute vehicles during construction, and promote mode change</td>
<td>■</td>
</tr>
<tr>
<td>32</td>
<td>V2I for real-time applications (also enabling V2V data collection)</td>
<td>■</td>
</tr>
<tr>
<td>33</td>
<td>Integrated data exchange, management and sharing to improve access and mobility (school buses, emergency services, etc.)</td>
<td>■</td>
</tr>
</tbody>
</table>
3.3 Traffic Signals

3.3.1 Signal Priority

What is it?

Traffic signal priority (TSP) is an operational strategy to reduce the delay to transit vehicles at signalized intersections. This requires communication between the transit vehicles and the traffic signals to alter the signal timings to favor the transit operations. The basic concept involves detecting the presence of and predicting the arrival of transit vehicles. Depending on the current traffic conditions and internal system logic, the traffic signal can alter and adjust the signal timings. These adjustments are achieved without interrupting the system coordination of green indications between adjacent intersections.

The basic techniques used to adjust the traffic signal timings are reducing the red time (red truncation) or extending the green time (green extension).

*Figure 11: Signal Priority Concept*

What are the benefits?
Traffic signal priority can improve transit reliability, efficiency, and mobility. The most common benefits are reduced delay and improved travel times of transit vehicles.

Where is it currently in place?
Traffic signal priority was first implemented and tested in the Atlanta region in 2000 along Candler Road in DeKalb County at 17 intersections. In 2010 additional corridors in DeKalb County implemented traffic signal priority along with MARTA’s Bus Rapid Transit (BRT) project. The corridors included 23 intersections on Buford Highway and 27 intersections along Memorial Drive. However, due to low ridership of the BRT along Buford Highway and Memorial Drive, the service was discontinued. As part of the Renew Atlanta Smart Cities Project traffic signal priority and bus rapid technology was deployed at 23 intersections along Campbellton Road in 2018. As Smart City technology projects move forward throughout the region additional implementations of traffic signal priority will occur.

Within the United States there are numerous municipalities that have implemented traffic signal priority systems. One of the first was the City of Los Angeles as part of a demonstration project. Other municipalities with major transit system include King County, Washington and Portland, Oregon.

Are there any lessons learned?
There have been numerous studies and reports on traffic signal priority over the past 10 to 15 years. They all have similar several lessons learned, including:

- Utilizing a robust detection system;
- Involving and including the signal controller vendors early and often; and
- To identify the operational priorities and understand trade-offs on the overall traffic flow along the route.

How much does it cost?
The cost of traffic signal priority systems depends on the technology utilized. The demonstration project in Los Angeles cost approximately $10 million and averaged $13,500 per intersection and $75 per bus transponder.
How difficult is it to implement?
The majority of current traffic signal control software has internal logic and is capable of traffic signal priority applications. Detection of transit vehicles and input to the traffic signal controller are required to initially implement a system.

Is it interoperable?
Current traffic signal controllers meet the Advanced Transportation Controller (ATC) 2070 standards. The specific software and inputs, including traffic signal priority, are interchangeable.

As Smart City technology advances, devices that offer multiple functions are evolving.

3.3.2 Signal Pre-emption

What is it?
Traffic signal pre-emption is a system that allows the normal operation of traffic signals to be deterred. The Manual on Uniform Traffic Control Devices (MUTCD) defines traffic signal pre-emption as “the transfer of normal operation of traffic control signal to a special mode of operation”. Preemption is different from signal priority, which alters the existing signal operations to shorten or extend phase time settings to allow a priority vehicle to pass through an intersection as discussed in the previous section.

Typical traffic signal pre-emption applications modify the traffic signals for emergency vehicles or trains by stopping conflicting traffic and transferring right-of-way.

There are several types of technology available to detect trains and vehicles requesting pre-emption. These include use of sound (sirens), light (strobes), radio transmissions (900 MHz), cellular, and traditional in-pavement loops or push buttons.

What are the benefits?
The benefits of traffic signal pre-emption vary with the type of application. Some of the comment benefits include improved response/travel times and improved safety and reliability for the emergency vehicle or train. Additionally, improved safety and knowledge of who has the right-of-way for all roadway users.
Where is it currently in place?
Traffic signal pre-emption has been deployed and operation in various municipalities in the Atlanta region for several decades. Railroad pre-emption is present at nearly all traffic signals in Georgia that are adjacent to railroad grade crossings.

The City of Alpharetta started requiring all new traffic signals be installed with emergency vehicle signal pre-emption devices in the mid ‘90’s. Earlier this year, the City of Dunwoody and DeKalb County partnered for a pilot project for Fire Station 18 and two intersections on North Peachtree Road. The City of Marietta is also using emergency vehicle signal pre-emption as well.

There are countless municipalities throughout the United States that have implemented traffic signal pre-emption systems.

Figure 12: Signal Preemption Concept

Are there any lessons learned?
There are various operation issues and lessons learned from the implementation and use of traffic signal pre-emption. These included the following:

- After a pre-emption call, the traffic signal goes through transition before it returns to its normal timing plan. This causes less-than-optimum splits, offsets, and corridor progression. The overall effect is additional delays and queues, particularly during peak traffic volume periods.
Depending on the set-up of the system, a pre-emption call can drastically reduce pedestrian walk and flash don’t walk intervals. Special attention is necessary to ensure safe pedestrian crossing or return to the curb.

Any implementation of pre-emption will require coordination among multiple stakeholders, such as transit authorities, emergency responders, and roadway agencies to minimize any adverse impacts from the pre-emption system on each stakeholder’s operations.

**How much does it cost?**
The cost of traffic signal pre-emption systems depends on the technology utilized. The pilot project in the City of Dunwoody cost approximately $5,000 per traffic signal and $2,500 per emergency vehicle.

**How difficult is it to implement?**
The majority of current traffic signal control software has internal logic and is capable of traffic signal pre-emption applications. Detection of emergency vehicles and trains and input to the traffic signal controller are required to initially implement a system.

**Is it interoperable?**
Current traffic signal controllers meet the Advanced Transportation Controller (ATC) 2070 standards. The specific software and inputs, including traffic signal pre-emption, are interchangeable.

As Smart City technology advances devices that offer multiple functions are evolving.

### 3.3.3 Adaptive Traffic Control

There are a variety of adaptive (or dynamic) traffic signal control technologies and solutions currently being used or have the potential to improve corridor traffic performance, including:

- Detector-based Adaptive Signal Control (ASCT); and
- Connected Vehicle (CV)-based ASCT.

Further detail on each is provided below.

**Detector-based Adaptive Signal Control (ASCT)**

**What is it?**

Point detector-based adaptive signal control technologies (ASCT) are used to make traffic signal operation more responsive to real-
time traffic demand. Traditional adaptive traffic signal control systems employ upstream detector data to estimate incoming traffic flow and seeks an optimal timing strategy.

Several current adaptive signal control systems commonly in use today include SCOOT, SCATS, OPAC, RHODES, InSync, and others. There are two primary limitations on any system that utilizes detectors. First, they depend on detectors that can only provide instantaneous vehicle information data (presence, speed, etc.) when a vehicle is passing over the detector and cannot measure the vehicle states (such as, position, heading, and acceleration). Second, the installation and maintenance cost of the fixed sensors is considered high. If one or more loop detectors are not operating, the performance of the adaptive signal control system might be notably degraded.

**What are the benefits?**

Successful ASCT deployments can improve a traffic signal system in the form of improved measures of effectiveness (MOE) including reduce travel time, fewer stops, reduced accidents, cost savings, and other intangibles. While ASCT has the potential to improve aspects of a traffic signal system, in order to fully realize these benefits, it is essential that the ASCT is deployed at a location that meets certain physical and traffic characteristics.

On average, adaptive signal control technologies have been shown to improve travel time by more than 10 percent. In areas with particularly outdated signal timing, improvements can be 50 percent or more.

Studies also indicate that crashes could be reduced by up to 15 percent through improved signal timing. Adaptive signal control

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technology can reduce the intersection congestion that causes many crashes.

Where is it currently in place?
Adaptive traffic control systems are deployed in many locations around the country.

Are there any lessons learned?
ASCT systems have more components than other traffic signal systems with each component playing a critical role in the operation of the system. The ASCT processor is the “brains” of the system and will require significant up-front configuration, periodic tuning, and regular maintenance in order to maximize the benefits of the system.

In addition, communications between controllers (or processors) must be uninterrupted, for both the coordination and conveyance of detector data. Typically, ASCT requires detection that is at a minimum as abundant as a fully actuated signal, with most systems also requiring advance upstream detection on the main street.

Accurate operational detection is critical, and agencies must place maintenance of detection systems as a high priority to have the system operating at its fullest potential.

How much does it cost?
Traditional ASCT system the average cost of installing an ASCT system ranges between $40,000 to $60,000 per intersection.34

How difficult is it to implement?
The majority of traffic signal controller software has internal logic to support adaptive traffic signal deployments. It requires traffic timing analysis and data collection to properly implement to optimize traffic flow along a corridor.

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Is it interoperable?

Adaptive traffic control systems should be consistent and compliant with the overall traffic signal control system standards implemented.

Connected Vehicle (CV)-based ASCT

What is it?

Connected Vehicle (CV) technology, allows for vehicles to communicate with each other (V2V) and with the infrastructure (V2I) through DSRC, cellular (4G/5G) and/or Wi-Fi technologies.

Compared to the traditional detectors, CV technology can provide real-time spatial information (such as, position, speed, acceleration, and other traffic data) necessary for evaluating traffic conditions on a road network. Communication between vehicle and infrastructure enables the intersection controller to obtain a much more detailed information of the surrounding vehicle states within the transmission range. Further, data from connected vehicles provide real-time vehicle location, speed, acceleration, and other vehicle data.

What are the benefits?

CV-based ASCT technology has the potential to reduce travel time by 25% or more, reduce emissions by 30%, and improve safety indicators by 45%. As a component of mobility, intersection traffic signal control has an important influence on traffic efficiency. Inspired by such benefits, CV has been attracting increasing attention in traffic signal control.

Where is it currently in place?

- None (being studied by universities)

Are there any lessons learned?

- None (being studied by universities)

How much does it cost?

To be determined. CV-based adaptive systems are not ready for today as they are currently being studied by universities.

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How difficult is it to implement?
Unknown at this time.

Is it interoperable?
Unknown at this time.

3.4  Pedestrian and/or Bike Technology

There are a variety of technologies and solutions currently being used or have the potential to improve pedestrian and bicyclist mobility, access and enhance pedestrian safety including the following:

3.4.1  Countdown Pedestrian Signal - Digital Signage

What is it?
Countdown signals are used in conjunction with conventional pedestrian signals to provide information to the pedestrian regarding the amount of time remaining to safely cross the street.

*Figure 13: Countdown Pedestrian Signal*36

It is thought that pedestrians will use this information to make better decisions about when to enter the crosswalk.

Depending on user preference, the count-down timer starts either when the WALK or Walking Person indication appears or when the flashing DONT WALK or Hand indication appears. The timer continues counting down through the flashing DONT WALK (Hand) clearance interval. When the steady DONT WALK or Hand appears, the countdown signal will be at zero.

What are the benefits?
Benefits include:

- Easy to understand

36 Countdown Pedestrian Signal, [www.dialightsandcomponents.com](http://www.dialightsandcomponents.com)
- Increased feeling of safety when crossing the street
- May discourage some pedestrians from crossing when only a few seconds are left
- Appropriately suited for wide crossing and areas where there are many senior citizens and people with walking disabilities

**Where is it currently in place?**

Pedestrian countdown signals are widely deployed and have been around for many years.

**Are there any lessons learned?**

- This solution is not difficult; yet tends to have higher installation and maintenance costs.
- It is not accessible to pedestrians with impaired vision.
- Some suppliers start the countdown at the beginning of the pedestrian phase and others at the beginning of the pedestrian clearance interval, which may confuse some pedestrians.

**How much does it cost?**

Unit costs for countdown timer module range up to $2,000.\(^{37}\)

**How difficult is it to implement?**

Most installations are a simple drop-in replacement.

**Is it interoperable?**

Countdown pedestrian signals follow industry standards, including Federal Highway Administration’s Manual on Uniform Traffic Control Devices (MUTCD), and is wired to traffic signal cabinets per DOT requirements.

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\(^{37}\) Costs for Pedestrian and Bicyclist Infrastructure Improvements, UNC Highway Safety Research Center, October 2013
3.4.2 Flashing Beacon Systems

Flashing beacons are typically used at pedestrian crossings to provide an enhanced warning for vehicles to yield to pedestrians. There are two primary types of flashing beacon systems, including:

- Rectangular rapid flashing beacon (RRFB); and
- Pedestrian hybrid beacon (PHB).

A comparison between the two types is provided in Table 1. Figure 15 includes a photo of a PHB demonstration.

**Figure 14: PHB Demonstration in Phoenix, AZ**

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Table 1: Comparison of Pedestrian Beacons

<table>
<thead>
<tr>
<th>What is it?</th>
<th>Rectangular Rapid Flashing Beacon (RRFB)</th>
<th>Pedestrian Hybrid Beacon (PHB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Have a rapid strobe-like warning flash, are brighter, and can be specifically aimed.</td>
<td>• Used to warn and control traffic at an un-signalized location (mid-block) to assist pedestrians in crossing a street at a marked crosswalk.</td>
<td>• Unlike a traffic signal, the PHB rests in dark state until a pedestrian activates it via push-button or other form of detection. When activated, the beacon displays a sequence of flashing and solid lights that indicate the pedestrian walk interval and when it is safe for drivers to proceed.</td>
</tr>
<tr>
<td>• An effective alternative to RRFBs, is a Blinking LED Sign Pedestrian Crosswalk system with a LED enhanced flashing sign panel, solar panels and wireless connections that can be used to increase crosswalk safety for a variety of applications.</td>
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<td></td>
</tr>
</tbody>
</table>

| What are the benefits?                                                                 | Research indicates RRFBs can result in motorist yielding rates as high as 90% at marked crosswalks. It is shown to be significantly more effective that traditional flashing beacon systems. RRFBs are particularly effective at multilane crossings with speed limits less than 40 mph. Consider the PHB instead for roadways with higher speeds. | The installation of PHBs can lead to lower crash rates for pedestrians and vehicles. FHWA’s evaluation of pedestrian PHBs found that their installation can reduce crashes. Pedestrian crashes were reduced by 69% and there was a 19% reduction in total crashes. PHBs provide benefits to motorists as well: Compared to traditional signalized crossings, PHBs reduce delays at pedestrian crossings by 50% as reported by the NCHRP Research Report 841 for uncontrolled pedestrian crossing treatments. |

| Where is it in place?                                                                 | As a relatively new treatment, RRFBs have not been implemented extensively throughout this country, | Phoenix, Arizona  
Whitlock Avenue, Marietta, GA  
Columbus, OH |

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<table>
<thead>
<tr>
<th>Where is it in place? (cont’d)</th>
<th>Rectangular Rapid Flashing Beacon (RRFB)</th>
<th>Pedestrian Hybrid Beacon (PHB)</th>
</tr>
</thead>
</table>
| but are now becoming more prevalent with excellent performance results and effectiveness in several states and cities. | | South Cobb Drive, Smyrna, GA  
GA Tech at North Avenue, Atlanta, GA |

| Are there any lessons learned and/or deployment considerations? | Installation of two versus four RRFBs: Installation of two RRFBs (one for each direction of approach mounted at the right-hand side of the approach) compared to the installation of four RRFBs (two per approach with one on the roadway median and one on the right-hand side) has shown to increase driver yielding to pedestrians up to 80%.\(^{42}\)  
Aimed versus un-aimed Beacons: Driver yielding also increased significantly when RRFBs with LEDs were specifically aimed toward the eyes of approaching drivers at a given distance in advance of the crossing compared to LEDs aimed parallel to the approach roadway.  
FHWA has issued interim approval for the use of the RRFB (IA-21). \(^{43}\) State and local agencies must request and receive permission to use this interim approval before they can use the RRFB. IA-21 does not provide guidance or criteria based on number of lanes, speed, or traffic volumes. RRFBs are usually placed on both ends of a crosswalk. If the crosswalk contains a pedestrian refuge island or other type of median, an RRFB should be placed to the right of the crosswalk and on | PHBs are a candidate treatment for roads with three or more lanes that generally have AADT above 9,000.\(^{44}\) PHBs should be strongly considered for all midblock and intersection crossings where the roadway speed limits are equal to or greater than 40 mph. The MUTCD provides guidance on pedestrian volume warrants, design features, and restrictions associated with the PHB. |

\(^{42}\) Development of Crash Modification Factors for Uncontrolled Pedestrians Crossing Treatments, FHWA, 2017, [https://www.nap.edu/download/24627](https://www.nap.edu/download/24627)  
\(^{43}\) Interim Approval for Optional Use of Pedestrian-Actuated Rectangular Rapid-Flashing Beacons at Uncontrolled Marked Crosswalks (IA-21), FHWA MUTCD, March 2018, [https://mutcd.fhwa.dot.gov/resources/interim_approval/ia21/index.htm](https://mutcd.fhwa.dot.gov/resources/interim_approval/ia21/index.htm)  

<table>
<thead>
<tr>
<th>Are there any lessons learned and/or deployment considerations? (Cont'd)</th>
<th>Rectangular Rapid Flashing Beacon (RRFB)</th>
<th>Pedestrian Hybrid Beacon (PHB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ When RRFBs are not in common use in a community, consider conducting an outreach effort to educate the public and law enforcement officers on their purpose and use.</td>
<td></td>
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</tbody>
</table>

| How much does it cost? | The cost associated with RRFB installation ranges from $15,000 to $25,000 each (compared to $5,000 to $15,000 for traditional flashing beacons), depending on site conditions and the type of device used. These costs include the complete system installation with labor and materials. | The costs associated with the PHB are less expensive than a full traffic signal installation. The costs range from $21,000 to $100,000, with an average unit cost of $58,000. |

| How difficult is it to implement? | This is a standard traffic signal subsystem and is commonly installed | This is a standard traffic signal subsystem and is commonly installed |

| It is interoperable? | Yes, RRPB systems follow industry standards | Yes, PHB systems follow industry standards |

### Options for Activation

There are several options to activate the pedestrian crossing alert systems, including the following:

- **Push-Button**: Activated with less than two pounds of force, the Push button that provides two-tone audible activation confirmation as well as visual confirmation. This is a common activation option and meets ADA and MUTCD requirements, and the housing components comply with NEMA specifications.

- **LED Push-Button**: Push button that would provide an instructional sign, a push button with voice message and yellow LEDs for visual activation confirmation. Also, can include an optional locate tone that automatically adjusts to ambient sounds via a built-in microphone.

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45 Costs for Pedestrian and Bicyclist Infrastructure Improvements, UNC Highway Safety Research Center, October 2013
- **Wireless Bollard (Automated):** Most commonly installed at pedestrian crossings, the pedestrian would passively trigger system activation by passing through bollards placed on either side of the crosswalk. With the capability to determine pedestrian traffic direction, the bollards are battery operated, requiring no in-ground wiring.

- **Motion and Presence Activated (Automated):** Presence detectors would activate systems by using infrared and/or microwave technologies to provide precise presence and motion detection. Ideal for systems where pedestrians are not utilizing the push button and detection is needed to enhance roadway safety.

- **Video Detection (Automated):** Video camera would be mounted overhead and used to detect pedestrians.

**Connected Vehicle Interface**

The Connected Vehicle Interface (CVI) provides an enhancement option that increases traffic safety by integrating Pedestrian intelligent warning systems with CV-ready infrastructure.

Upon activation of the pedestrian crossing alert system, the CVI communicates the activation data with an RSU to relay an Intelligent Warning System to connected vehicles via DSRC or cellular (4G/5G) networks.

Drivers receive instant in-vehicle alerts—such as the presence of a pedestrian in an approaching crosswalk—via mobile device alert, smart dashboard or smart rearview mirror.

### 3.4.3 Accessible Pedestrian Signal

**What is it?**

Accessible pedestrian signal (APS) treatments for pedestrian signal indications, include directly audible or transmitted tones, speech messages, Talking Signs, and vibrating surfaces, which make real-time pedestrian signal information accessible to pedestrians who are visually impaired.

Using infrared modulated transmitted light, a voice message can be carried to a handheld receiver and is announced through a speaker on the receiver or an earphone. It is directional so that the user knows exactly where the transmission is coming from.
Under the ADA, accessible pedestrian signal information is required at newly signalized intersections that have actuated pedestrian signals and at intersections that lack the cues needed by people with visual disabilities and that are undergoing signal upgrades.

**What are the benefits?**

Benefits of APS treatments include:

- Redundant auditory information results in getting all pedestrians to leave the curb faster, thereby speeding both pedestrian and vehicular flow.
- Most accessible signal products in the U.S. are responsive to ambient sound, so they are not intrusive in neighborhoods.
- Directly audible or transmitted speech messages can identify the location of the intersection and the specific crosswalk controlled by the push button.
- A vibrating arrow at the push button can provide signal information to persons who have hearing impairments.

**Where is it in place?**

- Atlanta, GA
- Ann Arbor, MI
- Newton, MA
- Waukesha, WI
- Dunedin, FL
- New York, NY
- Newark, NJ

**Are there any lessons learned and/or deployment considerations?**

The MUTCD provides guidance and standards for accessible pedestrian signals in 4E.06 and 4E.09. New types of APS are integrated into the pedestrian push button and include speakers and vibrating surfaces incorporated in the pedestrian push button housing. These provide crossing indications to the waiting pedestrian at the departure curb rather than from overhead, as

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46 [https://americawalks.org/accessible-pedestrian-signals/](https://americawalks.org/accessible-pedestrian-signals/)
in older technology, and permit speaker volume to be set at a significantly lower and less obtrusive level (older technology was often too loud or too quiet).

Tactile arrows and other features—push button locator tones, additional audible or Braille information, crosswalk maps, actuation indicators—enhance the effectiveness of these new devices.

Configuration, functioning and adjustment methods vary somewhat by manufacturer. Most push button-integrated APS can provide additional features including Braille labels for street names, actuation indicators (a light or beep), tactile crosswalk maps, and options activated by an extended button push: audible beaconsing (useful for directional guidance at irregular or long crossings), extended pedestrian timing and recorded information of street names or additional information about the intersection.

The assumption of pedestrian walking speeds of 4 feet per second (fps) is often inadequate and needs to be accounted for in the design.

**How much does it cost?**

Unit costs for audible pedestrian signal range up to $1,000 and pedestrian signals range up to $10,000.47

**How difficult is it to implement?**

This is a standard traffic signal subsystem and is commonly installed.

**Is it interoperable?**

Yes, APS systems follow industry standards.

### 3.4.4 In-Pavement Illuminated Pedestrian Crosswalks

**What is it?**

In-pavement illuminated pedestrian crosswalks are crosswalks that are embedded with amber lights on both sides of the crosswalk and oriented to face oncoming traffic. The warning

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47 Costs for Pedestrian and Bicyclist Infrastructure Improvements, UNC Highway Safety Research Center, October 2013
Lights can produce a bright, daytime-visible light focused directly in the driver’s line of sight clearly indicating the curve, hazard, crosswalk, variable lane, or lane edge. And it requires no interpretation by the driver resulting in increased visibility.

When the pedestrian activates the system, either by using a push-button or through detection from an automated device, the lights will begin to flash in unison, warning the drivers and motorists that a pedestrian is in the vicinity of the crosswalk ahead. The flashing LEDs will shut off after a set period, i.e., the time required for a pedestrian to safely cross the street.48

**Figure 15: In-Pavement Illuminated Crosswalk**49

![In-Pavement Illuminated Crosswalk](image)

**What are the benefits?**

Drivers and motorists are warned of pedestrians crossing the road; therefore, the number of potential crashes could be largely reduced and traffic safety at crosswalks and intersections could be greatly improved, which helps to build a safer traffic environment for both pedestrians and drivers.

**Where is it in place?**

- Rock Island Rail Trail, Amarillo, TX, 201750

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50 RAIL TRAIL PEDESTRIAN SAFETY PROJECT SUMMARY, Lightguard Systems, June 2018, [https://www.lightguardsystems.com/wp](https://www.lightguardsystems.com/wp)
Are there any lessons learned and/or deployment considerations?

In-pavement illuminated pedestrian crosswalks could operate together with LED illuminated flashing warning signs to further enhance traffic safety at crosswalks. The design and installation of flashing lights should be compliant with MUTCD standards.

How much does it cost?

Prices vary according to specific site information, technical standards (including type of power needed, power standards etc.) and other requirements. Different manufacturers also offer a wide range of options to choose from. Quotes from LightGuard Systems offer 10 in-roadway warning lights using high-intensity amber LEDs with 2 signs, A/C power and push-button systems with a price starting from $11,800 (product fee only, installation not included). Price could increase if the type of power shifts to solar power and lights are activated by passive detection bollards.

How difficult is it to implement?

Roads should be resurfaced to install all the in-road flashing lights, and flashing lights can be activated in two ways: automatically via bi-directional infrared sensors that trigger passively as pedestrians enter the crosswalk or by manually pushing the crosswalk button. Moreover, right now most manufacturers offer two power choices for in-road flashing lights, either with an existing A/C power source or through solar power. Once lights are installed, they require minimal maintenance.

Is it interoperable?

In-pavement illuminated pedestrian crosswalks can operate with LED illuminated flashing warning signs to create a safer traffic

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environment at crosswalks. Under a connected traffic environment, in-pavement flashing lights can operate with multiple RSUs and connected vehicles to further detect the crossing of pedestrians and exchange information.

3.4.5 Transit-Pedestrian Warning System

What is it?
The transit-pedestrian warning system would equip transit and school buses with the capability for bus drivers to avoid and mitigate imminent collisions and protect road users including bicyclists, pedestrians, and motorcyclists.

Figure 16: Bus Pedestrian Warning System

The system has cameras / sensors placed around the vehicle continuously monitoring the driving environment in order to detect pedestrians and cyclists hidden in the vehicle’s blind spots, and upon detection alerts the driver to act. The sensors view the

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road ahead and identifies pedestrians, vehicles, cyclists, lane markings and speed limit signs as part of its decision-making process. Gathering all this information allows the system to continuously measure the distance and relative speed of your vehicle in relation to other vehicles and pedestrians, the location of the vehicle relative to the lane markings, and the speed of the vehicle. This consistent gathering of information is tracked and measured repeatedly. The system then determines if there is a potential danger and then warns the driver with visual and audible alerts.

Equally important, the system is intelligent enough to ignore inanimate objects and to distinguish between situations where the driver needs to be warned and those where immediate emergency-action is required.

The system sends a visual and audio alert before an imminent collision with a pedestrian or cyclist, allowing the driver time to react. A time-to-collision metric is calculated and when it drops below a certain time threshold, a warning is generated.

An example of this type of system is Mobileye Shield (a U.S.DOT Smart City partner) which has already or is being deployed on multiple Smart City and Corridor pilot projects around the country.

What are the benefits?
The primary benefit expected is safety, including fewer collisions and safer driving habits fewer repairs/new parts, and potential emission reductions.

Mobileye can discern texture for visual readings, differentiating between signs, pedestrians, vehicles, and more, rather than just identifying solid objects.

Where is it in place?

- Miami, FL
- Jamaica, NY
- Washington State – Transit
Are there any lessons learned and/or deployment considerations?

Challenges to deployment include:

- Retrofitting – buses are a large investment and their collision avoidance system must be suitable for installation on existing buses.
- Buses have large blind spots, so the system must cover these areas. Blind spot detection must account for pedestrians and others in these spots.
- Minimize false positives or drivers will soon to start to ignore warnings altogether.
- Consider the large turning radius of a bus in the set-up of the system with the various on-board sensors.

How much does it cost?

The cost of a Mobileye installation (including all equipment and cabling) is about $6,000 per vehicle (average).

How difficult is it to implement?

Deployment would consist of installing the system on a selected number of public transit buses in order to test and observe the performance of the system.

The deployment would be a one-time installation and with no ongoing subscription fees.

In addition, this solution can include a full telematics system which tracks the vehicle and reports all warnings made by the Mobileye System to your fleet management system, providing fleet managers with valuable information about their drivers’ daily driving behavior.

Is it interoperable?

The Mobileye system communicates with an RSU through an OBU using DSRC or C-V2X standardized communications.

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3.4.6 Bike Signal and Detection

What is it?
This solution provides detection for bicyclists at signalized intersections to facilitate safe, comfortable, and convenient crossings at intersections bicyclists while also minimizing delay.

At many traffic signals, a detector is used to “call” a green light. Typically, these detectors are designed to detect motor vehicles, but may not be located correctly or be sensitive enough for the small amount of metal in bicycles. Consequently, bicyclists are often not detected and given a green light resulting in unsafe bicyclist behaviors such as red light running or simply undue intersection delay.

Detection devices need to be placed in the path of a bicyclist (whether in a motor vehicle lane or bike lane) and be designed/calibrated to pick up the small amount of metal in bicycles. Bicycle detection devices can be used to call a phase or to prolong the phase to allow a bicyclist to clear an intersection. For bicyclists to prompt the phase at a signalized intersection, bicycle detection devices should be in the most conspicuous location and supplemented by appropriate signing and pavement markings to inform bicyclists of where to wait.

In some cases, a push button can be used, but it must be placed so that bicyclists do not have to dismount or ride onto the sidewalk to activate.

What are the benefits?
Properly designed bicycle detection system can facilitate safe crossings at signalized intersections and can help deter red light running and unsafe behaviors by reducing delay at signalized intersections.
Where is it in place?

- Cary and Chapel Hill, NC\textsuperscript{57}
- Los Angeles and Davis, CA\textsuperscript{58}

Are there any lessons learned and/or deployment considerations?

Detection devices should be placed in the expected path of the bicyclists and aimed to maximize efficiency and responsiveness. Some deployment considerations include:

- It may be desirable to install advanced bicycle detection on the approach to the intersection to extend the phase, or to prompt the phase and allow for continuous bicycle through movements.
- If a pushbutton is used, the location of the device should not require bicyclists to dismount or be rerouted out of the way or onto the sidewalk to activate the phase. Signage should supplement the signal to alert bicyclists of the required activation to prompt the green phase.
- Signal timings and phasing may need to be adjusted or modified to account for the unique operating characteristics of bicycles.
- It is important that the design of loop detectors consider the amount of metal in typical bicycles. Certain types of loop configurations are better at detecting bicyclists than others and settings for loop detectors should be adjusted to properly detect bicycles.

How much does it cost?

Detection devices are used to determine if a pedestrian or bicyclist is waiting for the signal. There are many ways that these devices detect pedestrians and bicyclists. For instance, bicycle\

detectors ($1,920 on average per intersection approach, $1,070 to $2,680 range)\textsuperscript{59} are usually loop detectors embedded in the pavement, while pedestrian detectors use pushbuttons to detect the presence of pedestrians waiting to cross.

How difficult is it to implement?
This is a standard traffic signal subsystem and is commonly installed

It is interoperable?
Bike detection systems follow industry standards.

\textsuperscript{59} Costs for Pedestrian and Bicyclist Infrastructure Improvements, UNC Highway Safety Research Center, October 2013
3.5 Streetlighting

3.5.1 Smart Streetlights

What is it?
Smart streetlights implement several technologies at one location. Multi-use options include sensors for on demand lighting, audio systems for public alerts, accident and traffic monitoring, electric car charging, security cameras, parking assistance, signal management, and public Wi-Fi access.

*Figure 17: Smart Streetlighting Concept*[^60]

What are the benefits?

- Significantly reduce energy costs
  - LEDs use significantly less energy than standard lights
  - Sensors can monitor when lighting is needed and turn it off or dim it when not needed

[^60]: Georgia Power
- Environmental benefits
  - Reduce CO2 emissions
  - Sensors can monitor air quality
- Reduced maintenance costs
  - Longer lifespan of LED bulbs
- Traffic and accident monitoring
  - Provides data for near misses and trouble spots
  - Can alert to pedestrian crossings
- Means for generating revenue
  - Park and charge systems for electric vehicles
  - Renting advertising space
- Increased safety features
  - On-demand lighting
  - Public speaker systems
  - Gunshot noise detection
- Dynamic smart parking
  - Alerts drivers to available parking spots
- Increase in citizen satisfaction
  - Increased safety
  - Reduced costs
  - Free Wi-Fi
  - Parking assistance
  - Traffic alerts

Where is it currently in place?
- Sydney, Australia, 2018

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- New Delhi, India, 2018
- Dubai, UAE, 2017
- Cardiff, Wales, 2017
- Hongze County, China, 2016

Are there any lessons learned?

- London district unable to turn off lights for 3 months straight due to a financial snag
- With new research projecting a cumulative savings of $15 billion through 2023 in cities implementing smart lights and LEDs, the return can justify the initial costs. One city predicts they will pay for themselves in 6 years.
- Privacy concerns – reassuring citizens that the data collected is anonymized, will help to alleviate these concerns

How much does it cost?

Depending upon whether there is an existing streetlight in place, the cost of a smart streetlighting system may involve the fee of converting an existing traditional streetlight to LED, including the internet infrastructure. Retrofitting traditional streetlights could cost from $200 to $2,000 each, with another $150 for internet and network connections. However, costs could also fluctuate.

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64 Snag leaves London Streetlights on During the Day for 3 Months, LEDs Magazine, March 2019, https://www.ledsmagazine.com/articles/2019/03/snap-leaves-london-street-lights-on-during-the-day-for-three-months.html
66 Town’s Smart Streetlights to Pay for Themselves in 6 Years, Times Union, November 2018, https://www.govtech.com/fs/Clifton-Park-to-buy-streetlights-to-save-on-energy-costs.html
based on different current electrical scenarios. For example, the City of Chicago plans to invest $160 million to replace 270,000 traditional street LED lights.\(^6^9\)

**How difficult is it to implement?**

Implementing smart streetlight systems can be done in two ways; install a completely new streetlight system and replace the old system, or by transforming and upgrading an existing traditional streetlight into a smart one.

Retrofitting and upgrading an existing streetlight requires installation of new equipment and infrastructure, including installing multiple sensors, motion detectors, and cameras, equipping streetlights with telecommunication technology and setting up routers and cables to enable advanced traffic control. If installing a new smart streetlight from the beginning, in addition to all the above, LED luminaires must also be purchased and installed.

Other considerations include:

- Cities with tight budgets may have difficulty implementing due to start-up costs, even though there are proven long-term savings.
- Requires a high level of communication and collaboration due to different entities owning lights within the same area (city, county, utility company, HOA, private owner). Prior in-depth audits are essential.\(^7^0\)

**Is it interoperable?**

- Smart streetlight technologies integrate well with other digital applications and can function as a main hub for multiple technologies.
- Universal sockets can be installed to accommodate future applications.
- Can be adapted to meet each city’s unique needs.

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\(^6^9\) Chicago is spending $160 million on smart streetlights, Statescoop, March 2017, [https://statescoop.com/chicago-is-spending-160-million-on-smart-street-lights/](https://statescoop.com/chicago-is-spending-160-million-on-smart-street-lights/)

\(^7^0\) Lighting the Way: Smart Streetlights are Smart for Everyone, Facility Solutions Group, [https://www.asmag.com/showpost/28146.aspx](https://www.asmag.com/showpost/28146.aspx)
3.6 Pavement and/or Sidewalks

3.6.1 Solar/Smart Pavement/Sidewalks

What is it?

Solar pavement and walkways are a modular system of individual panels typically constructed of 3 layers: a base plate layer, an electronics layer embedded with microsensors, and a top road surface layer. The microsensors make the panels intelligent and able to communicate with each other and multiple other systems. LED lights (on top of the pavement) can also be used in place of white and yellow lines, and to alert drivers to roadway conditions. They are much more costly currently than asphalt roads, but some of the expense can be recouped through energy production.

Figure 18: Solar Pavement

What are the benefits?

Below is a list of anticipated benefits, although it should be noted that many are still being evaluated:

- Produce clean energy

To power streetlights
To charge electric vehicles

- Impervious to potholes
- Can be heated to melt snow and ice
- With the use of LED lights instead of white and yellow lines, the need to repaint roads is removed
- No energy is lost in transmission because the roadways lie next to the areas, they are supplying power to, unlike outlying areas of energy production
- Reduces resurfacing costs needed for asphalt every few years

Where is it currently in place?
- Alabama/Georgia border, U.S. – powers the adjacent Georgia Information Center (as part of “The Ray”)
- Tourouvre-au-Perche, France – generates enough energy to power streetlights in the entire village
- Jinan, China – generates 1 million kw hours of renewable energy each year

Are there any lessons learned?
- Heating elements needed to melt snow can consume all the energy the panels are producing.
- Overheating, dust and debris buildup which reduce energy production, can be an issue.
- It is estimated that flat solar roads produce 30% less energy than angled roof panels at higher elevations free from shade.
- Safety issues result due to less traction than asphalt, although a new polymer is being developed by

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Pavenergy that has slightly more friction than a conventional road.\(^75\)

- On SolaRoad, a solar bicycle path in the Netherlands, the top layer had to be replaced with a more durable material after one year. It also did not generate enough energy to justify the cost.

**How much does it cost?**

Average cost is $310 - $460 per square foot.\(^76\) The bikeway project in the Netherlands cost $3.7 million for 230 feet of bikeway. That translates to approximately $1,225 per square foot, while rooftop solar panels cost approximately $3 per square foot. The cost to date for the limited solar roadway projects out there appears to be very high compared to the kilowatts of energy generated.

**How difficult is it to implement?**

The biggest obstacle is cost. Other issues include durability, and safety. To let the light in, the top layer is usually made of glass, which is not durable enough for heavy tractor trailer use and not safe in a heavy rainstorm. The alternative is using textured glass, which does not allow for as much energy production. And finally, the amount of energy they can produce can vary widely based on geographical location, weather patterns, and traffic.\(^77\)

**Is it interoperable?**

Some solar road vendors state that solar road panels can be embedded with sensors to warn drivers of obstacles in the road, and upcoming traffic conditions such as an accident or pedestrian crossing. Embedded LED lights can also be used to differentiate between lanes and turn red, for example, to stop


traffic for an approaching emergency vehicle. However, information is limited based on actual deployments.

3.6.2 Roadside Sensors to Communicate Roadway Conditions

What is it?

Roadside sensors are devices that can either be embedded in the pavement or smart street panel or mounted to the side or above the road surface. They can monitor weather and road surface conditions, traffic flow, speed detection, accidents and approaching emergency vehicles. Additionally, sensors communicate with each other as well as with vehicles and multiple other technologies to coordinate across a network. Types of technology include: Inductive Loop Detectors (ILD), Microwave Radar Detectors, Infrared Sensors, Ultrasonic Detectors, Acoustic Detectors, and Magnetometers.

What are the benefits?

- Increased safety measures
  - Can automatically alert emergency services and specify the location, when a vehicle goes off road
  - Collect data for accident-prone area to help improve conditions
  - Sensors on infrastructures can alert to impending dangers such as tunnel and bridge collapse
  - Ability to remotely monitor the condition of road

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surfaces such as potholes and floods
  - Ability to remotely monitor weather conditions such as fog, ice and crosswinds.

- Alert motorists to traffic jams and road hazards improving traffic flow
- Revenue generation and financing options from the sale of traffic data
- Rapidly and remotely survey broad areas, especially important after natural disasters
- Pavement management to reduce costs
  - Completely reconstructing a road that has not been maintained, can cost 3 times as much as properly maintaining a road to extend its life.  
  - More effective plowing and treatment of roads in winter conditions.

- Can evaluate a city’s transportation and climate action plan goals.

Where is it currently in place?
- North Avenue between Georgia Tech campus and Ponce City Market, Atlanta, Georgia, October 2016
- Portland, Oregon, October 2016
- Denver, Colorado, Summer 2018

Are there any lessons learned?
The emergence of autonomous vehicles, which rely on these, has increased their value and importance.

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How much does it cost?
The Intelligent Transportation Systems Joint Program Office in USDOT provides a quite detailed table on each device and equipment cost to be included in roadside detection system, which range from approximately two hundred to thirty thousand.\(^{83}\) Totaling up, the capital cost per site could reach $90,000.\(^{84}\)

How difficult is it to implement?
Maintaining network connectivity and high-speed wireless communication, as well as distributing information in a timely and reliable manner, can be extremely challenging for vehicular sensor networks.\(^{85}\)

Is it interoperable?
All detectors used should be standardized devices and should come back to an industry network device (Ethernet switch) for transport back to a control center.

3.6.3 Smart Dots in Street Centerlines

What is it?
Smart dots are solar powered LED lights embedded in centerlines that collect and communicate information to drivers in real time, using color.

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\(^{85}\) Sensor Networks on the Road: The Promises and Challenges of Vehicular ad hoc Networks and Grids, Semantics Scholar, [https://pdfs.semanticscholar.org/b416/7e2abad230a974bf2e066692121b526ae3eb.pdf](https://pdfs.semanticscholar.org/b416/7e2abad230a974bf2e066692121b526ae3eb.pdf)
What are the benefits?

Smart street technologies can not only benefit the environment but can save, as well as generate revenue.

- Works the same for smart cars and cars without smart technology
- Works in rural and suburban areas which are often omitted from smart city planning
- Developers consider this life-saving technology because it increases safety
- Solar powered therefore energy efficient

Where is it currently in place?

Smart dots, or studs, have been invented by and planned for deployment along “The Ray,” an 18 mile stretch of I-85 in Georgia from La Grange to the Alabama border, which serves as a live example of a smart road.

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laboratory for smart street technology and other technologies aimed at reducing the carbon footprint.

Are there any lessons learned?
At this time, there are no lessons learned available as they have not been installed yet.

How much does it cost?
For all technologies they are testing, not just smart dots, The Ray spends approximately $1 million per year.88 Costs of just the smart dots were not isolated as part of publicly available information.

How difficult is it to implement?
There are different methods to install different types of smart road studs in street centerlines, which include milling and coring. It should also be noted that studs must only be installed in a hard-aggregate surface, such as asphalt or concrete.89

Is it interoperable?
- Works collaboratively with other smart technologies to improve hazard perception and speed compliance at junctions
- Works collaboratively with other smart technologies to transform driving behavior and provide advanced driving guidance
- Can be designed to adapt to different types of roads

3.6.4 Technologies for Extreme Weather Conditions

What is it?
Technologies to sense and predict extreme weather systems include:
- Doppler radar;

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- Dual polarization
- Phased-array radar
- Geo-stationary satellites; and
- Polar satellites.

Individually, these each help to improve warning times, but collectively gathering data from all sources provides even greater warning time.\(^9^0\)

Figure 21: Example of Extreme Weather Alert Process \(^9^1\)


\(^{91}\) Development of Technology for the Mitigation of Snow and Ice Disasters Caused by Extreme Weather, Public Works Research Institute, https://www.pwri.go.jp/eng/research/project/1-5.html
What are the benefits?

- Increasing current warning times for dangerous weather systems will save lives and reduce damages to infrastructure.
- If the derived data is considered, it allows for better development of a city’s infrastructure revitalization plans.

Where is it currently in place?

- The United States and its territories have used NDFD (National Digital Forecast Database) since 2003.\(^{92}\)
- Kuala Lampur, May 2007, a SMART traffic tunnel opened than becomes a stormwater management tunnel in the event of flooding.
- T9 Bridge, Greece, planned for February 2021.
- Saint Petronilla Tunnel, Italy, planned for July 2021.\(^{93}\)

Are there any lessons learned?

- Gradual climate changes are more difficult to adapt to than a single significant weather event.\(^{94}\)
- Uncertainty is the new normal and resilience-based approaches are needed.

How much does it cost?

The cost of NOT using these technologies is high. In 2017, in the U.S. alone, damages due to extreme weather are estimated to have reached $300 billion, the costliest year so far. In 2018, the top ten disasters around the world cost $85 billion.\(^{95}\)

How difficult is it to implement?
Alternate communication systems are needed in the event of a natural disaster which may break down standard networks.

Is it interoperable?
The best approaches combine data from different technologies, such as CAP (Common Alerting Protocol) which uses extensible Markup Language (XML) (programming language designed to store and transport data) to exchange all emergency alerts and weather warnings.  

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3.7  **Wayfinding**

3.7.1  **Digital Wayfinding Signs/Kiosks**

*What is it?*

Digital Wayfinding is a means for replacing traditional printed signage with interactive digital screens. They are commonly used in cities, universities, airports, conference centers and shopping malls to automate the direction of pedestrians to their destinations, assist them with questions, and provide other essential information. They can be customized to increase sale, provide public service messages and limitless other applications.

*Figure 22: Digital Wayfinding Kiosk on a City Street*  
![Digital Wayfinding Kiosk on a City Street](image)

*What are the benefits?*

- **Ecological**
  - No use of paper or plastic for disposable signage
  - Updated digitally rather than manually reprinting.

- **Flexible and Interactive**

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97 Studio Binocular, September 2015,  
Self-service kiosks can answer questions presented by each individual user

Unlimited formats can be used such as maps, calendar of events, videos, call buttons, social media links, etc.

Can communicate in multiple languages

- Simple Maintenance for Owners
  - Updates are similar to revising Excel spreadsheets

- ADA Compliant
  - With the right design, it ensures equal access of information to all, regardless of disability.

- Increases service and sales
  - Direct shoppers to exactly what they are looking for in retail settings
  - Direct airline passengers directly to their gate
  - Direct conference attendees directly to their meeting rooms in a hotel or convention center

- Information to Go
  - Send directions and other information directly to a mobile device or print out.

- Interior wayfinding takes over where Google Maps ends

Where is it currently in place?

- Hartsfield-Jackson Atlanta International Airport, Atlanta GA, 2012
- Georgia World Congress Center, Atlanta, GA, January 2016
- Emory University Hospital Midtown, Atlanta, GA, August 2018

Are there any lessons learned?

- Understand your audience and their needs
  - Interactive wayfinding for children needs to be installed at a lower height than for adults
  - Be sure the languages available, service the population of the area

- Keep it simple
o Too much information and overly detailed graphics confuse users\textsuperscript{98}
o Signs are typically written at a 3\textsuperscript{rd} grade reading level

\textit{How much does it cost?}

Much of the budget goes into the methodology, mapping and programming. There is a huge range in prices depending on the application, approximately \$20,000 for a single exterior wayfinding sign to \$200,000 for an interior system.\textsuperscript{99}

\textit{How difficult is it to implement?}

Extensive planning is essential to a successful sign:

- Analyze needs and goals
- Establish a budget
- Research regarding industry standards and best practices
- Develop an action plan
- Create a design
- Implement the plan

\textit{Is it interoperable?}

The main benefit of digital wayfinding signs is their multifunctionality. With unlimited design options they can be custom tailored to meet the needs of most businesses and organizations.

3.7.2 Artificial Intelligence (AI) Conversation Agent Robot

\textit{What is it?}

Artificial Intelligence (AI) conversation agent robots are developed by IBM. With its name as Josie Pepper, they are humanoid robots equipped with IBM Watson Internet of Things (IoT) cloud-based artificial intelligence technologies seen in airports, stores and similar locations to welcome passengers and


\textsuperscript{99} Randy Cooper, Cooper Signage & Graphics, Loganville, GA
provide various types of assistance and guidance to them. The robots’ brains contain a high-performance processor with a WLAN internet access to create a connection to a cloud service where speech is processed, interpreted and linked to the related region’s data. The highlight of this kind of robot is that it not only delivers pre-defined texts and information, but it is also equipped with the ability to learn and answer each question individually.\textsuperscript{100}

\textit{Figure 23: AI Conversation Agent Robot}\textsuperscript{101}

What are the benefits?
They can welcome customers and passengers, answer questions about shops, restaurants and flight operations and accept complaints. In summary, they could provide some guidance and assistance to passing-by people and direct them towards local restaurants and shopping.

\textsuperscript{100} Hi! I’m Josie Pepper, Munich Airport, \url{https://www.munich-airport.com/hi-i-m-josie-pepper-3613413}
\textsuperscript{101} \url{https://www.munich-airport.com/hi-i-m-josie-pepper-3613413}
Where is it in place?
- Big Bang Pizza, Brookhaven, Georgia, 2019\textsuperscript{102}
- Munich Airport, Germany, 2018
- Japan, Asia

Are there any lessons learned and/or deployment considerations?
For testing phase one, the robot should be set to remain at one location and the test phase should last for several months before deciding whether they should be installed and deployed at more locations. In order to remain competitive in the long term, it is essential for places with the AI robots to explore new technologies and functions both within their own industry and in cooperation with partners from other segments, and to integrate these when appropriate and feasible.

How much does it cost?
The price of conversation robots varies based on different levels of functions and intelligence, which may vary from $2,000 to $10,000 for the set-up fee, plus a monthly retainer fee varying from $100 to $5,000.\textsuperscript{103}

How difficult is it to implement?
AI conversation robots must be installed by professional teams with a supportive power type. Moreover, they require daily maintenance and continuous debugging and upgrade.

It is interoperable?
In the future, AI conversation robots could further cooperate and interact with connected transportation systems and traffic control centers to update and deliver real-time traffic information and related news to passengers.

\textsuperscript{102} Robots Welcome Customers, Serve Slices At New Big Bang Pizza, Brookhaven Local News, January 2019, \url{https://patch.com/georgia/brookhaven/robots-welcome-customers-serve-slices-new-big-bang-pizza}

\textsuperscript{103} How much does a chatbot cost?, Medium, February 2018, \url{https://chatbotslife.com/how-much-does-a-chatbot-cost-783bf583ac4}
3.7.3 Navigation Assistance Sensors for Visually Impaired

What is it?

Simply put, these navigation assistance systems are those that don’t rely on vision. Multiple types of systems for the visually impaired currently exist or are in development with varying technologies. Some are devices worn by the visually impaired, and in the case of a bus shelter, communicate directly with bus drivers approaching the stop. Some work in conjunction with wireless sensor networks, and others work off a network of communication involving all the above, with information sent to the user’s smartphone or to the wearable device in the form of vibrations and sounds.\textsuperscript{104}

\textbf{Figure 24: How Navigation Sensors Work for Visually Impaired}\textsuperscript{105}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure24.png}
\caption{How Navigation Sensors Work for Visually Impaired}
\end{figure}

\textsuperscript{104} Wearable sensor device helps visually impaired to sense their environment, January 2017, \url{https://www.sciencedaily.com/releases/2017/01/170110091907.htm}
What are the benefits?

- Increased safety and mobility for the visually impaired
  - Detection of obstacles in pathway
  - Independent use of mass transit systems
  - Direct communication with transit drivers
  - Avoids taking incorrect routes or missing stops

- Not just for the visually impaired, location-marking beacons can also help tourists and people unfamiliar with their surroundings

- They can be used in conjunction with canes, guide dogs, and wheelchairs

- GPS voice-guided apps are adequate at giving directions, but do not specify where specific items are such as a bus stop, and they do not work inside buildings.

Where is it currently in place?

- Denver, CO, 2004 – reliable transit timetables and automated bus stop announcements

- Warsaw, Poland, 2015 – uses small location-marking beacons

- Ife-Ife, Nigeria, 2013 – ultrasound guides worn in the show and accompanied by an earpiece (still in development at the time of publication)\(^{106}\)

Are there any lessons learned?

Developers should make use of current smartphone software as many already include options for screen content read-out by means of voice-response and touch screen operation through special gestures. These could ease the development of smartphone-based navigation assistance and make guidance for visually impaired people easier. \(^{107}\) Moreover, as artificial intelligence and computer technology continue to develop, advanced deep learning technology could be combined into the development of navigation assistance.

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How much does it cost?

Costs for responsive streetlighting is not publicly available.

Costs for wearable sensors for visually impaired people for the purpose of navigation assistance and guidance vary based on their functions and level of advancement. The price for the device could range from hundreds to thousands. The band developed by Sunu which uses sonar sensor costs approximately $250,\textsuperscript{108} while the headset developed by Nvidia which adopts GPU-accelerated computer vision, deep learning technology and sensors, costs approximately $2,000.\textsuperscript{109}

How difficult is it to implement?

For visually impaired people, it is quite easy for them to wear navigation assistance sensors and make use of their smartphones to receive guidance. The programmed system could recognize obstacles around surroundings and evaluate respective data in real time and then transfer information to users through speech, alerts, warning signals or vibration.\textsuperscript{110}

Is it interoperable?

Options for multi-functionality do exist, as follows:

- Responsive streetlights can respond to smartphones with software installed for the visually impaired and increase its brightness as you pass underneath it, assisting both those with low vision, as well as increasing their visibility to drivers of nearby vehicles.\textsuperscript{111}

- Canes can be equipped with a beaconing device that can request navigation information be sent to a secondary device, such as their phone.\textsuperscript{112}

\textsuperscript{109}This Powerful Wearable Is a Life-Changer for the Blind, NVIDIA, October 2016, https://blogs.nvidia.com/blog/2016/10/27/wearable-device-for-blind-visual-impaired/
3.8 Transit

3.8.1 Solar Bus Shelters

What is it?
Solar bus shelters are those powered by the sun to provide shelter, air conditioning (potentially), USB charger ports, digital transit maps and in some areas, free Wi-Fi.

Figure 25: Solar Powered Air Conditioned Sheltered

What are the benefits?

- Increases ridership of public transit which reduces road congestion
  - More comfort while waiting translates to more passengers
  - Shelters in Dubai have free Wi-Fi in the shelters for transit pass card holders
- Security enhanced
  - Must have a bus/transit card to enter
  - Equipped with video surveillance cameras
- Can be funded by ad revenue
- Environmentally friendly since they are powered by the sun and do not produce emissions
Where is it currently in place?

- Hialeah, FL, 2016
- Corona, CA, 2011
- Dubai, UAE, 2006

Are there any lessons learned?

As with any solar panels, the angle and orientation of the solar cells are crucial to their functionality. If the cells are not collecting enough energy, the system will not work. One study projected solar bus shelters would pay for themselves in 21 years without grants, and in 15 years with grants, after which they would make a profit.\(^\text{113}\)

How much does it cost?

The estimated cost for an air-conditioned shelter is $65,000 per unit.\(^\text{114}\) The costs for open-air shelters with rooftop solar panels could vary according to different manufacturers and different technological standards. Handi-hut offers solar powered shelter light kits starting from $495 per unit to $795 per unit with more lighting;\(^\text{115}\) whereas the thin solar-paneling film in London’s solar bus shelters costs $350 per square meter, which they stated cost is similar to conventional building materials.\(^\text{116}\) Moreover, the Go Green Company estimates that a bus shelter installed with rooftop solar panels cost $14,500 in 2011.\(^\text{117}\) Although it is expected that prices have likely decreased in recent years, the price varies based on different project requirements and technical standards.

How difficult is it to implement?

Initial up-front costs exist, with the potential to generate revenue down the road. Whether or not solar panels can generate


enough energy to power air conditioning has not been determined and should be evaluated further.

Is it interoperable?

Once the shelters are powered, multiple technologies can exist within the structures: USB ports, Wi-Fi, wayfinding and transit maps, security systems, digital advertising, etc.

3.8.2 Autonomous Shuttle

What is it?

Autonomous shuttles are vehicles that move small amounts of passengers (6-15) approximately 1 mile, on a set route, and without a driver. Autonomous shuttles use guidance and detection systems using a combination of sensors, cameras, and deep learning programs.\(^{118}\)

**Figure 26: Autonomous Shuttle**\(^{119}\)

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\(^{118}\) AUTONOM SHUTTLE, the Revolutionary First and Last Mile Travel Solution, Navya, [https://navya.tech/en/autonom-shuttle-na/?gclid=EAIaIQobChMlp6u7u-4glVAUqNCh0KMgPWEAYASAASglBEID_BwE](https://navya.tech/en/autonom-shuttle-na/?gclid=EAIaIQobChMlp6u7u-4glVAUqNCh0KMgPWEAYASAASglBEID_BwE)

Larger autonomous shuttles are also available, including Navya’s shuttle that carries a maximum of 15 passengers, with 11 seating and 4 standing.\(^{120}\) Larger autonomous buses can carry up to 40 passengers, such as the self-driving bus in Manchester, UK offering 43 seats.\(^{121}\)

**What are the benefits?**

- Clean mobility, as most are electric or hybrid
- Fill in gaps left by other modes of transport
- Provides mobility to those unable to drive due to age, impaired vision and other reasons
- Ability to communicate with passengers and the vehicle’s surroundings
- Adaptable for public use (cities) as well as private use (within large business or university complexes)
- Can be equipped with exterior digital panels that communicate with pedestrians such as “waiting for you to cross.” \(^{122}\)

**Where is it currently in place?**

- Las Vegas, NV
- Ann Arbor, MI
- Detroit, MI
- Denver, CO
- Columbus, OH

It should be noted that the Assembly Yards mixed-use development near the Doraville MARTA station recently deployed an autonomous shuttle. The Integral Group selected Navya’s shuttles to connect Assembly with the Doraville and Chamblee MARTA Stations. Assembly’s U.S. manufactured driverless clean

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\(^{120}\) Autonom Shuttle Specifications, Navya, [https://navya.tech/en/autonom-shuttle/](https://navya.tech/en/autonom-shuttle/)


energy Navya vehicle carries 15 people and will follow a route from Assembly Yards to the Doraville MARTA Station on scheduled 15-minute intervals and on-demand. The shuttle is the "first autonomous shuttle in the region, as well as the first autonomous shuttle in a transit-oriented mixed-use development."  

Are there any lessons learned?

- The term “driverless vehicle” is more widely understood by the general public than "autonomous vehicle."
- It is important to roll out educational programs in advance, to inform the public and get feedback regarding their concerns since this is brand new technology to most areas.
- Any accidents, no matter how minor, can greatly impact public perception regarding safety, however these perceptions can recover.  
- Starting autonomous programs at high schools and universities is a great way to begin; they educate as well as transport.
- Ethical questions exist such as who should be the primary safety concern, the rider or the pedestrian?  

How much does it cost?

With so many variables, costs are difficult to generalize. Cost variables include whether the equipment is leased or purchased, the number of vehicles, whether infrastructure already exists, and research costs. One pilot program in Arlington, TX, that is leasing 2 shuttles for a period of 6 months, is costing the city $270,000.

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125 On the Future of Transportation in an Era of Automated and Autonomous Vehicles, PNAS Proceeding of the Nation Academy of Sciences, April 2019, https://www.pnas.org/content/116/16/7684
How difficult is it to implement?

- The general population does not yet have a working knowledge of what autonomous vehicles are, and how they can be used in society.
- Those that are aware are skeptical with many questions and safety concerns.
- Infrastructure must be adapted due to a lack of driverless vehicle routes.
- They are susceptible to extreme weather conditions. Tornadoes, bomb cyclones, heavy rain and snow all affect their performance. This is mainly due to their power source of lithium batteries which prefer stable temperatures.

Is it interoperable?

- Being equipped with sensors and radars enable autonomous shuttles to connect and interoperate with other autonomous and connected vehicles and roadside units.
- Autonomous shuttles can exchange data and information with central network and clouds to realize traffic management and control.

3.8.3 Mobility as a Service (MaaS)

What is it?

MaaS is an on-demand system in which public and private transportation providers of all forms (buses, train, ride-sharing cars, scooters, bicycles etc.) are combined through one service application that creates and manages all aspects of the trip including planning, ticketing, and payments. It has the characteristics of data-driven and user-centered, which users can just enter their destination and everything is handled via the app or webpage. It is a shift away from personally managing your own trip with your own vehicle. Critical components of MaaS include infrastructure to provide widespread penetration of cellular networks, high levels of connectivity and transfers and interchanges between various transportation services, data providers to enable real-time traffic updates and serve as intermediary layer between transportation operators and end users, transportation operators to offer multiple types of transportation service and trusted mobility advisors to link service
between the private and the public, arrange books and facilitate payments.\textsuperscript{127}

\textit{Figure 27: Example of How MaaS Works}\textsuperscript{128}

What are the benefits?

\begin{itemize}
\item Could significantly increase the efficiency of transit providers
\item Reduces transportation costs for users with the goal to be cheaper than car ownership\textsuperscript{129}
  \begin{itemize}
  \item Monthly payments options
  \item Pay-as-you-go options
  \end{itemize}
\item Reduces congestion on city streets
\item Helps manage mobility costs for corporations to help them understand ways to save
\item The service is fully personalized with users choosing their
\end{itemize}

preferred methods of transportation

- With the population of urban areas increasing extensively of the next several years, MaaS helps alleviate the problems of overcrowded roadways and lack of available parking.

Where is it currently in place?

- Helsinki, Finland uses the Whim System, October 2016\textsuperscript{130}
- Stockholm, Sweden uses the UbiGo app-based travel system, May 2019\textsuperscript{131}

It should also be noted that the Atlanta Region Transit Link Authority (ATL) is currently cleaning up its General Transit Feed Specification (GTFS) feed, which will then be followed by a pilot effort for MaaS, expected in 2020. The GTFS is a data specification that allows public transit agencies to publish their transit data in a format that can be consumed by a wide variety of software applications.\textsuperscript{132}

Are there any lessons learned?

The biggest challenge is changing the mindset of urban dwellers from car ownership to shared transportation.\textsuperscript{133}

How much does it cost?

It is hard to tell whether MaaS could reduce the cost of users’ daily trips in total or not. As researchers observe the impacts of MaaS on North American trip markets, there could be an increase in net consumer costs as they pay more for increased convenience and reduced travel time, or they are losing access to cheaper transportation services as MaaS are replacing these options with


\textsuperscript{132} https://gtfs.org/

\textsuperscript{133} Sampo’s blog: The business model of Mobility as a Service (MaaS), MaaS Global, November 2018, https://maas.global/blog-the-business-model-of-mobility-as-a-service-maas/
more expensive ones, or they could pay less overall but still enjoy the improved travel.\textsuperscript{134}

Of the limited MaaS options currently in place, there are two typical ways of payment, as follows:

- A monthly subscription which enables the transportation operator (either a public entity or the third operator) to purchase the service in bulk for users and then offer them a discount; or
- Pay-as-you-go that works as travel-route-planner apps as they organize trips as single trip chains and users pay separately for each trip.

There are several challenges in both payment options. One of the biggest challenges is that with multiple transportation providers delivering various modes of transportation, for a single trip, a promised discounted fare can prevent many providers from offering the service. Right now, the way MaaS works is to ensure that each mode is being appropriately compensated for its portion. However, many fare structures are old and complex and require updates so that the public can understand what they are paying for. It is expected that future MaaS offerings could own an integrated end-to-end version of pay-as-you-go where users pay for the entire trip from origin to destination and there is pricing integration across different modes.\textsuperscript{135}

\textit{How difficult is it to implement?}

The coordination of multiple types of transportation makes the system extremely complex. In order to set up MaaS for success, it is recommended that the regional develop a MaaS readiness plan, which includes the efforts illustrated in Figure 29.

\begin{itemize}
\item \textsuperscript{134} Mobility-as-a-Service: The value proposition for the public and our urban systems, Arup, March 2018, \url{https://www.marsdd.com/wp-content/uploads/2018/04/Mobility-as-a-Service-the-value-proposition-Mar18.pdf}
\end{itemize}
**Is it interoperable?**

- The use of autonomous vehicles in MaaS is a large part of the projections regarding usage and costs;
- The entire concept behind MaaS depends on the sharing of route information between different forms of transportation, commercial and public, so they can be coordinated; and
- Compatible with ride sharing services, such as Uber and Lyft, as well as with Turo, an Air BNB of car services in which private owners rent out their vehicles to other users.\(^{136}\)

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\(^{136}\) What is Mobility as a Service?, Geotab, November 2018, [https://www.geotab.com/blog/what-is-mobility-as-a-service/](https://www.geotab.com/blog/what-is-mobility-as-a-service/)
3.8.4 Real-Time Transit Data and Systems Coordination

What is it?

Real-time transit data and systems coordination is an all-encompassing, holistic effort to provide passengers with real-time travel information and manage and coordinate travel for all passengers, rather than for each individual passenger.

Figure 29: Real-time Transit Data Example

What are the benefits?

▪ Makes better use out of existing roads
▪ Increases access to employment
▪ Reduces the need for individual car ownership

Where is it currently in place?

▪ London, England
▪ Vancouver, British Columbia
▪ Los Angeles, California

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Are there any lessons learned?
A willingness to partner with private stakeholders, provide open data, and having a robust inventory of different transportation modes available are all necessary for MaaS providers to come to a region.

How much does it cost?
With research for each city, app development, sensor purchases, local labor costs for installation, management of the software, ad campaigns to educate the public on the benefits, and many other factors, the cost is hard to quantify. Perhaps one way to measure is to compare the savings of cities who have implemented coordinated systems with those that have not, or to look at their costs before and after. One example is the Suburban Mobility Authority for Regional Transportation (SMART) in Michigan. SMART coordinates transportation technologies with community partnering to provide $7 million in transportation funds to communities for cost-effective and flexible local transportation services. If SMART provided all these services directly, the cost would be approximately 40% more – or $2.7 million every year.139

How difficult is it to implement?
A challenge is overcoming the knowledge that the quickest route for one person, may not be the solution that is best for everyone. For example: if individuals all hailed their own cabs, thinking this is the fastest option, the roadways would become more congested.

Is it interoperable?
Real-time transit data can be:

- Transferred to clouds and control centers to enhance traffic system management and control.
- Sent to mobile devices through certain applications and sent to vehicles and roadside units under a connected traffic environment.
- Play an important role in realizing Mobility as a Service.

3.8.5 Transit-Vehicle/Pedestrian Warning Applications

What is it?
Vehicle to Pedestrian (V2P) warning systems are used to detect pedestrians in the area surrounding a vehicle, as well as bicycles, wheelchairs, and other items such as strollers. They include warning systems that send alerts to drivers, and to pedestrians via their smartphones. There are also systems that will automatically brake a vehicle if a pedestrian enters a danger zone.

Figure 30: Vehicle to Pedestrian Warning Applications

What are the benefits?

- Decrease fatalities and injuries for pedestrians in traffic zones
  - By alerting the driver and/or pedestrians
  - By taking over control of the vehicle with AEBs (Autonomous Emergency Braking Systems)
- Assist the visually impaired at crosswalks
- Prepares the roadways for future use of autonomous vehicles
- Reduce accidents due to driver fatigue and negligence

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Where is it currently in place?
Adelaide, Southern Australia

Are there any lessons learned?
The accuracy of detecting pedestrians before a fatal collision ranges from \(<30\%\) to \(>90\%\), when one type of sensor is used.\(^{141}\)

How much does it cost?
Accuracy increases when multiple types of sensors are used, but the extreme cost of using multiple systems is prohibitive.

How difficult is it to implement?
There are many uncertainties in both pedestrian and driver behaviors in the split seconds before a collision which make predictions difficult. Factors such as physical agility, degree of tiredness, the influence of alcohol and reaction times can vary greatly.

Is it interoperable?
Transit vehicle/pedestrian warning applications:

- Deliver real-time information and warnings to smartphones through programmed applications;
- Shares information and data with other connected vehicles and roadside units to enhance traffic management and control; and
- Can be designed to adapt to different traffic scenarios in various cities.

3.8.6 Bus Stop Warning Applications

What is it?
Bus stop warning technology is typically installed on buses to alert pedestrians and vehicles in the vicinity to approaching buses, buses entering a crosswalk area, and other warnings to improve safety. Warnings can be flashing lights, audio beeping or voice messages such as “caution, bus is turning”. There are also systems

that use visual signs mounted to crosswalk posts that flash when a bus is entering or making a left turn.

*Figure 31: Transit Bus Stop Pedestrian Warning*¹⁴²

What are the benefits?

- Improves safety for distracted pedestrians which is an ongoing problem due to texting
  - Automatically detects when a bus is turning and sends an audio alert to pedestrians on the street
- Makes turning easier and safer for bus drivers

Where is it currently in place?

- New York, NY\textsuperscript{143}
- Tampa, FL\textsuperscript{144}
- St. Louis County, MN\textsuperscript{145}

Are there any lessons learned?

- Mobile device warnings are not used when pedestrians are in the street, as these would be counterproductive.\textsuperscript{146}
- Devices must be able to accurately detect both mobile and stationary pedestrians, as well as cyclists.

How much does it cost?

In a study published by Federal Transit Administration in 2015, the estimated cost for advanced bus stop warning system ranges from approximately $1,500 to $3,500 per warning system, based on different standards.\textsuperscript{147}

How difficult is it to implement?

Hardware and software are required to be installed to enable bus stop warning applications. Hardware components include a common computing platform, telecommunications support, a cellular modem, pedestrian detection system, Global Navigation Satellite System receiver, human interface system and a cloud-based management system. Software components should function to provide real-time situational awareness to bus drivers, vehicle drivers and pedestrians. This warning application cannot work without telecommunication-enabled vehicles and pedestrian mobile devices.\textsuperscript{148}

\textsuperscript{143} New York City (NYC) DOT Pilot Connected Vehicle Deployment Program, ITSJPO—U.S.DOT, \url{https://www.its.dot.gov/pilots/pilots_nycdot.htm}
\textsuperscript{144} Tampa (THEA) Pilot Connected Vehicle Deployment Program, ITSJPO—U.S.DOT, \url{https://www.its.dot.gov/pilots/pilots_thea.htm}
\textsuperscript{145} ITS Solutions for School Bus Safety: A local intelligent transportation case study on dynamic school bus warning signs, University of Minnesota
\textsuperscript{146} Transit Bus Stop Pedestrian Warning Application, U.S. Department of Transportation, August 2016, \url{https://rosap.nrl.bts.gov/view/dot/31610}
Is it interoperable?
Alerts can be integrated with other systems such as collision avoidance technologies.

3.9 Parking

3.9.1 Automated Parking Systems

What is it?
The purpose of automated parking systems (APS) is to lessen the surface area needed for parking vehicles and to maximize convenience and safety. APSs have been around since the early 20th century when a semi-automated system in France opened a garage with an internal elevator to lift cars to higher levels, where attendants then parked them. Today, there are semi-automated and fully automated garages that typically have a common waiting area where one’s vehicle is brought to street level by an attendant or with a code. Payment is done at kiosks in this area.149

Figure 32: Parkmatic 10-Car Rotary System (Carousel) with Outer Turntable in Honolulu, Hawaii150

150 https://www.parkmatic.com/projects-1
What are the benefits?

Automated parking systems can be constructed to combat the growing problems of congestion, zoning, crimes and expensive land use. They target maximizing parking efficiency and saving costs for users. Below is a summary of the benefits of automated parking systems:

- Allows cities to keep up with urban growth and lack of land due to the increased number of cars that can be fit within a smaller space.
- Lower total construction costs when building up instead of out.
- Increased safety
  - Less vandalism and vehicle theft since there are no public access to parked cars.
  - Less chance of persons being mugged, accosted or attacked because drivers wait in a common area rather than walking around the garage to get to their vehicles.

151 https://www.parkmatic.com/projects-1
▪ Eliminates the difficulty in navigating small, tightly curved and often dark passageways of traditional garages.
▪ When customers do not see the upper levels, the need for passenger elevators in multiple locations, security lights and speakers and other security or cosmetic items typically seen in a public garage are no longer necessary.

Where is it currently in place?
▪ New York, NY (Parkmatic Quadstackers System)
▪ Honolulu, HI (Parkmatic 10-Car Rotary System (Carousel) with outer turntable)
▪ San Francisco and Oakland, CA, U.S.
▪ Germany
▪ Japan
▪ China

Are there any lessons learned?
Different types of automated parking systems function differently and are suitable for different scale buildings. For example, speeding tower automated parking systems are suitable for medium or large-scale buildings and optima automated parking systems are suitable for small and mid-sized scale buildings. It is important to select and construct automated parking systems based on how they could fit best with users’ needs and land use conditions. Some advanced technologies and integrated computer systems could be combined into the design of automated parking systems so that the overall operation and control of the parking system could be more convenient and user-friendly.

Many automated parking systems were operating in the United States throughout the 1900s, however, at the time, they experienced high maintenance costs, mechanical problems and most were eventually sold for the construction of apartments and offices with the rising prices of urban real estate.

How much does it cost?
Both land use expenses and construction expenses can go down when we adopt automated parking systems as a larger number of cars could use the same vertical space as a conventional garage so there is higher efficient use of the vertical spaces. Moreover, there are other aspects of potential cost savings
include reduced construction time, reduced excavation, reduced air right costs, reduced operator requirements, reduced lighting, heating and ventilation requirements, reduced insurance premiums and tax benefits through accelerated depreciation.\footnote{152}

The following graphics provide comparisons on square footage used per car and overall costs per space by conventional parking garages and garages with automated parking systems.

\textit{Figure 34: Comparison on Square Footage Per Car}\footnote{153}

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{square_footage_comparison}
\caption{Comparison on Square Footage Per Car}
\end{figure}

\textit{Figure 35: Comparison on Overall Costs Per Space}\footnote{154}

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{cost_comparison}
\caption{Comparison on Overall Costs Per Space}
\end{figure}

The following table provides a construction cost comparison for conventional garages versus automated garages in different configurations.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
Garage Type & Square Footage & Cost per Car \\
\hline
Subterranean Garage & 600 & $30 \\
Efficient Above Ground Garage & 325 & $30 \\
Garage with Automated Parking Puzzle Lifts & 180 & $20 \\
\hline
\end{tabular}
\caption{Construction Cost Comparison}
\end{table}

\footnote{152}{System Cost, FATA Automation, \url{https://automatedparking.com/system-cost/}}
\footnote{153}{TO BUILD OR NOT TO BUILD PARKING: AUTOMATED PARKING LIFTS HAVE CHANGED THE RULES, CityLift, December 2016, \url{https://cityliftparking.com/build-not-build-parking-automated-parking-lifts-changed-rules}}
\footnote{154}{TO BUILD OR NOT TO BUILD PARKING: AUTOMATED PARKING LIFTS HAVE CHANGED THE RULES, CityLift, December 2016, \url{https://cityliftparking.com/build-not-build-parking-automated-parking-lifts-changed-rules}}
How difficult is it to implement?

The time it takes to build an automated parking system depends on the size of the project, but it can typically be completed within 10 to 14 months. The system is first built prior to installation. The installation process includes installing the vertical lifts, hoist systems and machinery, as well as building the façade. Then supportive systems and equipment are built within, including the electrical and backup system, fire alarms, firefighting and sprinklers, entry and exit terminals, electronics, sensors and cameras, together with computer hardware and software. After passing the stage of startup and testing of the completed garage, daily operation and maintenance work is initiated.

Improved technologies of today make implementation much easier than the earlier installations. Some of the biggest difficulties now arise from poor planning and the confusion met by drivers using these systems for the first time.

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Is it interoperable?
Can be used in conjunction with apps that direct drivers to available parking spots, and autopay parking systems.

3.9.2 Parking Availability App

What is it?
Apps that direct drivers to available parking rely on street level sensors to detect when a space becomes available. They work in real-time, as well as provide directions to the space, rates, and hours of operation.158

Figure 36: Streetline Parking App

158Streetline’s Solutions, Streetline, https://www.streetline.com/our-solutions/#demand
Figure 37: ParkMobile Parking App

What are the benefits?

- More convenient for cities and drivers
  - Eliminates the need for coin collection
  - Drivers have flexibility in payment options
- Saves time, money and reduces emissions when parking
  - No need to drive around looking for an empty spot
  - No need to stand in line at a kiosk
  - No need to find change for coin-fed meters
  - No need to go back to your vehicle from the kiosk to put a ticket in the window
  - No need to run back to feed the meter when time is expiring
  - Driving around looking for available parking is believed to burn 1 million gallons of oil worldwide per day\(^{160}\)
- Retail establishments can promote available parking near their businesses
- Makes use of under-utilized spaces drivers may not have been aware of
- Some apps can allow users to reserve parking ahead of time for events
- Studies have shown the use of these apps leads to cities writing fewer parking tickets which leads to less frustration for drivers. Lost revenue in tickets for cities, is sometimes gained back from greater usage of the apps\(^{161}\)

\(^{159}\) Parking Availability, ParkMobile, https://parkmobile.io/brochures/parking-availability/


Data from these apps allows for city planners to better understand parking patterns.

Where is it currently in place?

- Atlanta, GA, including Peachtree Corners Town Center and much of downtown Atlanta
- Sarasota, FL
- Los Angeles, CA
- Indianapolis, IN
- Reno, NV
- Washington, DC

Are there any lessons learned?

Preferential parking for ride-sharing vehicles located in prime locations, encourage the use of these services.\(^\text{163}\)

How much does it cost?

Ultrasonic sensors cost between $300 and $500 per space, installed, depending on local labor costs.\(^\text{164}\)

How difficult is it to implement?

Actual installation is simple, taking approximately 5 minutes to install a sensor and another hour for the adhesive to dry.\(^\text{165}\)

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Is it interoperable?
Parking apps are compatible with smart parking meters.

3.9.3 Smart Parking Meters and Other Parking Management Systems

What is it?
Smart parking meters are automated systems which allow for a self-parking, paperless system aimed at making parking easier for cities and drivers. They work in conjunction with parking apps, street sensors and/or mounted cameras.

Figure 38: Smart Parking Meter System Concept

What are the benefits?
- Paperless
- Bring in revenue
- Reduces congestion
- Some are solar powered
- Programmed remotely which saves service costs
  - Can be customized for events such as a flat rate after 5pm
- Fewer repairs compared to mechanical meters
  - They can also send automatic alerts to the city

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when repairs are needed

- Allows for the collection of parking data to analyze and improve city parking and technologies
- Extremely flexible in programming options, including how aggressive cities would like them to be:
  - Friendly meters, for example, can offer a grace period after expiration\textsuperscript{167} or send notification to users prior to expiration\textsuperscript{168}
  - Unfriendly meters flash a red light at expiration to alert a parking attendant about issuing a ticket\textsuperscript{169}

*Where is it currently in place?*

They are in almost every major U.S. city, with 78.9 million smart meters installed throughout the United States, as of 2017.\textsuperscript{170}

*Are there any lessons learned?*

They were initially praised by some cities for generating revenue and condemned by motorists for erasing leftover minutes in an open spot. Other cities refused to use them for fear of backlash from drivers and retailers.

Streamlined parking systems are a key factor in making a city an enjoyable place to live and work.\textsuperscript{171}

\textsuperscript{168} Parking Meters, City of Oakland, https://www.oaklandca.gov/topics/parking-meters
\textsuperscript{169} City of Bridgeport Smart Parking Meter System, https://www.bridgeportct.gov/filestorage/338125/FAQ.pdf
\textsuperscript{170} How many smart meters are installed in the United States, and who has them?, U.S. Energy Information Administration, October 2018, https://www.eia.gov/tools/faqs/faq.php?id=108&l=i=3
**How much does it cost?**

Smart parking meters typically cost between $250 - $500 per meter.\(^{172}\)

**How difficult is it to implement?**

The successful implementation and operation of smart parking meters requires the installation of a parking meter together with sensors with Internet of Things and Bluetooth technology and cameras for parking detection.\(^ {173}\) Moreover, there should be a parking management server (PMS) connected to smart parking meters monitoring all parking spaces and managing metering and billing for all users. And for drivers, a mobile app could be developed to interact with smart parking meters.

**Is it interoperable?**

Smart parking meters can be:

- Designed and programmed to fit for different parking rules and standards in different cities; and
- Connected with platforms and clouds to enable data exchange to enhance traffic system management and control.

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3.10 Electric Vehicle (EV) Charging

3.10.1 Electric Vehicle (EV) Charging Stations

What is it?

An Electric vehicle (EV) charging station is an infrastructure that can charge the battery of electric vehicles. EV charging stations can be categorized into three major levels:

- **Level 1 EV charging stations** – Use a 120V AC plug and fit standard power outlets. The charging efficiency is low (2 to 5 miles of range per hours of charging) so it’s usually used at home.

- **Level 2 EV charging stations** - Use a 240 V (for residential) or 208 V (for commercial) plug. They have higher charging efficiency that could deliver 10 to 60 miles of range per hour of charging. The level of charging stations could be in both residential and commercial use. Compared to level 1 EV charging stations, Level 2 EV charging stations can’t use standard power outlets.

- **Level 3 EV charging stations (DC fast chargers)** – This kind of EV charging stations can deliver 180 to 300 miles of range per hour of charging. But since the equipment is specialized, Level 3 EV charging stations are only in commercial and industrial use.\(^\text{174}\)

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What are the benefits?
Installing EV charging stations brings several benefits, as they:

- Contribute to environmental protection by reducing green-house gas emissions;
- Attract customers who own electric vehicles and increase their dwell time;\(^{175}\)
- Attract tenants for property owners and managers;
- Generate revenue directly from EV owners; and\(^{177}\)

\(^{175}\) Felix Kramer (CalCars), https://www.flickr.com/photos/56727147@N00/3292024112/in/set-72157614049251389/


\(^{177}\) The benefits of EV charging stations: Incentives offered under the BOMA Clean Connect program spur station installations, Canadian Property

- Encourage more people to buy EVs by reducing any range anxiety and providing supplemental charging infrastructure.

Where is it currently in place?

To date, there are almost 22,000 charging stations and over 63,000 charging outlets in the United States. In the state of Georgia, there are almost 800 charging stations and over 2,400 charging outlets, respectively.\(^{178}\)

Are there any lessons learned?

Lessons learned include:

- Building accessible EV charging infrastructure in major cities is significant for the development and market penetration of EVs;
- The cost of charging for EV users should be reduced;
- The EV charging stations need to have reliable real-time information displayed; and
- More public outreach is needed, including improved signage and wayfinding to EV charging infrastructure.\(^{179}\)

How much does it cost?

The costs of EV charging stations may vary based on the locations and the types of charging stations. As of 2018, the installation of a Level 2 charging station costs approximately $6,000-$10,000, while a Level 3 charging station costs almost 7-8 times of Level 2 charger.

How difficult is it to implement?

The number of EVs is increasing rapidly in the U.S., which boosts the demands of EV charging stations. However, the installation of EV infrastructure may still encounter numerous obstacles, as follows:

- Utility companies need to continue to implement pilot

References:


programs and cities need to prepare funding to support the installation programs. Each process takes a long period and during which, the installations have the risk of being cancelled.

- Cities found that the costs of installing EV charging stations may vary based on the types of charger and the location. Above and beyond the installation fee, other fees such as maintenance fee, can be a huge burden on cities.\textsuperscript{180}

\textit{Is it interoperable?}

Not all EVs can use all EV charging stations. However, multiple EV network providers (EV Connect, Greenlots and SemaConnect) have announced the network interoperability agreement to enable account holders of all three companies to recharge their vehicles at any Electrify America location more conveniently.\textsuperscript{181}

3.10.2 EV Charging Outlets in Light Poles Along Curb

\textit{What is it?}

As opposed to off-street EV charging stations, existing light poles can be transformed to EV charging hubs by simply installing a socket.


What are the benefits?

- Contribute to environmental protection by reducing greenhouse gas emissions
- Attract customers who own electric vehicles and increase their time of stay
- Attract tenants for property owners and managers
- Generate revenue directly from EV owners
- Incentivize more people to buy EVs

Where is it currently in place?

- Seattle, WA, U.S.
- Hounslow, U.K.

Are there any lessons learned?

Seattle is the first city in North America that deployed a light & charge system. In 2017, with the investment of BMW Group,

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182 New technology turns any street lamp into a charging station for your electric car, Curbed, June 2017, https://www.curbed.com/2017/6/22/15855130/ubitricity-electric-car-charging-lamp-posts

Seattle installed 20 Light & Charge EV charging stations that more than doubled the number of Fast Chargers publicly available in Seattle. Furthermore, the project aims to install more than 20 public EV charging stations and 100 chargers in the future.  

**How much does it cost?**

Transforming light poles to EV charging stations is becoming a cost-effective solution, as the costs of installing new EV charging stations is high and may change dramatically. Compared to a level 2 charging station, the costs of installing EV charging capabilities on a light pole is approximately half that of installing an entire charging station.  

**How difficult is it to implement?**

Compared to EV charging stations, installing a charger on the light pole is more convenient and timesaving. The major challenges include the following:

- Difficult to find light poles that are in good condition
  - The ownership of light poles varies
  - In most cases, there is no database that includes all light pole locations

- The location of light poles sometimes conflict with the Americans with Disabilities Act (ADA)

**It is interoperable?**

EV charging in light poles along the curb can indeed be interoperable, as:

- They can be connected to personally owned smart charging cables that have built-in meters; and

Various types of sockets in the light poles can be installed to allow for different charging standards and requirements.

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3.11 Video Surveillance

3.11.1 Automated Traffic Monitoring/Detection

What is it?
Traffic monitoring software is technology that can be added to existing camera surveillance to automatically record traffic flow, accidents, and incidents in real time and extract data using set parameters. Using intelligent sensors and algorithms these systems can also send out immediate alerts which are visually verifiable. They can also be installed temporarily to help in problem areas or areas designated for special events such as The Superbowl or Olympics, and provide data as needed to better manage the increase in traffic.

Figure 41: Object Detection Technology

What are the benefits?

- Helps provide safer and more efficient travel
  - Identifies stopped and wrong-way vehicles
  - Transmits extremely fast accident and dangerous situation alerts automatically
- Can detect the presence of smoke and spilled materials on a roadway improves the efficiency of traffic managers’ ability to monitor
  - Covers large areas at one time

187 www.trafficvision.com
Where is it currently in place?

- Arizona is using thermal imaging cameras to detect wrong-way traffic
- Ontario, Canada for temporary use prior to the 2015 Pan American Games\(^{188}\)
- Metropolitan Atlanta, as part of the GDOT NaviGAtor System
- Vietnam
- San Paolo, Brazil

Are there any lessons learned?

These systems must be capable of working in a wide range of illumination levels and weather systems.

How much does it cost?

The pilot program in Arizona for detecting wrong way vehicles by using thermal imaging cameras costs $3.7 million to install 90 thermal cameras along a 15-mile road.\(^{189}\) The Intelligent Transportation Systems Joint Program Office in USDOT also provides detailed cost information on traffic cameras, which is approximately $5,000 for capital cost and $2,000 for operation and management cost per unit.\(^{190}\)

How difficult is it to implement?

Many systems can be added to, and work with, existing equipment, making implementation simpler. The sensors used are typically non-intrusive and above ground.\(^{191}\)

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\(^{188}\) Traffic Intelligence from Video, Traffic Vision, [http://www.trafficvision.com/](http://www.trafficvision.com/)
Is it interoperable?

The data obtained from this technology is wide in scope. In real-time, it can be used by law enforcement and emergency services, and using different sets of parameters, the data can be extracted for analyses and research studies, now and in the future.

3.11.2 Cameras/License Plate Readers

What is it?

Automatic license plate readers (ALPRs) are either mobile devices attached to the top of law enforcement vehicles, or stationary units attached to poles along the street. They are used to monitor traffic, enforce parking, and monitor crimes, in addition to other uses. They capture images of passing license plates, the vehicles, and sometimes the driver and passengers, along with location and a time and date stamp. The information is stored in databases accessible by law enforcement as well as the private companies that collect the data.

Figure 42: Automatic License Plate Reader

**What are the benefits?**

- Removes the limitations of police officers capturing license plate numbers by hand. 50-100 by hand per shift vs. 5000 per shift with an ALPR\(^3\)
- Helps solve crimes
  - Can determine which vehicles were in the vicinity at the time a crime was committed
  - Helps track vehicles in the cases of abducted children
- Improves compliance of state regulations for auto insurance and vehicle registrations
- Can help enforce parking regulations

**Where is it currently in place?**

As of July 2012, it was being used in 38 states in the U.S.\(^4\) This includes the state of Georgia.\(^5\)

**Are there any lessons learned?**

- Failure to visually confirm a license plate from the data collected has led to false stops of vehicles, and false arrests.\(^6\)
- There are huge concerns that this technology invades privacy and the rights of citizens since it captures every single license plate and may incorrectly target someone who is not guilty of a crime.
- Concerns are also present regarding how the data is stored, who has access, and for how long.

**How much does it cost?**

Single mobile cameras, such as those atop police cars, will capture almost every passing vehicle that comes into view. If

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\(^3\) Expert Advice on the Most Effective ALPR Solutions, PIPS Technology, [http://www.pipstechnology.com/applications/](http://www.pipstechnology.com/applications/)

\(^4\) You are Being Tracked: How License Plate Readers Are Being Used To Record Americans’ Movements, ACLU, [https://www.aclu.org/issues/privacy-technology/location-tracking/you-are-being-tracked](https://www.aclu.org/issues/privacy-technology/location-tracking/you-are-being-tracked)


\(^6\) Street Level Surveillance, Electronic Frontier Foundation, [https://www.eff.org/pages/automated-license-plate-readers-alpr](https://www.eff.org/pages/automated-license-plate-readers-alpr)
multiple stationary cameras are used, more data can be collected such as speed, by analyzing time between captures. License plate reader cameras costs can vary due to different manufacturers and different technological standards, which could vary from approximately $200 to $1,000, as a higher resolution camera would cost more.

**How difficult is it to implement?**

Camera are easily installed, the biggest obstacle for some cities would be cost.

Is it interoperable?

Can be used in conjunction with systems enforcing speed limits and traffic lights. Integration is also possible with existing security management systems to allow for automatic gate access to authorized vehicles.

### 3.11.3 Gunshot Detection Technology

**What is it?**

Gunshot detection technology is essentially a 3-step system in which audio sensors detect gunshots, pinpoint the location and then send the information for analysis to a review center which checks for false positives, determines how many shots and what type(s) of weapon, and how many shooters there are), and then an alert is sent to law enforcement agencies. The entire process takes less than 60 seconds.

*Figure 43: Gunshot Detection System*\(^{197}\)

What are the benefits?

- Faster than calling 911
- Location is automated and more accurate
- Allows for faster collection of evidence when law enforcement can arrive on scene more quickly

Where is it currently in place?

In use today in various cities, hospitals, airports, borders, school systems and universities, hotels and other large venues. Cities include:

- Miami, FL
- Chicago, IL
- Cincinnati, OH
- New Haven, CT

Are there any lessons learned?

- Not yet 100% effective and should be teamed with other security measures.\(^{198}\)
- It is unclear if the technology is reducing gun violence.

How much does it cost?

Gunshot detection sensors cost $65,000 – 90,000 per square mile per year.\(^{199}\)

How difficult is it to implement?

Some cities have abandoned the technology due to the expense, in favor of hiring more police officers and installing more security cameras.


Is it interoperable?

- Can be connected to security cameras nearby to aim cameras in that direction and start livestream surveillance.
- Can be integrated with EAGL (Emergency Automatic Gunshot Lockdown) which operates with many different types of security systems.  

3.12 Public Wi-Fi

What is it?

Wi-Fi connectivity is foundational to Smart City and Corridor deployments. Lack of Internet access has implications for providing wide-spread services and addressing digital equity. Even in developed markets, it has been estimated that up to 25% of the residents can’t afford broadband access. Internet infrastructure is essential for municipal business investment and meeting resident expectations and attracting residents.

Even with the release of Wi-Fi 5 (802.11ac IEEE Standard) in 2013, which brought a significant increase of speed over previous generations, many people still find themselves wanting more speed and being limited in performance, especially in high-density urban areas and venues. To meet the challenge of high-density deployments, Wi-Fi 6 (802.11ax IEEE Standard) is expected to roll out products by mid to late-2019, which is the first to bridge the performance gap towards 10 gigabit speeds.

Also, of note, is that both Wi-Fi 6 and 5G Cellular have a similar foundation and are expected to co-exist and complement each other to support different use cases. Wireless Access Point (AP) manufacturers are also working on providing the capability to

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provide seamless connections through a feature called Open Roaming, which is expected to bridge devices to securely and automatically connect them from one network to another.

With an expected four-fold capacity increase over Wi-Fi 5, less congestion, and greater battery life, Wi-Fi 6 is also expected to transition Wi-Fi from being a best-effort endeavor to a deterministic wireless technology.203

A municipal wireless network ('Municipal Wi-Fi or MWN) is a citywide wireless network. This usually works by providing municipal broadband via Wi-Fi to large parts or all a municipal area by deploying a wireless mesh network. The typical deployment design uses hundreds of wireless access points deployed outdoors, often on poles. The operator of the network acts as a wireless internet service provider.204

Public transit vehicles, taxis, and other city fleet vehicles could be equipped with Wi-Fi access points (“hotspots”), enabling the creation of a mesh network covering a larger coverage area with lower amounts of power with vehicle hot-spots integrated with fixed hot-spot locations, which could include up to 10 wireless routers (access points) per square mile, to provide a free comprehensive public Wi-Fi network along the corridor increasing digital equity among residents and visitors.

Carrier-grade Wi-Fi is also something to consider for Public Wi-Fi deployment as it provides increased signal strength and greater capacity performance, reliability, and quality of service features. At present, certification of Wi-Fi devices and access points is optional with no minimum performance standards.

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204 https://en.wikipedia.org/wiki/Municipal_wireless_network
What are the benefits?

- Enabled Smart Corridor and IoT-based services
- Provide an amenity for residents, visitors and tourists
- Productivity
- Convenience
- Bridge digital divide

Where is it currently in place?

Public Wi-Fi is provided in many locations, including but not limited to the following:

- Downtown Decatur, GA (within metro Atlanta)
- New York, NY, 2014
- Boston, MA
- San Francisco, CA
- Port Angeles, WA
- Lompac, CA

Are there any lessons learned?

- Consider deployment options and that there is consensus on the selected business model for Wi-Fi deployment
- Digital equity is an important consideration in the design
- Rapid changes in technology dictate need for a proactive program to update technology to meet needs and expectations
- Ensure that there are adequate network security measures implemented
- Determine market attractiveness for potential broadband suppliers
- Make sure have adequate resources to support wireless deployment

How much does it cost?

Costs can vary widely ($25,000 to $200,000 per square mile) depending on the type of systems, coverage area, reliability, bandwidth to provide, and how the project is built as described below.

Several proven revenue-generation opportunities can fund or offset the cost of Public Wi-Fi deployments, including:
- **AACIDs**: Wi-Fi could be deployed by leveraging the deployment with a LED streetlight conversion project to enable low-cost deployments over large areas. Digital kiosks and signs could also be provided with Wi-Fi Access Points using their existing network connections, to provide funding to support larger Wi-Fi deployments.

- **Public Private Partnership (P3)**: Formal, contractual relationship could be established, where the AACID provides defined assets and a private entity deploys and operates the Public Wi-Fi (i.e. Access Points and streamline the permitting process to deploy fiber in return for Public Wi-Fi).

- **Operator-delivered**: Service providers could deploy Wi-Fi, in coordination with the AACIDs, and earn back their investment via their own business model, typically using advertising, charges for premium access, and business services.

*How difficult is it to implement?*

To deploy a Wi-Fi system within an urban environment will require specialized engineering experience with wireless systems and challenges in implementing them in the dense urban area.

*What are the telecommunication requirements?*

It is difficult to predict what technical standards will be employed by consumer devices for wireless communications in the future. Standards organizations continue to move forward on Wi-Fi platforms while commercial wireless smart devices will be adhering to other standards groups in the definition of the new 5G technology. And efforts are underway to merge, or at least bond, these two initiatives.

What is clear is that whatever technologies are deployed for wireless access points / Wi-Fi at the hardware/equipment level will have a relatively short life for each cycle of implementation (based on history, typically from five to seven years maximum).

On the other hand, investment in core wireless infrastructure—which includes mounting locations (poles, etc.), electric power, and high-capacity backhaul links for wireless access devices—will provide a foundation for much greater longevity for supporting the continual migration of wireless technology standards for access devices.
3.13 Curbside

3.13.1 Curb/Lane Flexibility and Associated Technologies

What is it?
Managing the valuable space along a city's curbs has become a crucial part of city planning. The abundance of rideshare services such as Uber and Lyft, electronic scooters which accumulate at curbside, shared bicycle services, in conjunction with traditional services such as buses, taxis, cars and delivery vehicles also vying for this space, these areas have never been more valuable. Therefore, curb/Lane flexibility is all about repurposing the parking and/or travel lane. Space for parking cars along the curbs could be transformed into a multi-use space that is adjustable based on a city's needs and goals. Usage can even change throughout the day; a loading zone in the afternoon, and a ride share drop-off space at night in an entertainment district. When metered spaces are eliminated, new technologies need to be utilized for collection of revenue from non-traditional transportation services, such as the shared services of cars, bicycles, hover boards and scooters that would be using this space. Analyzing microsimulations can help pinpoint areas of concern.
Occupancy sensors can be installed in the pavement along the curb to determine if the curb is occupied. Coupled with the sensors, over time, large data screams would enable prototype apps and platforms to inform users if a specific space is open or occupied, and furthermore, gives a prediction on when it would become available if it’s occupied. And information could be displayed and sent to users and drivers through a web-based or mobile-based platform to give suggestions on real-time parking decisions. This occupancy sensor technology is being tested by the Urban Freight Lab of University of Washington in an eight-block test location in Center City.²⁰⁶

Moreover, Coord Curb Explorer also releases data and digitizes curb rules in San Francisco. It can predict the duration, time of day, and day of week for the use. For instance, if deliveries are being made on a day or time, or if ride sharing is more common during certain times. This information could be used to establish time periods for different uses as part of a curbside flex zone.

Figure 47: Curbside Flex Zone Concept

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What are the benefits?

- Discourages double parking
- Prepares the space along the curb for future autonomous vehicles
- Maximizes usage of the valuable curbside space
  - Zones marked for loading can be repurposed when not in use
  - After business hours, zones can be designated for passenger pickup and drop-off
- Improves safety when drop-off/pickup zones are established for passengers of ride-share services, so they are not exiting or entering in active traffic lanes
- Helps alleviate congestion due to bike and scooter share services and from delivery vehicles due to the surge in online shopping
- Although the greatest needs appear to be in cities, better managing curbside space in rural downtown areas can be beneficial when they must deal with lack of space during special events or a tourist season.

Where is it currently in place?

- Curbside Flex Zones, Seattle, Washington\(^{209}\)
- Innovative Curbside Management, Washington, DC\(^{210}\)
- Curbside Solid Waste Services, Fort Lauderdale, FL\(^{211}\)
- Curbside Management, San Francisco, CA\(^{212}\)

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\(^{210}\) ParkDC -- Innovative Curbside Management, District Department of Transportation, [https://ddot.dc.gov/page/parkdc](https://ddot.dc.gov/page/parkdc)


\(^{212}\) CURBSIDE MANAGEMENT PRACTITIONERS GUIDE, ITE, [https://www.ite.org/pub/?id=C75A688B-E210-5EB3-F4A6-A2E2DA8A4A4](https://www.ite.org/pub/?id=C75A688B-E210-5EB3-F4A6-A2E2DA8A4A4)
Are there any lessons learned?

- Removing metered parking spaces will reduce a city’s revenue, alternative revenue collection technologies such as parking apps, ideally should be in place.
- Most effective when decisions are made on a block-by-block basis, examining the data and usage for each specific block.  
- Speed limits may need to be reduced in these areas to accommodate the changing needs of a zone with increased passengers and pedestrians.
- Transit stop areas require special consideration due to the number of people gathering there at one time. Also, if sloped driveway aprons overlap the pedestrian zone, it makes for an uneven walking service.

How much does it cost?

The costs of occupancy sensors could vary from $500 to $10,000, including the installation, maintenance and repair costs, based on different detection standards as estimated by FHWA. Programming occupancy sensors to specific requirements could add to the cost.

How difficult is it to implement?

The decision to remove parking spaces for cars is not always a popular one with cities and drivers. So, any curbside management must integrate with a city’s overall plan for parking management, as well as coordinate with business owners along the curb. Enforcement is needed as some vehicles are prone to disregarding designated zones, such as taxis and delivery vehicles. Also, climate must be taken into consideration with enough drainage for areas where rain will pool and management for access by snowplows.

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214 Sidewalk Zones, SFbetterstreets.org, https://www.sfbetterstreets.org/design-guidelines/sidewalk-zones/
Is it interoperable?

Smart curbside design can make use of occupancy sensors to gain information on road use and then integrates with mapping technologies and databases to provide real-time data to control center to enhance traffic management and control and provide road users with real-time traffic update.

3.14 Phone Apps

What is it?

Multiple apps have entered the market for the purpose of and providing travel guidance and enhancing travel convenience, including but not limited to navigation apps and parking-related apps. Navigation apps serve to navigate traffic due to volume, incidents and construction, provide users with multiple choices to destinations and offer rerouting options. Parking-related apps serve to provide detailed information on parking to drivers, specifically parking availability information (refer to section 3.8.2). MaaS-related apps are being developed to provide multimodal travel choice to users’ cross transportation modes, operators, and jurisdictions (refer to section 3.7.3). These mobile applications combine technologies of GPS, mapping, databases, cloud computing, operation research and optimization to assist in people’s daily travel.
What are the benefits?

- Alleviates stress to humans and to the environment caused by sitting in traffic.
- Automatically calculates all the route data (speed, distance, traffic volume, construction delays, accidents) to provide the most efficient route, and can also suggest the best time to leave.
- Combined with control center and cloud-computing to obtain real-time information on traffic systems.

Most are voice-activated to encourage hands-free use and are user-friendly to visually or physically impaired people.

Where is it currently in place?

Apps are available worldwide and mapping covers almost every paved area on earth. However, MaaS apps are still under

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development. A MaaS app has been implemented in Helsinki, Finland.

Are there any lessons learned?
Crowd-sourcing apps like Waze, work best in populated cities with more people using them and entering data. If there are not many users in an area, the information is limited. Moreover, as more travel options and technologies have emerged, such as carpooling and MaaS, apps should be upgraded to include these choices. In the future, as connected transportation systems further develop, it’s important to have mobile applications connected with vehicles and roadside units to enable systemwide connection.

How much does it cost?
Apps such as Google Maps, Apple Maps and Waze are free to download and use. Others range from a monthly subscription fee of $9.99 to a one-time fee of $50 to download maps while on Wi-Fi, and then use them offline. These are especially helpful in countries where you may not have data service, although most free apps now offer offline services as well. Developing an app which includes GPS and maps, drive planning, carpooling options and some other functions usually requires up to thousand hours of work production, and the average cost of developing could be approximately $30,000 to $40,000, with a wide range depending on functions, data availability, coordination, etc.\(^{217}\)

How difficult is it to implement?
Mobile applications are generally easy to use and user-friendly, however, with many states and countries enacting hands-free laws while driving, users need to be reminded to have their smart phones mounted on the dashboard for one-touch access. Holding the device in one hand while driving with the other hand and looking at the screen by taking your eyes away from the road, leads to accidents, injury and death.

Humans and hand signals or handheld signs are still used in some construction areas to redirect traffic or signal a slowdown or stop.

\(^{217}\) HOW MUCH DOES IT COST TO CREATE A NAVIGATION APP LIKE WAZE?, Artjoker, https://artjoker.net/blog/cost-to-create-a-navigation-app-like-waze/
Autonomous vehicles currently cannot respond to these signals. As a result, navigating construction areas for autonomous vehicles is a challenge: many cities don’t have a central database for construction job locations with enough detailed information to send real-time information to vehicles. Additionally, these zones are constantly changing. One solution is to embed Internet of Things (IoT) sensors in traffic cones that can communicate with manned and unmanned cars, or to have construction workers wear wireless beacons.\textsuperscript{218}

\textit{Is it interoperable?}

Google maps also offers walking and biking directions, while Apple Maps and Waze currently do not. Mobile applications will still have to be upgraded if they wish to keep pace with emerging technologies and connected transportation systems. Parking-related apps could cooperate with other smart roadside technology and central control to exchange information.

\textsuperscript{218} Our Cities are Designed Around Roads, Traffic Safety Source, Inc., February, 2017, \url{https://www.trafficsafetystore.com/blog/autonomous-cars-construction-zones/}
3.15 Data Exchange

3.15.1 Integrated System and Data Exchange

What is it?

The Virginia Avenue Smart Corridor would capture sensor and other types of open data in real time, to provide a processing environment to support multiple Smart Corridor elements, and then be capable of disseminating the resulting information to targeted groups in the user community.

Within the context of a Smart Corridor or City, providing unrestricted and continuous access to ever growing amounts of open data requires a system architecture that can provide a resilient, scalable, secure, and affordable infrastructure. The Smart Corridor could leverage a public Cloud service provider to deploy core components of the system architecture since this option provides numerous advantages.

What are the benefits?

Financially, the biggest advantage is the elimination of capital expenditures that would be involved in a traditional in-house data center.

From a technology perspective, the cloud option would provide the Smart Corridor with a scalable computing capability that can be provisioned in a matter of a few hours and would be cost prohibitive if deployed in an AACID-owned data center. The cloud environment also would provide a greater amount of fault tolerance and failover than would be typically affordable in an AACID-owned infrastructure.

From a software perspective, the system would leverage open standards to ensure interoperability with new sources of data as these become available in the future. Use of open standards is important for the Smart Corridor project, as it facilitates the use of Free and Open Source Software (FOSS) platforms when developing the Virginia Avenue Smart Corridor applications. The Smart Corridor project would need to define data governance policies to address how data privacy issues would be handled.

Where is it currently in place?

Another consideration would be to work with the on-going Atlanta Smart City initiatives and explore the possibility of
partnering with Georgia Tech to leverage their new High-Performance Computing Center to collect and store big data from the Virginia Avenue Smart Corridor and analyze, translate and deliver information to stakeholders and users. The center would provide data security, protect the data as well as disseminate results to the public domain and give access to the sanitized version of the dataset to anybody who is interested in the research to help grow the adoption of smart hyper-connected transportation.

Pertinent data (without any Personally Identifiable Information or PII) collected should also be made available via the U.S.DOT’s Research Data Exchange (RDE).

Are there any lessons learned?

- Leveraging existing data analysis and analytical services is something that should be considered to mitigate costs and provide integration of different systems across the region.
- Amount of dynamic data and types of services that will be implemented needs to be considered.
- Adequate communications bandwidth and reliability is important.

How much does it cost?

Costs will vary widely depending on specific requirements and expectation on this function. Costs can range from $50,000 to $100,000+ depending on the complexity and level of Big Data features and analytical services and capabilities required.

How difficult is it to implement?

This can be a large effort and consideration should be given to leveraging and cooperating with on-going similar initiatives in the City to provide a more efficient and cost-effective data collection and analysis solution.
4. CONCLUSIONS

4.1 DSRC v. 5G-NR C-V2X Deployment Considerations

For time-sensitive functions, satellite is not a viable communications solution. Since most technology strategies being evaluated along the Virginia Avenue Smart Corridor are indeed time sensitive, DSRC or 5G-NR C-V2X communications solutions are recommended.

Some development and deployment considerations include:

1. **DSRC/C-V2X Radios**: When deploying wireless radios along a corridor, radios should be required to be fully tested, including interoperability testing, field testing and certification testing based on IEEE 802.11p/cellular, 1609.2/3/4 and SAE J2945.1 Standards. To minimize the risks associated with inadequate testing and to ensure the integrity and performance of a product, engineers will need interoperability and device certification tests.

2. **V2X Pilot**: If the pilot testing occurs prior to 5G NR C-V2X technology standards being finalized and products being commercially available, then we would recommend a DSRC-based V2X solution be considered for the pilot. If 5G NR C-V2X is ready for deployment, then both technologies should be considered and tested assuming there is some sort of band sharing plan as discussed earlier to compare performance and determine which direction to go for full deployment. Of the 10 signalized intersections along the corridor, some of them could deploy DSRC and some could deploy 5G-NR C-V2X.

Metrics should be developed for each intersection based on the connectivity and latency, among others, to determine the best telecommunications fit for the selected use cases. The results of the pilot, including any lessons learned, would be shared with the rest of the Atlanta region to inform the decision to implement DSRC v. 5G-NR C-V2X going forward.

3. **System Interoperability and Compatibility**: The USDOT has developed the Connected Vehicle Reference...
Implementation Architecture (CVRIA)\textsuperscript{219} to facilitate and guide the design and implementation of connected vehicle and Smart City systems. To ensure maximum usage of systems and infrastructure, the Virginia Avenue Smart Corridor project should be compliant with the CVRIA Architecture and utilize an open-architecture and standards-based components during deployment to provide and promote interoperability with other Atlanta region Smart City initiatives.

4. **GDOT Deployment Plans**: GDOT is also actively deploying connected vehicle technologies and upgrades to over 1,700 additional traffic signals and ramps throughout the Atlanta region based on DSRC telecommunications. Any technology strategies recommended along the Virginia Avenue Smart Corridor should be coordinated closely with GDOT to leverage existing and future opportunities.

4.2 **Technology Strategies to Move Forward for Further Evaluation**

Based on the findings of this technical report, the consultant team will proceed with further evaluating the following technologies along the Virginia Avenue Smart Corridor:

- Transit signal priority
- Emergency vehicle signal pre-emption
- Transit-pedestrian warning system (in-bus)
- Bike signal detection
- Rectangular rapid flashing beacons (RRFB) and/or Pedestrian hybrid beacons (PHB) with automated options for activation, such as motion and presence activated or video detection
- In-pavement LED illuminated crosswalks
- Smart street-lighting
- EV charging stations

- Smart dots in street centerlines
- Autonomous shuttles
- Solar bus shelters
- Digital wayfinding kiosks
- Curbside occupancy sensors
- Automated Parking Systems
- Parking availability app
- Smart parking meters
- Cameras/License Plate Readers
- Automated Traffic Monitoring/Object Detection
- Public Wi-Fi

### 4.3 Technology Strategies Not Moving Forward for Further Evaluation

The following technologies are not recommended to move forward for further evaluation at this time based on the following reasons:

- **Automated parking systems:** Should there be a need for increased parking capacity in the future, automated parking systems can and should be considered by property owners along the corridor, particularly the hotels. However, since they would be built outside the right-of-way, there is currently not a major deficiency in parking along the corridor, and the cost is relatively high compared to other strategies moving forward, automated parking systems is not recommended for further evaluation.

- **Gunshot detection sensors:** To date, whether gunshot detection sensors prevent gun violence has been undetermined. Given the cost and unproven effectiveness, it is recommended that gunshot detection sensors not move forward for further evaluation at this time.

- **Solar pavement:** Due to high cost and maintenance requirements, it is recommended that solar pavement strategies not more forward for further evaluation at this time. As the technology improves over time, solar pavement could be revisited.
- **Countdown pedestrian signals:** Countdown pedestrian signals are not accessible for the visually impaired, nor do they provide advanced warning to drivers of vehicles that a pedestrian is crossing the road.

- **Roadside sensors:** At an estimated cost ranging from $3,400 to $8,600, including capital costs and O&M costs, per unit for a corridor provided by USDOT, the return on investment (ROI) is considerably low when considering that many of the desired safety outcomes of the roadside sensors can be derived by implementing other technologies.

- **Navigation assistance for the visually impaired:** Since it appears these are devices worn by the visually impaired and do not require any infrastructure improvements, it is recommended that navigation assistance devices for the visually impaired not move forward for further evaluation.

- **Transit-Vehicle/Pedestrian Warning Applications:** This technology notifies the pedestrian on their phone of nearby vehicles. It is expected that the reaction time for the pedestrian would be limited. Although this technology also notifies the vehicle of pedestrians, due to the high cost, it is expected that other technologies can achieve the same outcome. However, transit-vehicle/pedestrian warning applications for bus drivers are recommended for further evaluation.

- **AI Conversation Agent:** Requires daily maintenance.

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4.4 Other considerations

The following strategies are those that will require a much more robust coordination effort, due to data requirements and scope, between agencies.

- Extreme weather alert systems
- Mobility as a Service
- Real-time transit data and systems coordination
- Integrated system and data exchange

As a result, it is recommended that these four strategies be explored further by the AACIDs in coordination with regional stakeholders, as their scope extends well beyond the Virginia Avenue Smart Corridor.