IBM Center for The Business of Government

Creating Public Value using the AI-Driven Internet of Things

Gwanhoo Lee

The American University

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FOREWORD

On behalf of the IBM Center for The Business of Government, we are pleased to publish this new report, *Creating Public Value using the AI-Driven Internet of Things,* by Professor Gwanhoo Lee, American University.


DANIEL J. CHENOK


MARLON ATTIKEN

Government agencies seek to deliver quality services in increasingly dynamic and complex environments. However, outdated infrastructures—and a shortage of systems that collect and use massive real-time data—make it challenging for the agencies to fulfill their missions. Governments have a tremendous opportunity to transform public services using the "Internet of Things" (IoT) to provide situation-specific and real-time data, which can improve decision-making and optimize operational effectiveness.

In this report, Professor Lee describes IoT as a network of physical "things" equipped with sensors and devices that enable data transmission and operational control with no or little human intervention. Organizations have recently begun to embrace artificial intelligence (AI) and machine learning (ML) technologies to drive even greater value from IoT applications. AI/ML enhances the data analytics capabilities of IoT by enabling accurate predictions and optimal decisions in new ways. Professor Lee calls this AI/ML-powered IoT the "AI-Driven Internet of Things" (AIoT for short hereafter). AIoT is a natural evolution of IoT as computing, networking, and AI/ML technologies are increasingly converging, enabling organizations to develop as "cognitive enterprises" that capitalize on the synergy across these emerging technologies.

Strategic application of IoT in government is in an early phase. Few U.S. federal agencies have explicitly incorporated IoT in their strategic plan, or connected the potential of AI to their evolving IoT activities. The diversity and scale of public services combined with various needs and demands from citizens provide an opportunity to deliver value from implementing AI-driven IoT applications.

Still, IoT is already making the delivery of some public services smarter and more efficient, including public parking, water management, public facility management, safety alerts for the elderly, traffic control, and air quality monitoring. For example, the City of Chicago has deployed a citywide network of air quality sensors mounted on lampposts. These sensors track the presence of several air pollutants, helping the city develop environmental responses that improve the quality of life at a community level. As the cost of sensors decreases while computing power and machine learning capabilities grow, IoT will become more feasible and pervasive across the public sector—with some estimates of a market approaching $5 trillion in the next few years.

Professor Lee's research aims to develop a framework of alternative models for creating public value with AIoT, validating the framework with five use cases in the public domain. Specifically, this research identifies three essential building blocks to AIoT: sensing through IoT devices, controlling through the systems that support these devices, and analytics capabilities that leverage AI to understand and act on the information accessed across these applications. By combining the building blocks in different ways, the report identifies four models for creating public value:

- **Model 1** utilizes only sensing capability.
- **Model 2** uses sensing capability and controlling capability.
- **Model 3** leverages sensing capability and analytics capability.
- **Model 4** combines all three capabilities.

The analysis of five AIoT use cases in the public transport sector from Germany, Singapore, the U.K., and the United States identifies 10 critical success factors, such as creating public value, using public-private partnerships, engaging with the global technology ecosystem, implementing incrementally, quantifying the outcome, and using strong cybersecurity measures. Based on these critical success factors derived from the five case studies, Professor Lee outlines a set of recommendations for government agencies considering AIoT implementation, addressing topics that include data quality, security, public-private partnerships, and reducing potential bias. These recommendations are formulated to inform leaders at all levels of government.

This report joins a library of earlier IBM Center reports on topics related to AI/ML and IoT, including *Innovation and Emerging Technologies in Government: Keys to Success* by Dr. Alan Shark; *Risk Management in the AI Era: Navigating the Opportunities and Challenges of AI Tools in the Public Sector* by Justin Bullock and Matthew Young; *More Than Meets AI: Part II, Improving Outcomes in Government through Data and Intelligent Automation, The Rise of the Sustainable Enterprise: Using Digital Tech to Respond to the Environmental Imperative,* and *Managing Cybersecurity Risk in Government* by Anupam Kumar, James Haddow, Rajni Goel; and *Delivering Artificial Intelligence in Government: Challenges and Opportunities* by Kevin Desouza.

Professor Lee's report provides a new and important roadmap for governments at all levels to take advantage of the promise that AI and IoT hold for improving public services and operational effectiveness.

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EXECUTIVE SUMMARY

AI-Driven Internet of Things (AIoT) refers to the Internet of Things (IoT) enhanced by the power of artificial intelligence (AI) and machine learning (ML) capabilities.

Although it has great potential for creating public value, its successful deployment requires a clear focus on public value, a well-formulated implementation strategy and new kinds of organizational and technological capabilities. This research aims to develop a framework of alternative models for creating public value with AIoT and validate it with five use cases in the public domain. Specifically, this research identifies three essential building blocks to AIoT: sensing, analytics, and controlling capabilities. By combining the building blocks in different ways, the following four models for public value creation are presented:

- **Model 1** utilizes only sensing capability.
- **Model 2** uses sensing capability and controlling capability.
- **Model 3** leverages sensing capability and analytics capability.
- **Model 4** combines all three capabilities.

The analysis of five AIoT use cases in the public transport sector from Germany, Singapore, the U.K., and the United States identifies the following critical success factors:

- Focusing on creating public value
- Public-private partnerships
- Engaging with global technology ecosystem
- Incremental implementation approach
- Quantifying the outcome
- Addressing privacy issues
- Strong cybersecurity measures
- Expecting the unexpected
- Using data to create value in multiple ways
- Advanced wireless network infrastructure

This study discusses several risks associated with developing and deploying AIoT applications in the public domain. They include:

- Cybersecurity and privacy risks
- Lack of interoperability
- Inadequate wireless networks
- Premature, defective technology
- ML algorithm bias
- Maintenance

Finally, this report presents the following recommendations for government leaders to consider when planning and executing public AIoT systems.

- Develop a strategy for creating public value with alternative models
- Make your AIoT projects value-driven, not technology-driven
- Experiment, validate, and then scale
- Develop a data strategy for AIoT
- Promote “Security by Design” and “Privacy by Design” approaches
- Find alternative solutions to the ‘notice and consent’ framework for privacy protection
- Leverage external resources and capabilities
- Coordinate with other government agencies
- Promote public-private partnership
- Monitor and address errors and biases of ML algorithms

INTRODUCTION

The Internet of Things (IoT) can transform the way the government operates and serves the public.[1] Government agencies are mandated to deliver quality services in increasingly dynamic and complex environments.

However, outdated infrastructures and lack of systems collecting and utilizing massive real-time data make it challenging for the agencies to fulfill their missions. Governments have a tremendous opportunity to transform public services using IoT that is capable of providing situation-specific, real-time data, driving better decision-making, and optimizing operational conditions. However, strategic application of IoT in government is still in an early phase. Few U.S. federal agencies have explicitly incorporated IoT in their strategic plan. The diversity and scale of public services combined with various needs and demands from citizens may complicate government's attempts to implement IoT applications.

Despite those challenges, IoT is already making the delivery of some public services smarter and more efficient, including public parking, water management, public facility management, safety alerts for the elderly, traffic control, and air quality monitoring. For example, the City of Chicago has deployed a citywide network of air quality sensors mounted on lampposts. These sensors track the presence of a number of air pollutants. With increasingly cheaper sensors, computing power, and networking capabilities, IoT will become more pervasive in the public sector.[2] It was estimated that there could be $4.6 trillion at stake for the public sector between 2013 and 2022.[3]

While there are many definitions of IoT, it is defined in this report as a network of physical "things" equipped with sensors and actuators that enable data transmission and operational control with no or little human intervention. IoT has recently begun to embrace artificial intelligence (AI) and machine learning (ML) technologies to create even greater value. AI/ML takes the data analytics capabilities of IoT to the next level by enabling accurate predictions and optimal decisions that were previously impossible.[4] In this report, I will call this AI/ML-powered IoT the AI-Driven Internet of Things (AIoT for short hereafter). AIoT is a natural evolution of IoT as computing, networking, and AI/ML technologies are increasingly converging.

Although meaningful applications of AIoT in the public sector are nascent, the private sector has been embracing it. Venture capital funding of AIoT startups is growing rapidly, and major vendors of IoT platforms are integrating AI/ML capabilities. It is predicted that 80 percent of enterprise IoT projects will include an AI/ML component.[5] Companies are already experimenting or implementing AIoT systems to deliver new business value. For example, Hershey, one of the largest chocolate manufacturers globally, used AIoT to reduce weight variability during pro-

1. Lee, Gwanhoo. "What roles should the government play in fostering the advancement of the internet of things?." *Telecommunications Policy* 43, no. 5 (2019): 434-444.

2. Laura DeNardis, *The Internet in everything: Freedom and security in a world with no off switch,* (Yale University Press, 2020).

3. Joseph Bradley, Christopher Reberger, Amitabh Dixit, and Vishal Gupta. "Internet of everything: A $4.6 trillion public-sector opportunity," *Cisco white paper* (2013).

4. Matt Beane, "Learning to work with intelligent machines." *Harvard Business Review* 97, no. 5 (2019): 140-148.

5. Tom Austin and Mark Hung, "AI on the Edge: Fusing Artificial Intelligence and IoT Will Catalyze New Digital Value Creation," Gartner Group (2017).

duction by accurately predicting weight variability and enabling 20 times more frequent process adjustments than before. This AIoT application lowered production costs significantly, as one percent improvement in weight precision can save $500,000 for a 14,000-gallon batch of the product.[6] Other large organizations, including GE, Google, French power utility EDF Group, Progressive, Rolls-Royce, South Korean oil refiner SK Innovation, and Thomas Jefferson University Hospital in Philadelphia, have implemented AIoT applications to reduce equipment downtime, manage risks, improve safety, and enable new product/service offerings.[7]

The early successes of AIoT applications in the private sector suggest that there is potential for AIoT to create new value in the public sector. However, for effective implementation, the deployment of AIoT applications requires a clear focus on public value, a well-formulated strategy, and new kinds of organizational and technological capabilities.[8] Otherwise, government investments in AIoT will be wasted without producing meaningful results. Therefore, government leaders need a sound framework that can guide their deployment of AIoT applications. Furthermore, since the public sector context is different from the private sector context, it is important to learn lessons from early applications of AIoT in the public domain. By doing so, government leaders will better understand critical success factors as well as risks associated with AIoT applications.

In this report, I first propose three essential technological capabilities, namely sensing, analytics, and controlling, as building blocks for creating new value. Then, I present a framework of four value creation models for AIoT applications that leverage the three capabilities. These different models produce different kinds of public value, ranging from increased awareness of the current status of public assets, reduced human errors, better predictions and decisions, and optimized, adaptive operation. I introduce five use cases of AIoT applications in the public transport sector, which match the four different value creation models. From a careful analysis of the use cases, I identify critical success factors for AIoT applications in the public sector and discuss the risks associated with public AIoT, including privacy concerns, cybersecurity breaches, and ML biases. Finally, I make a set of recommendations for helping government leaders to effectively plan and execute AIoT applications to harvest new public value.

6. Alec Shirkey, “Sweet IoT Journey: How One Solution Provider Helped Implement Microsoft Azure Machine Learning at Hershey,” RCN, September 19, 2017, https://www.crn.com/news/internet-of-things/300092351/sweet-iot-journey-how-one-solution-provider-helped-implement-microsoft-azure-machine-learning-at-hershey.htm.

7. Schatsky, Kumar, and Bumb, "Intelligent IoT."

8. Michael E. Porter and James E. Heppelmann, "How smart, connected products are transforming competition." *Harvard Business Review* 92, no. 11 (2014): 64-88.

A Framework for Creating Value with AIoT

Given my research, I have identified three essential technological capabilities of AIoT that are building blocks for value creation: sensing, analytics, and controlling. AI/ML technologies can enhance these capabilities by preventing errors, improving accuracy, and discovering obscure patterns. As a result of delivering useful insights close to where the data is captured in a network, AI-powered IoT systems produce so-called edge intelligence. In this section, I discuss the three building blocks of AIoT systems. Then, I present four different value creation models that combine the building blocks differently.

Technological Capabilities as Building Blocks of AIoT

Sensing capability

AIoT systems are equipped with smart sensors. A smart sensor is a sensor that can convert and process data and send it to external devices, edge servers, and cloud servers. A traditional base sensor becomes a smart sensor when it is paired with data processing and communication capabilities. A smart sensor typically includes a base sensor, a microprocessor, a memory, a communication module, and a power source. Many different types of sensors are being used for AIoT systems. Some of the most widely used sensors include:

- **Temperature sensors** measure the amount of heat energy in a source and detect temperature changes.
- **Proximity sensors** detect the presence of nearby objects.
- **Pressure sensors** measure pressure of gases or liquids.
- **Water quality sensors** detect the quality of water and monitor ions.
- **Chemical sensors** detect chemical changes in air or liquid.
- **Gas sensors** detect changes in air quality.
- **Smoke sensors** sense the level of smoke (airborne particulates and gases).
- **Infrared sensors** measure the heat emitted by objects.
- **Level sensors** determine the level of substances including liquids and powders.
- **Image sensors** convert optical images into electronic signals.
- **Motion detection sensors** detect physical movement of objects or human beings.
- **Accelerometer sensors** measure an object's acceleration.
- **Gyroscope sensors** measure angular rate or angular velocity.
- **Humidity sensors** measure the amount of water vapor in the atmosphere of air.
- **Optical sensors** convert the physical quantity of light rays into electrical signals.

AI/ML technologies can enhance the performance of smart sensors. ML algorithms, especially, can significantly improve the accuracy of image recognition for applications such as video surveillance. As the algorithms continue to be trained with new data, their accuracy continues to improve.

Analytics capability

The data collected from smart sensors cannot create value unless they are used. Analytics capabilities turn raw data into information, knowledge, and insights that help make better predictions or decisions. With the advent of big data, analytics methods and tools have become much more powerful and sophisticated. The advances in technologies have enabled complex data processing to take place close to where the data is collected by sensors, leading to edge intelligence. Many technology companies, including Amazon, AT&T, GE, Google, IBM, Microsoft, Oracle, Salesforce, and SAS, offer IoT analytics platforms and solutions that facilitate exploratory analysis as well as hypothesis testing. With these tools, sensor data can be used for descriptive, diagnostic, predictive, and prescriptive analytics.[9] AIoT analytics tools typically have the following features:

- **Data modeling**—AIoT analytics tools provide data models for data generated by smart sensors. Data modeling is useful for revealing patterns and relationships in big data.
- **Data filtering**—Smart sensors may generate an enormous volume of data. AIoT analytics solutions include filtering capabilities, allowing users to collect the most relevant data.
- **Event scheduling**—AIoT analytics tools can determine when to generate reports of analytics results. They also allow users to track AIoT data in response to certain events such as significant environmental changes or equipment breakdowns.

Controlling capability

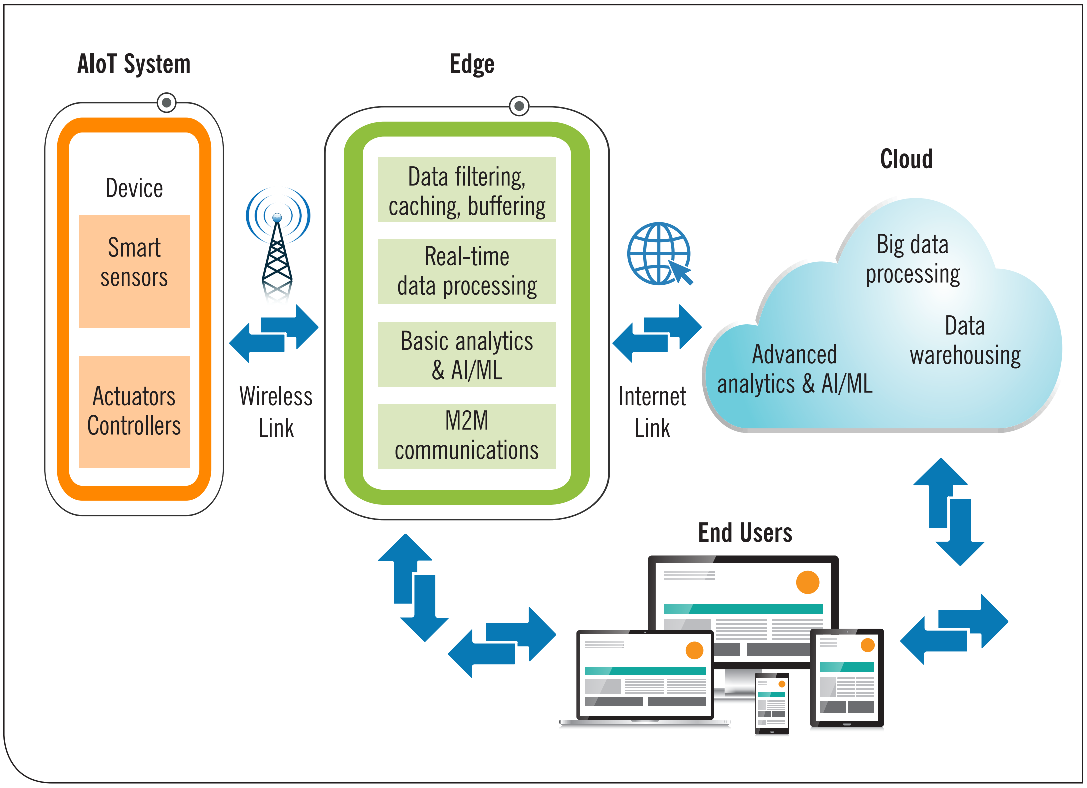
Sensor data can be used to control the AIoT system for optimal operation. In some cases, advanced analytics is applied for the data to inform how to control the system. In other cases, such advanced analytics is not necessary as simple calculations and rules are enough to turn sensor data into actions. An actuator takes an electrical input and turns it into physical action. Thus, actuators operate in the reverse direction of a sensor. An actuator can act based on its environment to enable correct operation of the system into which it is embedded. Actuators are grouped into four categories based on their construction pattern and the role they play in AIoT systems:

- **Linear actuators** enable motion of objects in a straight line.
- **Motors** enable precise rotational movements of device components or whole objects.
- **Relays** operate power switches in lamps, heaters, or smart vehicles.
- **Solenoids** lock or trigger devices; control gas and water systems.

Figure 1 depicts a conceptual diagram of an AIoT system comprised of sensing, analytics, and controlling capabilities. The data collected by smart sensors in the system are sent to edge servers, where they are filtered, cached, buffered, and processed. Basic analytics and AI/ML algorithms may be used there as well. Not all AIoT systems use edge computing, but it has become increasingly popular. Edge servers send a bulk of data periodically to cloud servers for more permanent storage and in-depth analysis using advanced analytics and sophisticated AI/ML algorithms. The analytics results are sent from edge servers and cloud servers to end-users. These results are then displayed on mobile apps and/or websites.

9. Vishal Mehta, "Four Types of Business Analytics to Know," Analytics Insight, October 13, 2017, https://www.analyticsinsight.net/four-types-of-business-analytics-to-know.

Figure 1. A conceptual diagram of an AIoT system



Value Creation Models for AIoT

The three technological capabilities of AIoT outlined in the previous section can be combined in different ways to enable four different value creation models. Table 1 shows technological capabilities leveraged for each value creation model and the main value each model individually delivers. The table also references use cases in the public transport sector for the models. A detailed description and an analysis of these use cases are presented in the next section.

Table 1. Four Models for Creating Value with AIoT

Model	Technological capability			Main value	Use case in the public transport
	Sensing	Analytics	Controlling		
Model 1	●			Awareness of status	Smart parking
Model 2	●		●	Preventing human errors	Smart traffic control
Model 3	●	●		Predictions & decisions	Smart bicycle routes
Model 4	●	●	●	Optimized, adaptive operation	Autonomous bus Smart highways

Model 1 uses only sensing capability to create new public value. Smart sensors collect data such as image, sound, light, location, movement, speed, temperature, air quality, etc., and send them to the server in the cloud. AI/ML technology can improve the accuracy of the data by using pattern recognition algorithms. Once the data is collected, cleansed, and stored, it can be shared with the public via web browsers and mobile apps. The primary value created by this model is increased awareness of the current state of 'things.' In public transport, ‘things’ could include parking spots, vehicles, bikes, roads, traffic lights, and more. By making accurate, real-time data available to the public, AIoT systems based on this model can help reduce uncertainties when using public transport systems. For these systems, real-time collection and dissemination of data are crucial for success.

Model 2 involves controlling capability as well as sensing capability to deliver new public value. Sophisticated, advanced analytics techniques are not used in this model. Instead, simple calculations or rules determine how to control a certain system based on the data collected by sensors. For example, simple calculations of queues of an intersection can help control the interval of traffic lights. One of the main benefits of the AIoT systems in this category is preventing human errors when controlling public assets. Strong cybersecurity measures are important for the AIoT systems in this category because hackers could take over the operation of public systems.

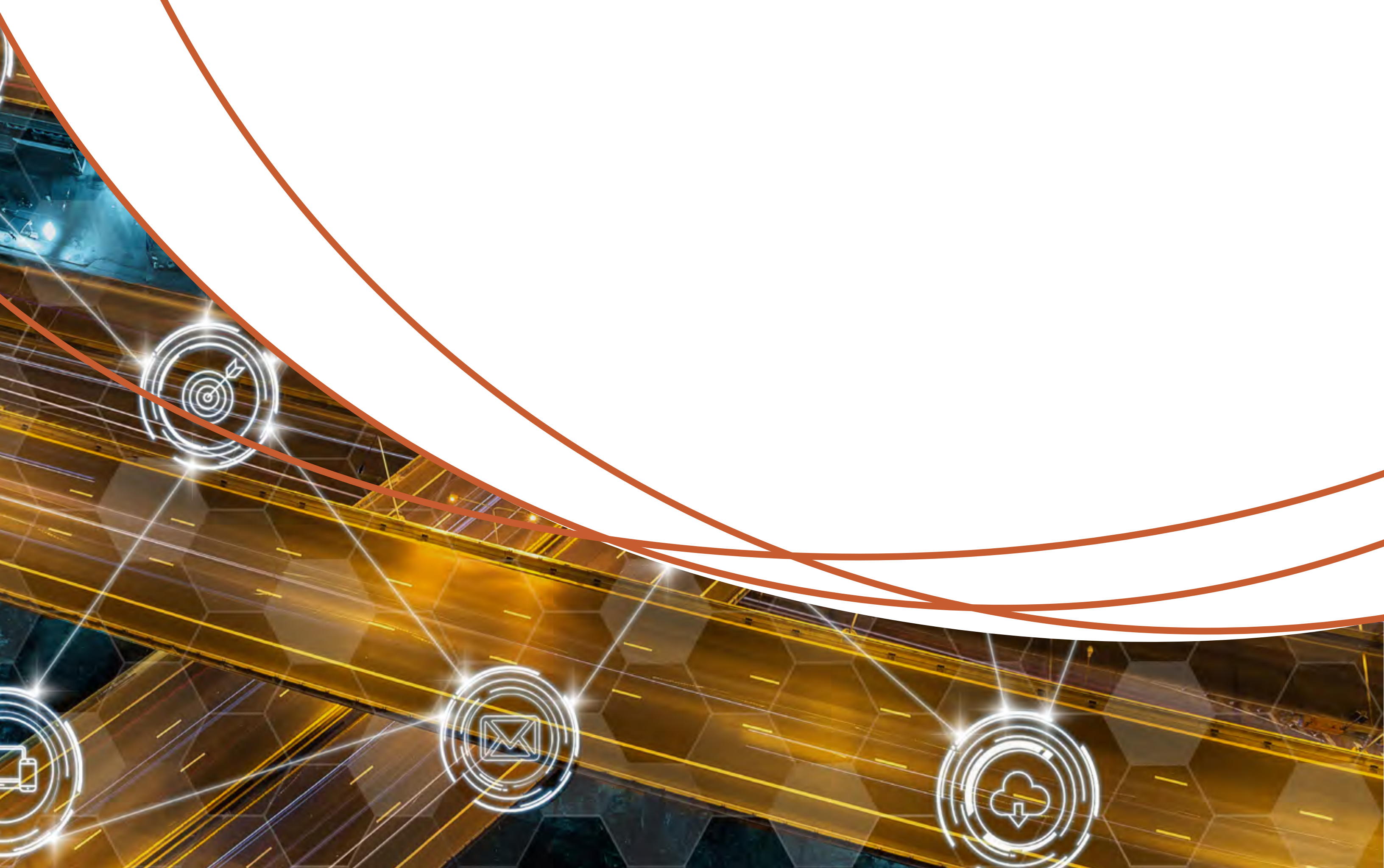
Model 3 leverages analytics capability as well as sensing capability to generate new public value. With this model, AIoT systems are not intended to control systems. Instead, the main value of this model is to support better predictions and optimal decisions. As the data collected by sensors are accumulated in the cloud, the data’s potential value increases. Advanced analytics methods and tools can help discover important data patterns that humans cannot easily detect due to the complexity and size of the data. For example, an in-depth analysis of traffic volume and flow in busy streets can help public administrators accurately predict the impact of certain changes to public transport systems. Thus, the administrators are better equipped to make optimal decisions about public transport systems. AI/ML algorithms can strengthen these analytics capabilities because their accuracy improves continuously as they are trained with more data. As the volume of data exponentially increases, it is important to have robust data processing capability to handle such data.

Model 4 combines all three capabilities. This model, among others, represents the most advanced and sophisticated way of producing new public value. The AIoT systems based on this model can deliver tremendous value as their operation can be continuously optimized by adapting to changing environments. However, the seamless integration of the three technological capabilities might require not only reliable technologies but also in-depth knowledge and skills gained from prior experience with AIoT systems. The AIoT system in this category needs to sense and analyze a large volume of data and control the system in real time. Therefore, no network latency is a critical condition. Furthermore, even if individual technologies may work well, integrating them into an autonomous, adaptive system could be a daunting task. For example, autonomous public buses may have to cope with many unknown challenges as they are implemented. AI/ML algorithms can improve the safety of autonomous vehicles by reducing critical errors as they continue to learn anomalies and exceptions.

The four models for creating value with AIoT require different levels of technological and organizational maturity. Therefore, the logical trajectory for government agencies is to start with Model 1, which only requires sensing capability and yet could pick the low-hanging fruit. In the next stage, agencies may pursue Model 2 and Model 3. However, compared to controlling capability, the development of analytics capability typically takes more time and resources and as it requires developing not only technological capability but also training employees on data analytics. Therefore, agencies are likely to adopt Model 2, followed by Model 3. Finally, agencies may implement Model 4 applications once they developed mature capabilities for sensing, analytics, and controlling. However, agencies may adapt the trajectory to suit their capability and priority.

In the next section, I discuss five use cases in the public transport sector to illustrate how AIoT systems are creating new public value with different value creation models.

Use Cases in the Public Transport Sector



Smart Parking in Cologne, Germany (Model 1)

Background

Cologne, Germany, was ranked as the third most congested city in Europe in 2015.[10] On average, drivers in Cologne spend 71 hours per year sitting in traffic. The search for parking in Europe accounts for 30 percent of urban traffic; this urban traffic accounts for 8 percent of Europe's CO2 emissions. In attempts to reduce traffic congestion and CO2 emissions, the City of Cologne has invested significant resources towards its transformation into a smart city.

In 2011, the SmartCity Cologne Program (SCC) was launched by the City of Cologne and Rhein-Energie AG, Germany's fifth-largest energy supplier.[11] The SCC is a platform for various projects on climate protection and the energy transition. It brings individuals and corporations together to reduce emissions and increase innovation, digitalization, and mobility.[12] It conducts innovative product-testing at more than 15 locations across the city. The centrally-located Neusser Street, often referred to as 'Climate Street,' has been the site of testing for more than 50 projects, including smart parking sensors.[13] Rhein-Energie AG partnered with Cleverciti, a parking solution provider, to develop and deploy smart parking sensors with the goal of significantly decreasing traffic congestion and CO2 emissions in Cologne.[14]

How the System Works

Eighty-nine sensors have been deployed along Neusser Street in Cologne Nippes, a heavily populated and trafficked urban district of Cologne. Unlike other parking sensors, Cleverciti does not use ground sensors. Instead, overhead sensors are mounted on existing lampposts along the road to collect data efficiently and unobtrusively.[15] Each sensor can monitor a maximum of 100 parking spaces. Currently, 89 sensors monitor approximately 800 street-parking spaces. The sensors utilize AI and edge computing to detect and recognize the GPS coordinates of available parking spaces. For privacy purposes, the system does not involve license plate recognition. The sensors conduct image processing using AI and edge computing and then instantaneously transmit space availability data to 360-degree omnidirectional LED displays located at road intersections.[16] Drivers at these intersections can know the exact amount of available parking spaces without needing to drive down the road. Figure 2 illustrates a smart parking sensor and an omnidirectional LED displays installed on the street. Figure 3 depicts the locations of the LED displays in the District of Nippes in Cologne.

10. Chloe Pantazi, "These 10 cities have the worst traffic jams in Europe," *Insider,* March 16, 2016, https://www.businessinsider.com/cities-with-the-worst-traffic-in-europe-2016-3.

11. "SmartCity Cologne: Projects for a modern city," *SmartCity Cologne,* https://www.smartcity-cologne.de/ (accessed March 2, 2021).

12. "Cleverciti deploys World's most Comprehensive on-street parking guidance system in the city of Cologne," *Parking Network,* February 18, 2020, https://www.parking-net.com/parking-news/cleverciti-systems-gmbh/on-street-parking-guidance-system-in-cologne.

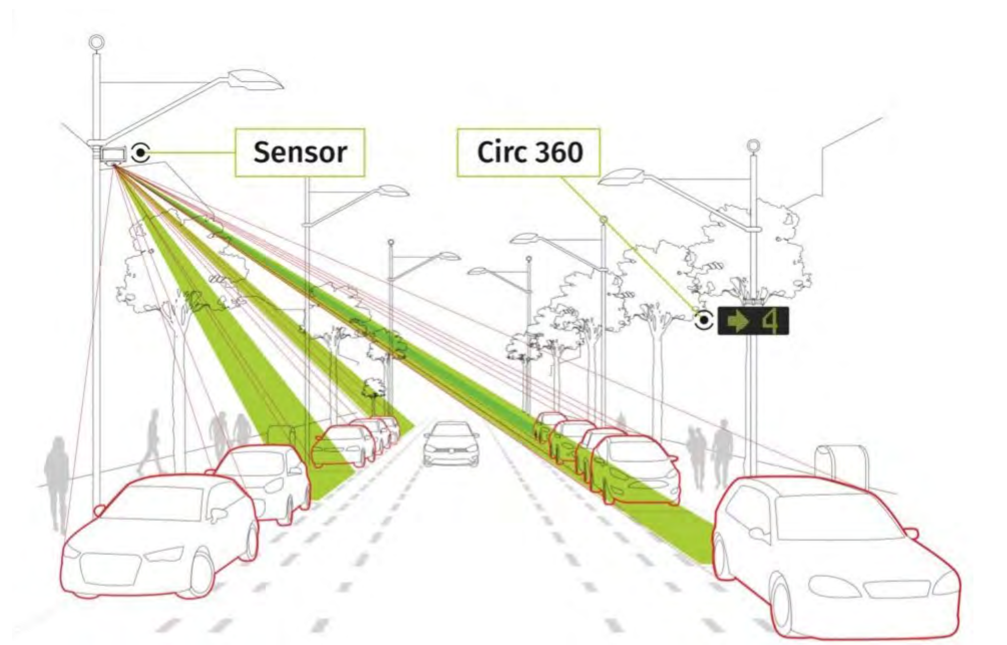
13. Ibid.

14. "Cleverciti Systems Flip the Switch on the World's Most Comprehensive Intelligent Parking Guidance System in Cologne," *Parking Network,* June 3, 2020, https://www.parking-net.com/parking-news/cleverciti-systems-gmbh/flips-switch-on-comprehensive-intelligent-parking-guidance-system.

15. Ibid.

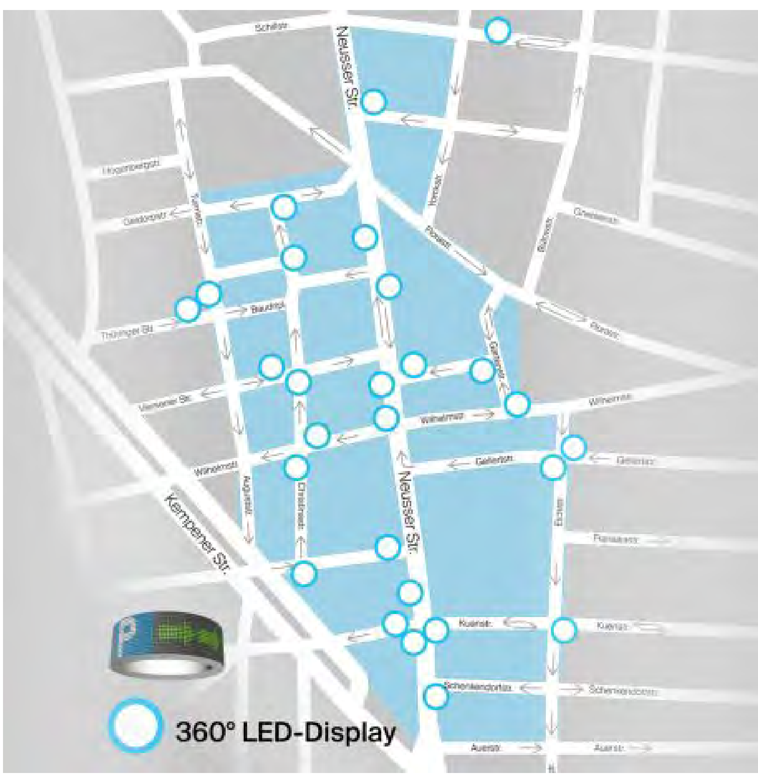
16. "Cleverciti Shares Smart City Insights on Parking Talks," *Parking Network,* March 7, 2019, https://www.parking-net.com/parking-news/cleverciti-systems-gmbh/shares-smart-city-insights-on-parking-talks.

Figure 2: Diagram of a smart parking sensor and an omnidirectional LED display



Source: https://www.cleverciti.com/en/.

Figure 3: Locations of omnidirectional LED displays in the District of Nippes in Cologne



Source: https://blog.rheinenergie.com/index.php/detailseite-totallokal/parkpilot-so-machen-wir-das-parken-in-nippes-smart.html.

Outcomes

As Cleverciti has deployed their technology in Cologne and other cities, they have adapted their smart parking technology to cope with implementation challenges. For example, parking sensors required additional light to capture images accurately. In response, lights were installed in conjunction with the sensors for additional lighting. Furthermore, while the LED displays reduce drivers' unnecessary roaming, drivers still need to drive by road intersections to read the omnidirectional displays. To expand the accessibility of the parking sensors' data, Cleverciti is testing an app that displays a map of the city with available parking spots as monitored by the sensors.[17] The LED displays were also installed at the entrances of several large cities in Germany to show parking space availability by the city sector.

A study conducted on behalf of the Research Association for Automotive Technology suggests that increased use of AI-based parking technology in German cities could reduce the total hours spent searching for parking by one-third.[18] Germany's National Platform for the Future of Mobility estimates that the deployment of smart parking solutions could reduce CO2 emissions by 900,000 tons annually.[19] The smart parking system in Cologne went live in June 2020, so its public value has not been fully realized yet. However, the early outcomes are encouraging. Citizens provided feedback that they experienced less frustration while driving and a decrease in traffic noise. Furthermore, increasing parking efficiency benefits local businesses that rely on high parking turnover.

Smart Traffic Control in Pittsburgh, Pennsylvania, USA (Model 2)

Background

Pittsburgh, Pennsylvania, ranked 29th out of 297 cities in the U.S. in 2017 for the longest traffic waits.[20] According to the 2019 TomTom study, Pittsburgh drivers spent 87 extra hours on their commute throughout the year because of rush hour traffic.[21] In 2012, Pittsburgh implemented the Scalable Urban Traffic Control (SURTRAC) system to better control the city's traffic and reduce commuter's travel time. SURTRAC was developed by researchers at Carnegie Mellon University, and then was commercialized by Rapid Flow Technologies, an intelligent transportation systems provider spun out of Carnegie Mellon University.[22] SURTRAC's initial trial period in 2012 including nine intersections proved highly successful.[23] Between 2012 and 2015, SURTRAC was implemented at 50 intersections across Pittsburgh. Figure 4 depicts the locations of the 50 intersections which implemented the SURTRAC system. These intersections ranged from low to high traffic, with one intersection averaging 35,000 vehicles per day.[24]

17. "Cleverciti Systems Flip the Switch."

18. "Research Association for Automotive Technology (FAT)," *Verband der Automobilindustrie,* https://www.vda.de/en/topics/innovation-and-technology/fat/the-fat (accessed March 2, 2021).

19. "Cleverciti deploys World's most."

20. Julie Pawlikowski, "The 6 Most Common Traffic Jams in Pittsburgh," *Pittsburgh Magazine,* April 13, 2018, https://www.pittsburghmagazine.com/the-6-most-common-traffic-jams-in-pittsburgh/.

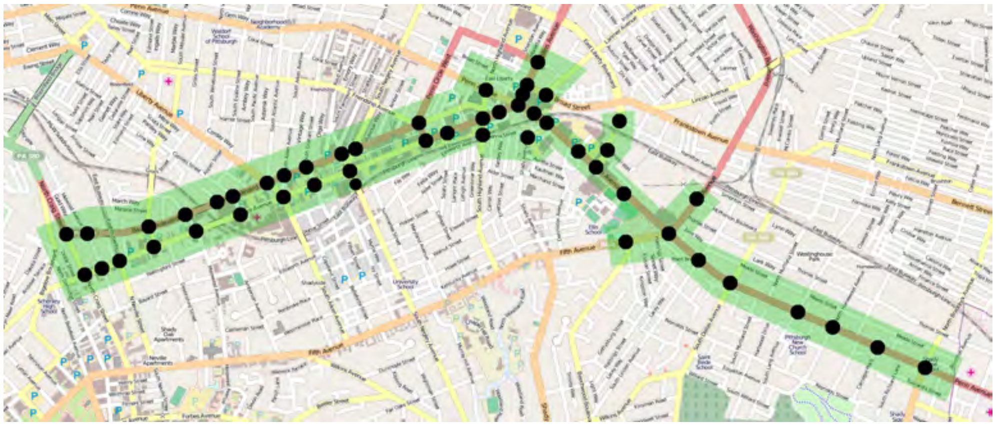
21. "Traffic 2019 Index," *TomTom,* https://www.tomtom.com/en_gb/traffic-index/pittsburgh-traffic/ (accessed March 2, 2021).

22. "Pittsburgh cuts travel time by 25% with smart traffic lights," *Apolitical,* August 14, 2017, Available: https://apolitical.co/en/solution_article/pittsburgh-cuts-travel-time-25-smart-traffic-lights.

23. Heidi Opdyke, "Surtrac Allows Traffic to Move at the Speed of Technology," *Carnegie Mellon University,* October 25, 2019, https://www.cmu.edu/news/stories/archives /2019/october/traffic-moves-at-speed-of-technology.html.

24. "Surtrac Deployment at Urban Grid Networks in Pittsburgh Neighborhoods," *Rapid Flow,* August 30, 2018, https://www.rapidflowtech.com/blog/surtrac-deployment-at-urban-grid-networks-in-pittsburgh-neighborhoods.

Figure 4: Locations of SURTRAC system locations



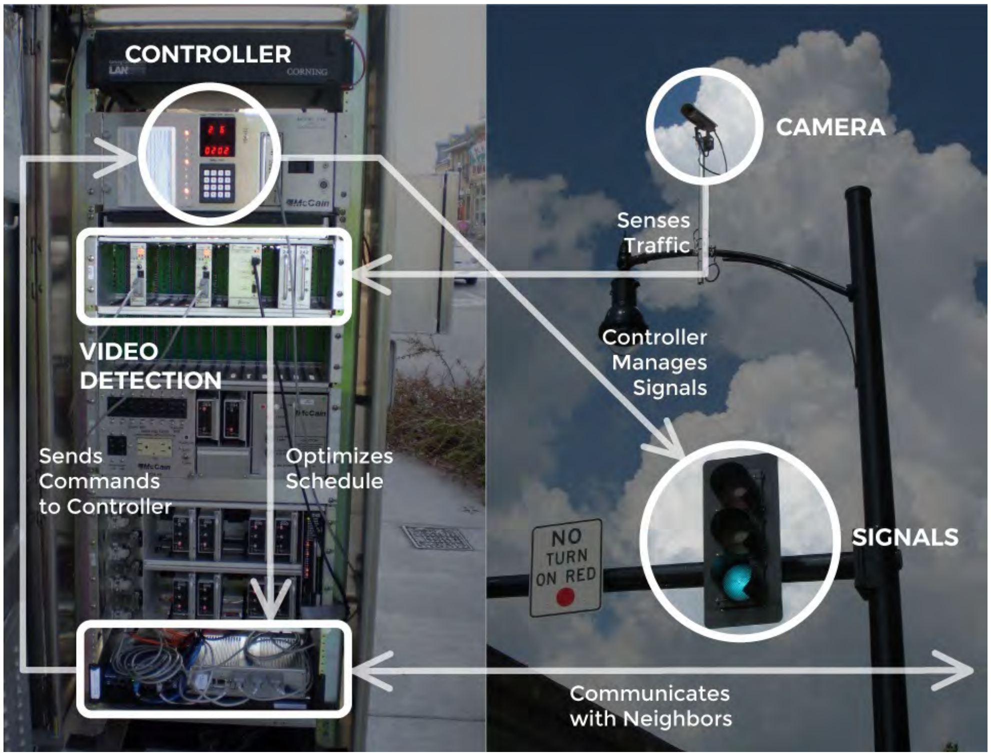
Source: https://www.rapidflowtech.com/blog/surtrac-deployment-at-urban-grid-networks-in-pittsburgh-neighborhoods.

How the System Works

The SURTRAC system is decentralized and easily adaptable to networks of various sizes and shapes. Each intersection is equipped with cameras, radars, and a computer. The cameras and radars can collect information from a distance of approximately 100 meters.[25] AI-based image processing technology logs traffic as clusters of vehicles from each direction of the intersection. This allows the system to prioritize the lighting plan's direction flow based on the size of vehicle clusters and the distance between distinct clusters. The system separates roadways into distinct zones. The amount of time a cluster of vehicles takes to travel through each zone informs the estimated time it will take the vehicles to reach the intersection. This data is then transmitted to the intersection's computer, which interprets the cameras' data on its surroundings, uses scheduling software to construct a lighting plan, and communicates this plan to the controller to coordinate the traffic signals. Intersections also communicate with adjacent intersections regarding vehicles' locations and the estimated time it will take them to reach the next intersection. Communication between intersections is shared through either fiber-optic cable or point-to-point radios. Figure 5 illustrates the communication between the camera, controller, and traffic signal at each intersection. The system is constrained by the limited information available to it. Cameras and radars cannot predict individual drivers' decisions to deviate from the cluster or roadway. Besides, vehicles that enter the roadway between intersections cannot be accounted for in predicted traffic flow patterns.[26]

25. "Pittsburgh cuts travel time."
26. Ibid.

Figure 5: SURTRAC system processes



Source: https://www.rapidflowtech.com/surtrac/how-it-works.

Outcomes

While SURTRAC's use of close-circuit television cameras has raised privacy concerns among road users, SURTRAC's traffic sensors' functionalities are similar to other existing cameras, such as speed cameras, already in use at intersections.[27] The high cost of the SURTRAC system presents a barrier to its widespread adoption, with an installation rate of $20,000 per intersection.[28] Pittsburgh is a largely populated city covering over 58 square miles; while the SURTRAC system covers 200 intersections, its current installation is not exhaustive. Thus far, the estimated cost of the SURTRAC implementation is $4 million.

Despite the challenges associated with privacy issues and costs, the implementation of the smart traffic control technology has produced positive outcomes. It has decreased intersection wait times by 40 percent, vehicle travel time by up to 25 percent, and lowered emissions by a maximum of 20 percent.[29] According to the INRIX Global Traffic Scorecard, Pittsburgh improved its ranking for the longest traffic waits from 29th in 2017 to 34th in 2019. The Department of Mobility and Infrastructure of the City of Pittsburgh plans to deploy the SURTRAC system at an additional 150 intersections between 2019 and 2021, specifically

27. Carnegie Mellon University, "SURTRAC Smart Traffic Light: Non-Market Strategy Analysis Project Report," May 2014, https://www.cmu.edu/epp/people/faculty/course-reports/SURTRAC%20Final%20Report.pdf.
28. Jackie Snow, "This AI traffic system in Pittsburgh has reduced travel time by 25%," *Smart Cities Dive,* July 20, 2017, https://www.smartcitiesdive.com/news/this-ai-traffic-system-in-pittsburgh-has-reduced-travel-time-by-25/447494/.
29. "Pittsburgh cuts travel time."

along major routes to and from downtown Pittsburgh.[30] Since its initial deployment, the system's scope has evolved to include considerations for older adults and individuals with disabilities. For example, mobility advancements allow for pedestrians to communicate with the intersection, requesting longer crossing times. A major goal for the future advancement of the SURTRAC system is direct communication between the system and autonomous vehicles. This capability could potentially decrease travel time by an additional 25 percent.

Smart Cycling Routes, London, U.K. (Model 3)

Background

The City of London in the U.K. is the sixth most congested city for drivers globally. London drivers waste 227 hours a year stuck in traffic, traveling at an average speed of seven miles per hour.[31] To reduce the traffic and promote environmental sustainability, London recently affirmed its commitment to increasing active travel by encouraging citizens to walk or cycle instead of using motor vehicles.[32] The key challenges in this endeavor include improving road safety and optimizing cycling routes for cyclists.[33] Information on rates of active travel and road safety for pedestrians and cyclists is critical to the success of London's investment in active travel.

Before 2018, Transport for London (TfL), a government body responsible for London's transportation operations, gathered information on road traffic manually. These manual counts were severely limited geographically and temporally. In 2018, TfL began testing the Cycling Sensors utilizing AI technology to gather anonymized information on road traffic. These sensors developed by Vivacity Labs went through a trial phase consisting of two sensors placed at strategic locations in Central London.[34] Given the successful trial, 20 proposed locations for 43 additional sensors were announced in January 2020.

How the System Works

Using AI technology, Vivacity Labs' sensors gather information and analyze road traffic 24/7 at multiple locations across London, touting a 98 percent accuracy rate.[35] The sensor begins by identifying potential motorists in its field of vision. Figure 6 illustrates how AI, trained to understand road transport, analyzes each motorist and categorizes them into forms of transportation: Pedestrian, Car, Van, Cyclist, Truck, Bus, Motorbike, etc. Once the transportation has been categorized, the sensors employ an Anonymization Filter, which discards the video and retains only the data.[36] This anonymized data is then transmitted to Vivacity Labs, where it is analyzed by AI algorithms and then shared with TfL and local governments. The sensors have the ability to receive software updates remotely and to immediately capture new datasets. Figure 7 depicts the flow of information from the sensor to the dataset. Informed by the sensors' data, London aims to increase pedestrian and cyclist traffic by improving roadways and prioritizing travel.

30. Bob Bauder, "Pittsburgh Plots 2019 Expansion of Smart Traffic Lights," *Government Technology*. November 29, 2018, https://www.govtech.com/fs/infrastructure/Pittsburgh-Plots-2019-Expansion-of-Smart-Traffic-Lights.html.

31. Cathy Adams, "London Drivers Spend 227 Hours Each Year in Traffic," *The Independent,* February 12, 2019, https://www.independent.co.uk/travel/news-and-advice/london-uk-most-congested-cities-traffic-hours-driving-roads-busy-birmingham-glasgow-manchester-a8775056.html.

32. "Local councils choose Vivacity Labs for Active Travel insights ahead of funding deadline," *Vivacity Labs,* August 5, 2020, https://vivacitylabs.com/local-councils-choose-vivacity-labs-for-active-travel-insights-ahead-of-funding-deadline/.

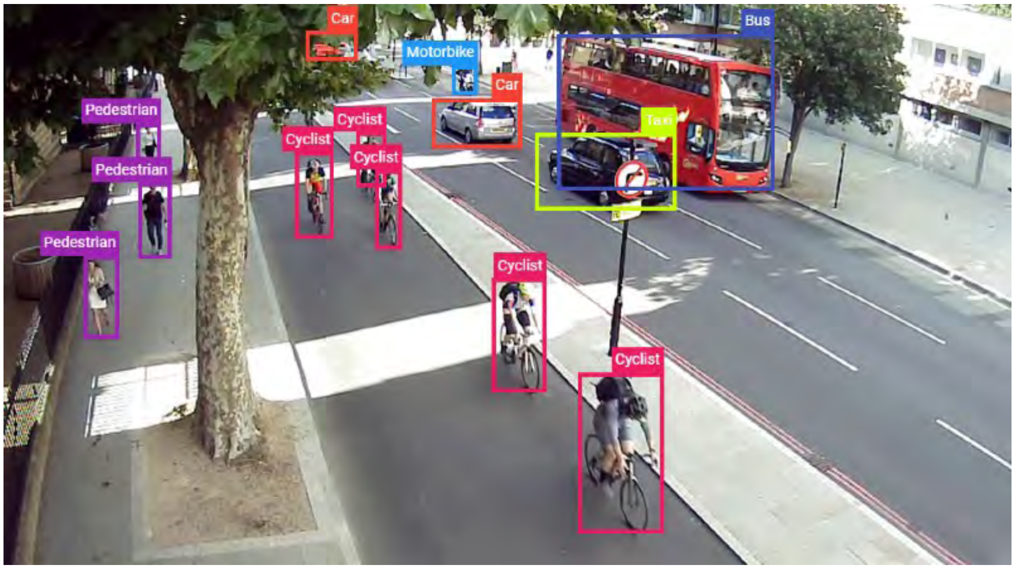
33. Mark Nicholson, "A virtuous cycle: how councils are using AI to manage healthier travel," *Information Age,* September 4, 2020, https://www.information-age.com/virtuous-cycle-how-councils-are-using-ai-manage-healthier-travel-123491379/.

34. Sam Mehmet, "TfL tests AI technology to plan and operate new cycle routes in London," *Intelligent Transport News,* January 16, 2020, https://www.intelligenttransport.com/transport-news/94780/tfl-tests-ai-technology-to-plan-and-operate-new-cycle-routes-in-london/.

35. "Local councils choose Vivacity Labs."

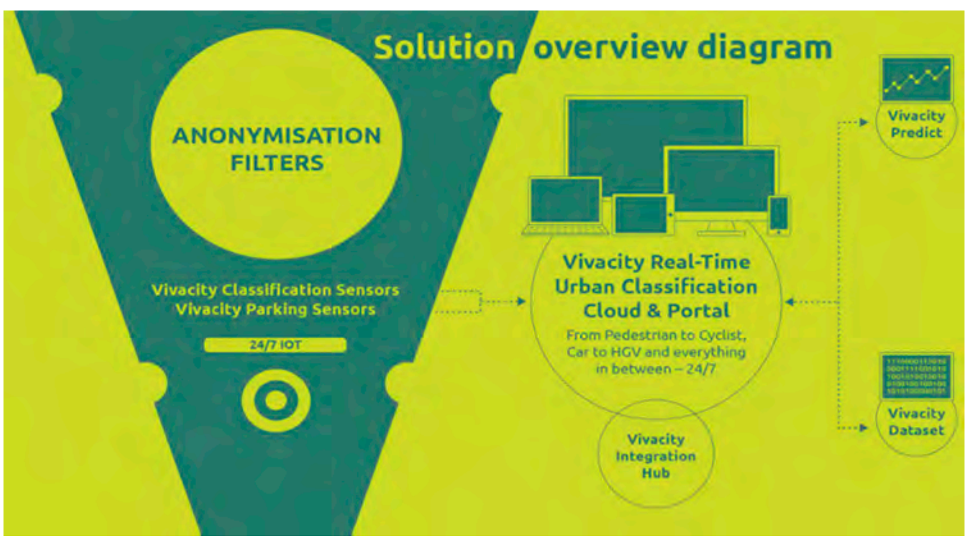
36. "Technology," *Vivacity Labs,* https://vivacitylabs.com/technology/#use-cases (accessed March 2, 2021).

Figure 6: Sensor Analysis



Source: https://cyclingindustry.news/vivacity-labs-to-provide-active-travel-insights-to-local-councils/.

Figure 7: Solution Overview Diagram



Source: https://vivacitylabs.com/technology/#use-cases.

Outcomes

In April 2020, it was reported that cycling had increased 250 percent in select areas of London when compared to earlier in the year.[37] As the U.K. commits resources for increasing active travel, the demand for AI sensors increases. More than 30 U.K. councils have adopted the technology by August 2020.[38] Data collected from the sensors has already informed changes to roadways in the facilitation of active travel. TfL and local governments have used this data to begin redesigning road junctions, with increased priority given to cyclists.[39] In addition to providing datasets, Vivacity Labs can provide traffic-flow predictions using AI technology. In May 2020, they released a new product that tracks "interaction patterns," which monitors cyclists using pavement and "dangerous undertaking manoeuvres."[40] Studying information from these sensors will increase road safety for cyclists. By expanding the sensors' monitoring capabilities, TfL will be able to rely on more data when making improvements to road design.

Autonomous Public Bus, Singapore (Model 4)

Background

Singapore's roadways and transport infrastructures occupies 12 percent of its land.[41] With more than one million vehicles on the roads, Singapore is dedicated to optimizing efficiency for vehicles, drivers, and commuters. In 2020, Singapore ranked first among the countries most prepared for autonomous vehicles.[42] Singapore's Land Transport Authority believes autonomous vehicles can improve the accessibility and connectivity of their public transport system.[43] The Ministry of Transport, Sentosa Development Corporation, and ST Engineering Ltd. collaborated on the development of autonomous on-demand mobility vehicles for intra-island travel in Sentosa.[44] In August 2019, public trials were launched following successful nonpublic on-road tests. Two autonomous minibuses and two smaller driverless shuttle buses transported passengers along the 5.7 kilometer route.[45]

How the System Works

Figure 8 illustrates a driverless shuttle bus on the first day of the public trial on Sentosa Island. Commuters can request shuttle rides via a mobile app "Ride Now Sentosa" or kiosks located at select shuttle stops along the 5.7 kilometer route.[46] The shuttles use sensors and navigation controls, including light detection and ranging sensors (LIDAR), stereo-vision

37. Press Association, "Cycling surges on sunny weekends during coronavirus lockdown," *Daily Echo,* April 20, 2020, https://www.bournemouthecho.co.uk/news/national/18392586.cycling-surges-sunny-weekends-coronavirus-lockdown/.

38. "Local councils choose Vivacity Labs."

39. "Vivacity Labs Releases New Product to Support Government on Urgent £250m Active Travel Initiative," *Realwire,* May 27, 2020, https://www.realwire.com/releases/Vivacity-Labs-Releases-New-Product-to-Support-Government.

40. Ibid.

41. "Transport," *Smart Nation Singapore,* https://www.smartnation.gov.sg/what-is-smart-nation/initiatives/Transport (accessed March 2, 2021).

42. Abigail Ng, "Singapore has big driverless ambitions and the pandemic is unlikely to stop them," *CNBC,* September 21, 2020, https://www.cnbc.com/2020/09/22/singapore-hopes-to-take-its-driverless-ambitions-to-the-public.html.

43. "Autonomous Vehicles," *Land Transport Authority,* https://www.lta.gov.sg/content/ltagov/en/industry_innovations/technologies/autonomous_vehicles.html#:~:text=Set%20to%20transform%20land%20transport,in%20the%20land%20transport%20industry (accessed March 2, 2021).

44. "ST Engineering Driving Development of Autonomous Vehicles for Urban Mobility," *ST Engineering,* April 10, 2017, https://www.stengg.com/en/newsroom/news-releases/st-engineering-drives-development-of-autonomous-vehicles-for-urban-mobility/.

45. Sam Forsdick, "Driverless bus hits the roads of Singapore in first public trial," *NS Business,* August 29, 2019, https://www.ns-businesshub.com/transport/driverless-bus-singapore/.

46. "Autonomous Bus Trial at Sentosa," *Land Transport Guru,* August 20, 2019, https://landtransportguru.net/sentosa-autonomous-bus-trial/.

cameras, and a global navigation satellite system.[47] Using multiple data sources, these mechanisms give pin-point accuracy of the shuttle location to the centimeter and capture 3-D imagery of the surrounding area. The satellite system operates in conjunction with an "inertial management unit" monitoring the shuttle's own operations, specifically speed and movement.[48] This management unit ensures a smooth ride for passengers especially when the shuttle goes over uneven surfaces and around sharp curves. Cybersecurity measures have been installed in the operating system to protect the shuttle from cyberattacks such as hacking.

Figure 8. Autonomous shuttle bus on Sentosa Island

Source: https://uk.reuters.com/article/instant-article/idUKKCN1VH0K5.

Outcomes

The autonomous shuttles faced several obstacles during the public trial. On the first day of the public trial, one bus came to a stop when bushes blown by the wind and pedestrians along the road triggered sensors.[49] The system also faced unexpected challenges in the form of roaming peacocks unexpectedly flying onto the road. While plans currently exist to test autonomous vehicles at night and on motorways, the Sentosa shuttle tests only carried passengers between 10 a.m.-12 p.m. and 2 p.m.-4 p.m.[50]

Singapore's Ministry of Transport and ST Engineering emphasize safety as their top priority. Each shuttle had a driver ready to take the wheel if necessary. Figure 9 shows the interior dashboard of the smaller driverless shuttle, with a seat for the safety driver. Also, the shuttles

47. Augusta Pownall, "Volvo unveils "world's first" autonomous electric bus in Singapore," *Dezeen,* March 6, 2019, https://www.dezeen.com/2019/03/06/volvo-autonomous-electric-bus-design-singapore/.

48. Ibid

49. "Singapore launches public trial of driverless buses," *Engineering and Technology,* August 27, 2019, https://eandt.theiet.org/content/articles/2019/08/public-trial-of-autonomous-shuttle-buses-begins-in-singapore/.

50. Ng, "Singapore has big driverless ambitions."

were equipped with a "vehicle fault system" capable of detecting faults and relinquishing control to the safety driver if necessary.[51]

Road tests and public trials of autonomous shuttles have enhanced the development of other autonomous vehicles. For example, 80-passenger autonomous electric buses will be deployed in three districts of Sentosa in 2022. The electric bus "produces zero emissions and uses 80 percent less energy than a diesel bus of equivalent size."[52]

Figure 9. Autonomous shuttle dashboard

Source: https://landtransportguru.net/st-autobus/.

Smart Highway—The Ray Project, Georgia, USA (Model 4)

Background

In 2019, there were over 36,000 deaths on U.S roadways.[53] Concurrently, transportation emissions account for approximately 28 percent of pollution in the United States.[54] To address these problems, The Ray Foundation has dedicated an 18-mile stretch of Interstate 85 in Georgia to testing innovative transportation technology. The Ray Project collaborates with the Georgia Department of Transportation (GDOT) and corporations to deploy technology aimed at eliminating highway fatalities, decreasing pollution, and preparing roadways for smart transportation technology.

51. "Autonomous Bus Trial at Sentosa."
52. Pownall, "Volvo unveils 'world's first' autonomous," *Dezeen,* March 6, 2019.
53. NHTSA Releases 2019 Crash Fatality Data," *United States Department of Transportation,* December 18, 2020, https://www.nhtsa.gov/press-releases/roadway-fatalities-2019-fars.
54. "Carbon Pollution from Transportation," *U.S. Environmental Protection Agency,* Available: https://www.epa.gov/transportation-air-pollution-and-climate-change/carbon-pollution-transportation (accessed March 2, 2021).

How the System Works

Figure 10 demonstrates the locations of the numerous technological implementations along the stretch of 'The Ray,' named after Ray C. Anderson, a Georgia business leader in green energy. The Ray Welcome Center serves as a rest area and visitors' center for the Interstate while simultaneously serving as a testing site for new models of transportation technology. Designed in collaboration with KIA, the welcome center boasts a solar-powered electric vehicle (EV) charging unit capable of restoring up to 80 percent of an EV's battery in 30 to 45 minutes.[55] In partnership with WheelRight, a British tire safety solutions company, the welcome center has a free roll-over tire safety station that can assess tire pressure and tread depth.[56] In addition, The Ray installed the first solar road in the United States. Developed by Colas, a French transportation company, Wattway is a photovoltaic road surface. Solar road panels are installed in a patented frame to provide as much skid resistance as conventional pavement. Using roadside solar panels and solar roads, The Ray is working towards wireless charging lanes for electric vehicles.[57]

Figure 10: Diagram of The Ray

Source: https://theray.org/.

The Ray Project predicts that more than 105 million connected vehicles will be on the road globally by 2022. These vehicles will constantly talk to each other and the roads, producing an annual data stream up to 150 petabytes, the equivalent of 15,000 years of TV content. In 2019, The Ray began a two-year trial for a new V2X (vehicle to everything) system in collaboration with Panasonic. The Cirrus by Panasonic V2X platform is being tested as a “digital

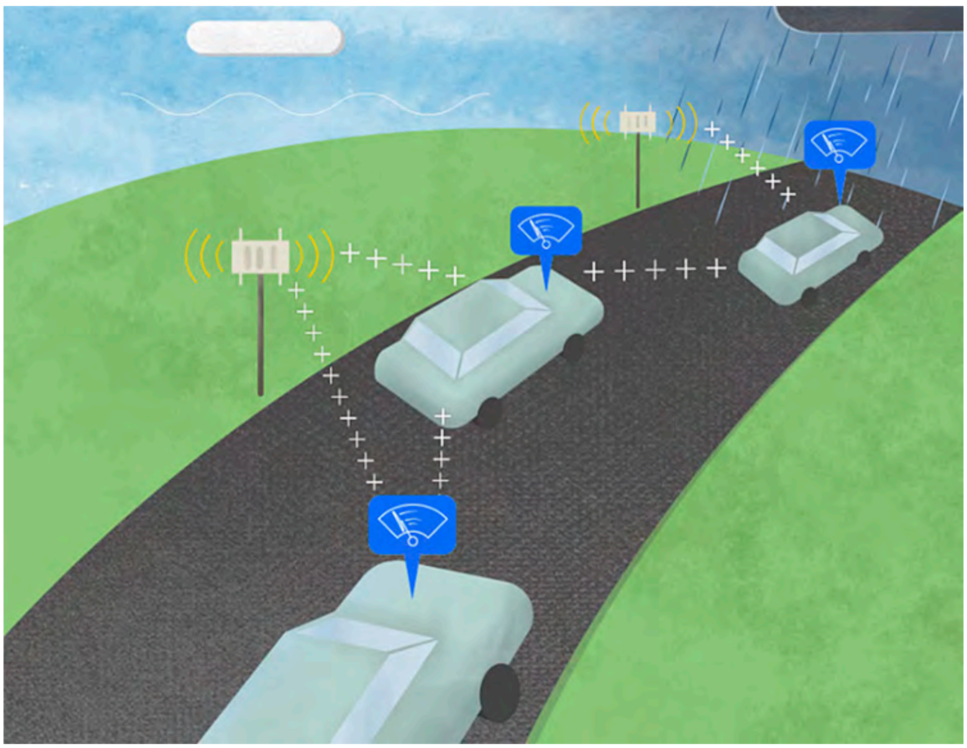
55. “Creating the Highway of the Future: The Ray,” *Georgia Department of Economic Development,* May 22, 2018, https://www.georgia.org/2018/05/22/creating-the-highway-of-the-future-the-ray.

56. “The Ray Today,” *The Ray,* https://theray.org/technology/the-ray-today/ (accessed March 2, 2021).

57. “Transportation + Energy: Smart Powered Highways,” *The Ray,* September 24, 2020, https://theray.org/2020/09/24/transportation-energy-smart-powered-highways/.

architecture for traffic management."[58] The GDOT will receive data from roadway operators and vehicles equipped with V2X technology including smart sensors. By utilizing machine-learning technology, the V2X system searches for patterns that translate vehicle data into information regarding road conditions. Georgia currently has six roadside units and four demonstrating vehicles sending information about braking, windshield wiper activity, speed location, and direction data. Figure 11 illustrates the capability of the V2X system to inform roadway operators and other vehicles of road conditions. In addition to easing congestion, communication from vehicles that transmit information about airbag deployment or loss of traction could decrease emergency response time and help the GDOT warn other drivers and reroute traffic if necessary.

Figure 11: Illustration of the V2X system



Source: https://theray.org/tech/v2x-connected-technology/.

58. "Cirrus by Panasonic," *Panasonic,* https://na.panasonic.com/us/smart-mobility/cirrus (accessed March 2, 2021).

Outcome and Value Added

As technologies on The Ray are in their early stages of testing, results are not yet extensive. Although it was estimated that solar roads could enable states to generate low-carbon electricity with a value of millions to tens of millions of dollars annually,[59] the deployment of Wattways in France produced only half of the expected power.[60] Developers of transportation technology credit government-sponsored initiatives such as The Ray Project for allowing them to test their products and make improvements as needed. Testing of the solar road has already led to the creation of newer models that eliminate the risk of moisture in panels and reduce gaps at the joints.[61] The Ray also aims to reduce vehicle collisions and the approximate annual waste of two billion gallons of fuel attributed to improperly inflated tires.[62]

The Ray Project predicts that autonomous and connected vehicles could reduce vehicles collisions by 40 percent or more.[63] Panasonic projects that IoT linked roads could potentially reduce travel time by half and non-impaired vehicle crashes by up to 80 percent. With the integration of solar roadways, tire safety stations, solar EV charging stations, and the V2X system, The Ray Project aims to prepare roadways for an interconnected efficient system of drivers, vehicles, and roads while reducing pollution and fatalities.

59. Emily Beagle, Kelsey Richardson, Joshua Rhodes, and Michael Webber, "The Ray Solar Highway Project," *Webber Energy Group.* (2020), https://www.tagonline.org/wp-content/uploads/2020/09/Solar_Interstates_Ray_Report_FINAL_Aug2020.pdf.

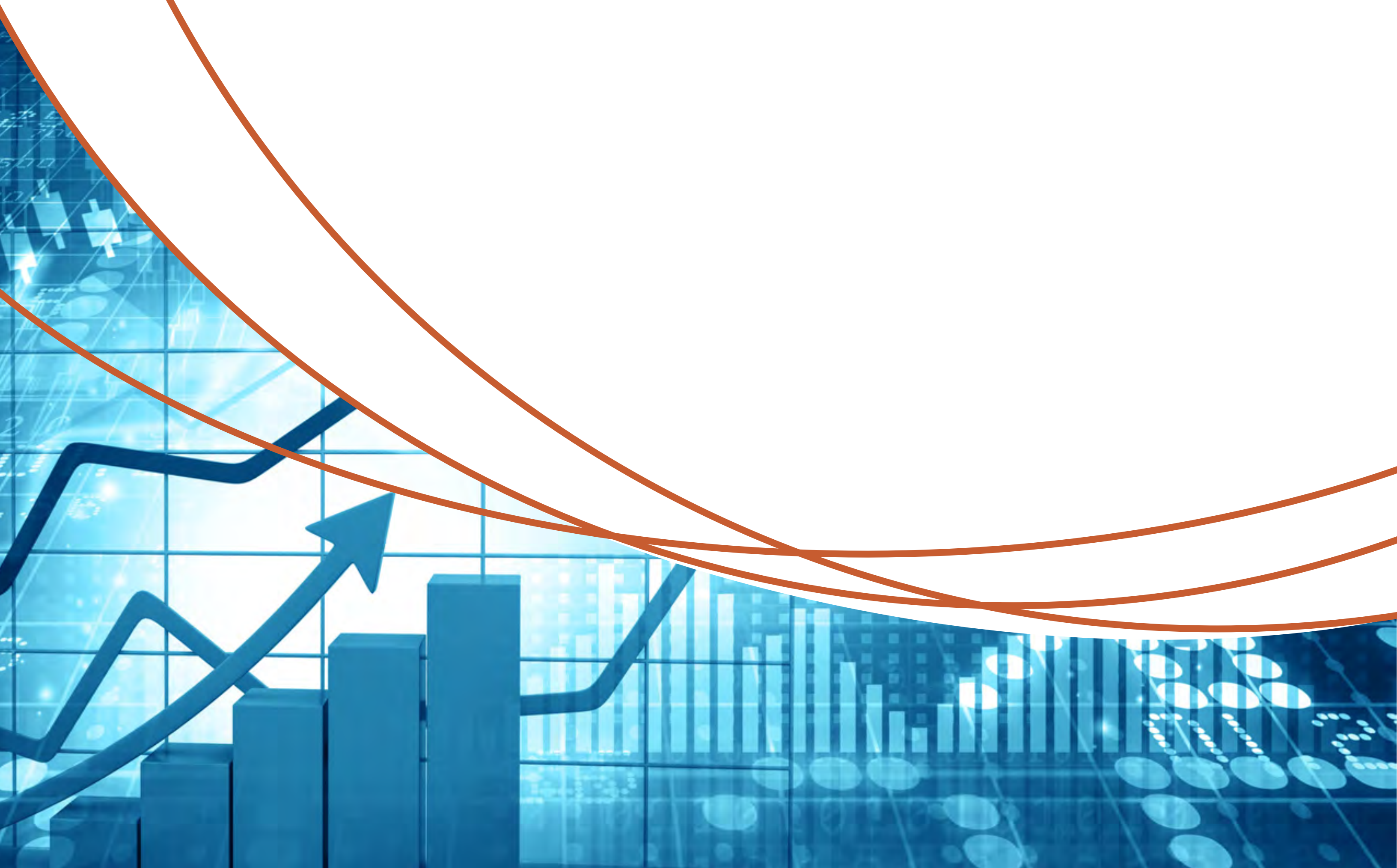
60. James Pasley, "Photos show the world's first solar road that's turned out to be a colossal failure because it's falling apart and doesn't generate enough energy," *Insider,* August 15, 2019, https://www.businessinsider.com/first-solar-road-france-failure-photos-2019-8.

61. Gillian Neimark, "Despite criticism, solar roads remain part of Georgia sustainable highway lab," *Energy News Network,* February 26, 2019, https://energynews.us/2019/02/26/southeast/highway-to-sustainability-in-georgia-zero-carbon-transportation-is-the-goal/.

62. "The Ray Today."

63. "Georgia highway innovation project to be featured at CONEXPO," *DCN-JOC News Services,* February 25, 2020, https://canada.constructconnect.com/dcn/news/infrastructure/2020/02/georgia-highway-innovation-project-to-be-featured-at-conexpo.

Critical Success Factors



The analysis of the five use cases identifies several critical success factors for public AIoT systems.

- **Focusing on creating public value:** The first step in any government-led AIoT initiative should be identification of public value that can be created by the new system. As the AIoT moves to the later stage of the hype cycle, it is going to be increasingly difficult to get top management support for an AIoT investment if no compelling use case is proposed. A clear focus on tangible public value increases the likelihood of success for a public AIoT project. For instance, London's Smart Cycling Routes initiative aims to improve road safety and optimize cycling routes for commuters.

- **Public-private partnerships:** All the five use cases discussed earlier benefited from effective public-private partnership. Private partners included not only established firms but also tech startups and universities. The AIoT solution providers must have the capacity and maturity to fulfill their commitments to the projects. The government counterpart must have a project sponsor who has the authority to allocate the required budgets. The sponsor also should be able to promote and defend the business case of the AIoT project.

- **Engaging with global technology ecosystem:** When it comes to implementing a public AIoT system, no single government agency or company can do it all. The system is likely to require collaboration of multiple organizations and use of multiple technologies. The most advanced and reliable technology is not necessarily available from domestic vendors. The best AIoT technology will emerge from around the world. Therefore, instead of being limited to domestic tech firms, the project team need to engage with a broader ecosystem of global tech companies. The Ray Project, for instance, collaborates with solution providers from France and the U.K. to acquire cutting-edge technologies.

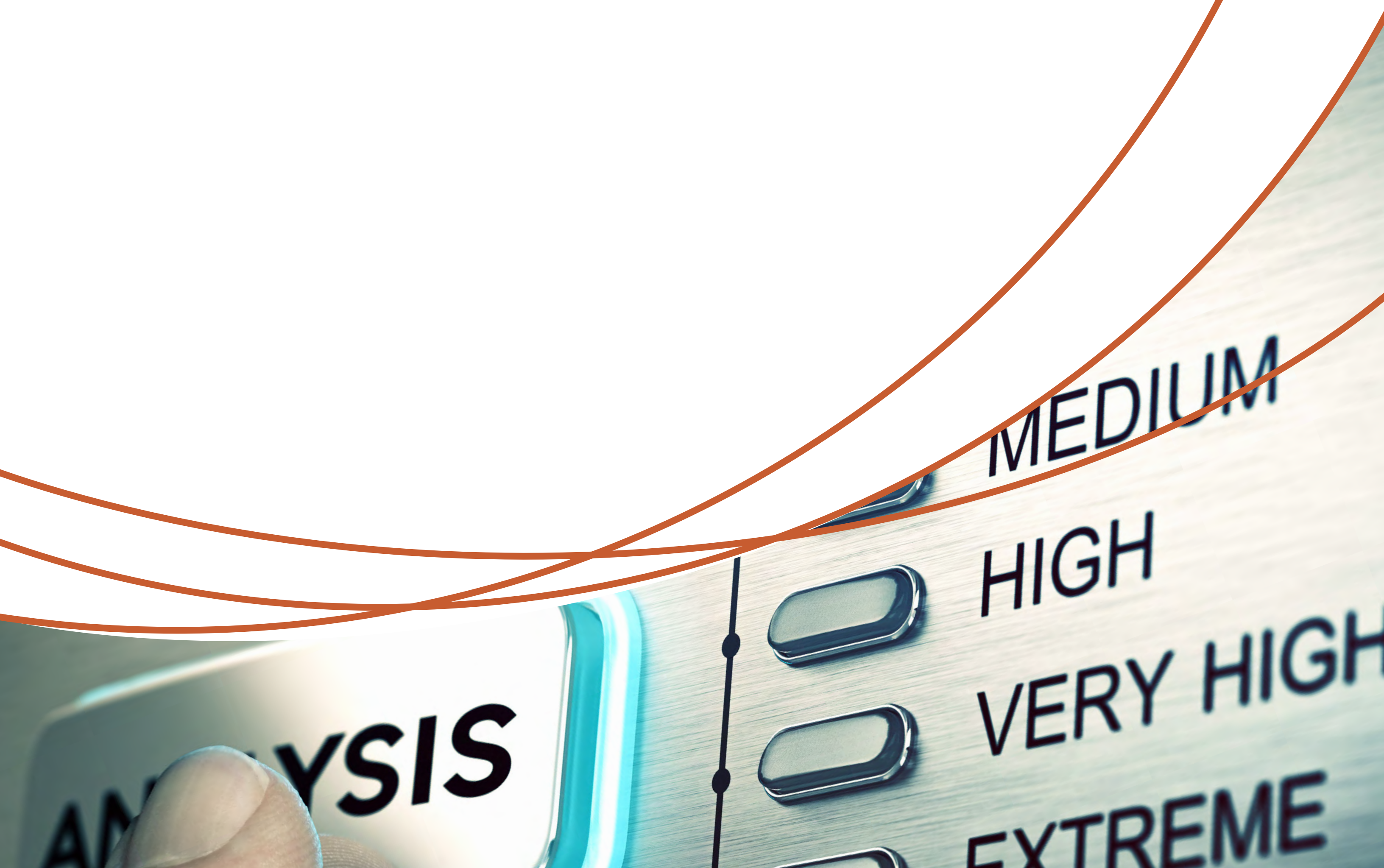
- **Incremental implementation approach:** It is important to develop an overarching strategy for implementing public AIoT applications. But, when it comes to actual implementation of a specific system, an incremental approach, rather than a big bang approach, is more effective. The incremental approach uses experiments and pilot tests for a proof of concept before a large-scale rollout. This approach helps to build momentum through quick small wins. All the five use cases took an incremental approach to implementing the AIoT systems. Singapore's autonomous public bus was first tested on non-public roads before the public trial on Sentosa Island. AIoT projects typically require experienced software developers, who are in high demand and in short supply. That said, the incremental approach helps to better manage the acquisition of such tech talents.

- **Quantifying the outcome:** Public value is often difficult to measure due to its intangible elements. Nevertheless, it is desirable to demonstrate the value of an AIoT system by quantifying the outcome to the extent which the outcome is quantifiable. Pittsburgh's smart traffic control system demonstrated quantitative positive outcomes such as decreased intersection wait times and lowered emissions. Quantified outcomes help to boost public trust and confidence in the new technology and secure organizational support for further implementation.

- **Addressing privacy issues:** As technology advances, people are increasingly concerned about information privacy. AIoT applications potentially heighten privacy-related risks as they often collect individuals' private data such as their presence in a certain location at a certain time. The city of Pittsburgh had to address the privacy concerns raised by SURTRAC's use of close-circuit cameras. Cologne's smart parking system was designed not to recognize the vehicle's license plate to protect privacy. Failure to address the public's privacy concerns will inhibit the widespread adoption of a new system. An important way to ensure protection for the privacy of users of an AIoT system is to take the Privacy by Design (PbD) approach, which incorporates privacy into the system throughout the system design process.

- **Strong cybersecurity measures:** As cybersecurity breaches have become all too common, it is crucial to ensure that AIoT systems are equipped with strong security measures. AIoT devices and networks significantly increase the number of entry points for cyberattacks. Cyber risks for AIoT systems not only affect data and technology but also impact physical systems, potentially threatening public safety, national security, and even human life. Therefore, the consequences of security breaches of AIoT systems could be profound and far-reaching. Achieving a high-level security starts with safeguarding the transmission of data as they travel from decentralized devices, across networks, and to and from the Cloud. The developers of an AIoT application should adopt the principle of Security by Design (SbD) and implement other important security strategies, including end-to-end encryption, access management, secure provisioning, and open-port management.
- **Expecting the unexpected:** AIoT technologies continue to evolve. The AIoT implementation team will inevitably run into unexpected problems and obstacles. Singapore's driverless shuttle faced several unexpected problems during the public trial. Cologne's smart parking system had to install additional lights on the street for accurately capturing vehicle images. The project team need to have a mindset to expect the unexpected. They should be flexible and agile to adapt their system to cope with unexpected challenges. Anticipating the unexpected, they should add project buffers in terms of extra time and budget.
- **Using data to create value in multiple ways:** Albeit a cliché, it is true that data is the new oil for AIoT. The ultimate source of new public value is the data collected from sensors. As such, the hard-earned data should be explored and exploited in many ways to create maximum public value. For example, London' TfL uses the data collected from cycling sensors for multiple purposes, ranging from improving road design, to predicting traffic flow, and to identifying cyclists' risky behaviors. Unfortunately, only a very small portion of the data generated by smart sensors are being used. For example, the oil and gas industry is using less than one percent of the data gathered from smart sensors installed on offshore oil rigs for informing decisions. To reap the full benefits of AIoT data, government agencies should ensure data quality through data standardization and cleansing and use advanced analytics and AI capabilities to extract actionable insights.
- **Advanced wireless network infrastructure:** Reliable and fast connectivity is a crucial pre-condition for the successful implementation of public AIoT applications. Wireless networks should have low latency and provide the real-time speed necessary to control and monitor connected devices. Deployment of 5G (the fifth generation of wireless communications technology) is essential to handle the traffic generated by AIoT. 5G offers speeds measured in multiple gigabits per second and latency in the single milliseconds. Furthermore, the performance of AIoT systems will improve significantly by adopting intelligent gateways and edge servers that aggregate, filter, process, and store data near the edge of the network.

Risks



The deployment of AIoT applications creates several significant risks ranging from data security and privacy to lack of interoperability and ML algorithm bias. The highly competitive AIoT industry, however, creates an environment in which AIoT manufacturers are pressured to be first to market and do more with less. As a result, they may not prioritize addressing those risks. Failure to mitigate the risks might prevent the public from adopting AIoT systems that have the potential to deliver new public value.

Cybersecurity and privacy risks

The most significant risks of implementing AIoT applications in the public sector center on the security and privacy of citizen data. Smart devices' characteristics such as connectivity, ubiquity, and mobility contribute to heightened security and privacy concerns. The large volumes of data created by AIoT applications will generate concerns over how the government handles the data. It is imperative to strike the right balance between fostering IoT innovation and protecting data security and privacy.[64] Seventy percent of commonly used IoT devices have been found to contain various security vulnerabilities ranging from inadequate passwords to more serious security holes.[65] In particular, low-powered small IoT devices may not have the necessary processing power to maintain high levels of security. What is alarming is that the cybersecurity risks of IoT devices can affect not only software and network but also the operation of physical systems, endangering public safety, national security, and even human life. As we have witnessed the hacking of connected cars and medical devices, these risks are real and growing. Rapid technological changes make it very difficult to develop a stable set of security standards that can be used as a basis for determining the security compliance of AIoT systems.

AIoT applications may increase users' privacy concerns as they could bear the risk of intrusive monitoring or the misuse of sensitive personal information. Users may not always know how their data are being used or if they are even being collected in the first place. Furthermore, as AIoT systems become pervasive, users run the risk of becoming desensitized to their vulnerabilities. Many AIoT devices are too small to have direct user interfaces such as screens. Therefore, it is challenging to protect user privacy based on the conventional privacy protection methods of 'notice and consent.'

Lack of interoperability

As IoT devices proliferate, their ability to communicate with one another is critical for realizing potential value. Global standards are crucial for facilitating interoperability across IoT systems. Industry standards bodies, including the Open Connectivity Foundation and the Industrial Internet Consortium, are in the process of developing open standards to connect and integrate various IoT devices. However, there is no single agreed-upon global standard for IoT devices yet.

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64. Gwanhoo Lee and Rebecca Lewis, "Preparing for a Connected World," in *Building a Smart Partnership for the Fourth Industrial Revolution* (The Atlantic Council, 2018), 46-55.
65. "HP Study Revels 70 Percent of Internet of Things Devices Vulnerable to Attack," *HP,* July 29, 2014, https://www8.hp.com/us/en/hp-news/press-release.html?id=1744676#.YA8rd-hKiWw.

Inadequate wireless networks

Data collected from sensors embedded in AIoT systems need to flow freely over wireless networks. Increasingly more AIoT systems require no latency in data transmission as they use sensor data to control physical systems in real time. As the volume of AIoT data surges, current wireless networks may not be able to keep up with the demand. If the bandwidth of wireless networks does not increase, advanced AIoT applications will not function properly. Speedy deployment of 5G would help mitigate this risk.

Premature, defective technology

Many of the technologies being used for AIoT applications are still in their early stage of development. Such technologies could have minor glitches or even serious defects. As a result, the AIoT applications using premature technologies may experience errors and malfunctions. Additionally, utilizing defective technologies can create safety risks. Therefore, it is important to test technologies in a safe environment and fix glitches before adopting them for public use.

ML algorithm bias

Although ML can increase productivity significantly, it could be biased in terms of race, gender, age, and other aspects. For example, commercial facial recognition systems misclassify gender much more often when presented with darker-skinned women compared with lighter-skinned men. A major source of bias in ML is the training data, and another source is the algorithms themselves. An ML algorithm maximizes prediction accuracy for the training data. If a particular type of individual appears more frequently than others in the training data, the algorithm will optimize for those individuals to maximize accuracy. The issue of sample selection and bias in the training dataset needs to be addressed for certain AIoT applications that involve predictions and decision making.

Maintenance

As the number of smart devices associated with AIoT systems increases, their maintenance becomes challenging. The sheer complexity of connections between a plethora of devices on multiple networks makes it difficult to monitor and resolve problems. Certain smart devices may require a software upgrade and battery replacement periodically. The IT department can be overwhelmed by the resources and efforts required for monitoring and maintaining the AIoT systems, along with continuous integration of new devices.

The environment in which ML operates may itself evolve or differ from what the algorithms were developed to face. However, since ML is typically embedded within a complex system, it will often be unclear what led to a breakdown or an undesirable outcome. Thus, it is difficult to assess whether there was an issue with the algorithm and which party (e.g., the algorithm developer, the system deployer, or a network operator) was responsible for the issue. All these factors contribute to the difficulty in maintaining ML algorithms.

RECOMMENDATIONS

Based on the critical success factors derived from the five case studies and the risks discussed in the previous section, I present the following recommendations for government agencies that are considering AIoT implementation. Three cases are at the municipal level, whereas one case is at the state level and the Singapore case is at the city-state level. That said, the following recommendations are formulated as generally as possible to inform leaders at all levels of government.

- **Develop a strategy for creating public value with alternative models:** Different government agencies have different levels of organizational and technological capabilities for deploying AIoT systems. Therefore, some of them may not be ready to create public value with advanced AIoT models such as Model 4. In that case, they are better off by starting with Model 1, with which they can deliver a new AIoT system relatively quickly. Considering their level of organizational readiness, governments should develop a strategy that lays out how to create public value using the four different models while managing the risks associated with them. This strategy should also include how to develop organizational and technological capabilities over time in order to utilize advanced value creation models.

- **Make your AIoT projects value-driven, not technology-driven:** As AIoT technologies are advancing fast, it is tempting to initiate AIoT projects mainly based on new technological capabilities. Government leaders should never implement a new AIoT application without a compelling business case suggesting significant value to the public. Citizens are more willing to adopt new technologies and provide personal information if they perceive tangible benefits from using them. Delivering real value also helps build public trust in the new systems. Governments should engage the public to let them know what benefits they intend to deliver with the proposed AIoT project.

- **Experiment, validate and then scale:** Before implementing a large-scale AIoT application, government leaders should take an experiment-validate-scale approach to manage risks and uncertainties. The project team should identify the problem that has the most impact on the public, but they should scope the project small enough to design, implement, and validate quickly. During the process, the organization should develop not only new technological capabilities but also a new mentality and a new innovation culture because, unlike traditional IT systems, AIoT systems require physical things (as compared to software) to get installed, connected, secured, and managed. Furthermore, AI/ML is different from previous software paradigms in terms of design, construction, testing, and implementation. Without the right technological capabilities and innovation culture in place, experiments and pilot projects are not easily scaled to full-blown applications.

- **Develop a data strategy for AIoT:** Sensors will generate an enormous amount of data, much of which might have little value. Governments should develop a strategy for identifying, organizing, using, and maintaining data that are relevant to their AIoT applications, while efficiently handling other data that have little value. To train ML algorithms, governments need a large volume of labeled data for the target applications. The data strategy should address issues such as how to acquire such labeled data and how to ensure the test data are not biased. Furthermore, governments can foster innovation by making the data collected by AIoT devices accessible to the public. By doing so, governments empower citizens, companies, and researchers to create new value out of the data.

- **Promote Security by Design and Privacy by Design approaches:** Security by Design (SbD) is an approach to product development that seeks to minimize vulnerabilities and reduce cyberattacks by designing and building security in every phase of the product development process. Similarly, Privacy by Design (PbD) is an approach to product development that seeks to ensure protection for the privacy of individuals by integrating considerations of privacy issues from the earliest stages of product development. These approaches are different from the traditional product development process in which security and privacy issues are considered or addressed as add-ons or modifications to a near-final product or as after-market solutions. Given their responsibility to protect the public interest, governments are uniquely positioned to help develop a secure IoT. The U.S. Federal Trade Commission (FTC) published guidance on what companies should consider when designing and marketing IoT products.[66] Governments should promote SbD and PbD and ensure that their IoT vendors are adopting these principles.

- **Find alternative solutions to the 'notice and consent' framework for privacy protection:** The traditional 'notice and consent' framework that protects user privacy may not make sense to certain IoT devices with limited or nonexistent user interfaces. It will not be possible for those devices to provide users with privacy-related information and check-box options. For the AIoT applications that pose no real threat to user privacy, citizens do not benefit from being inundated with notices. Privacy solutions should focus on outcomes such as data transparency and user control rather than requiring a specific type of check-the-box consent. Governments should encourage, lead, and incentivize IoT manufacturers to develop alternative solutions to the 'notice and consent' method. For example, IoT devices can use online dashboards, apps, or customer support to increase transparency about data practices.
- **Leverage external resources and capabilities:** As AI/ML technologies are advancing rapidly, an ecosystem around them is also quickly flourishing. Many AI/ML capabilities are becoming standardized and commoditized. Several open-source AI frameworks and a plethora of cloud-based ML libraries are available in the marketplace. Considering the limited expertise and resources that governments have, they should actively leverage that external expertise, resources, and capabilities to develop and manage AIoT applications instead of reinventing them with internal resources.
- **Coordinate with other government agencies:** It is crucial to establish interagency coordination mechanisms for AIoT for two reasons. Firstly, as industries and sectors are converging, the same AIoT application might have impacts on multiple government agencies and could be subject to conflicting regulations imposed by different agencies. Secondly, as governments are still in the early stages of implementing AIoT systems, they will go through a learning curve. A government agency will greatly benefit from sharing its best practices and lessons learned with other agencies. To foster interagency coordination, governments should consider creating an interagency AIoT Center of Excellence that coordinates on AIoT-related issues and promotes knowledge sharing.
- **Promote public-private partnership:** Our analysis of the use cases suggests that a strong public-private partnership is essential for the success of AIoT. Government alone cannot do everything effectively regarding application of rapidly changing technologies. Companies also benefit from partnering with the government not only for funding purposes but also because they will have an opportunity to build a good reputation through successful implementation. For productive public-private partnerships, the government should monitor technological development and consistently interact with the private sector.
- **Monitor and address errors and biases of ML algorithms:** Government should develop plans for certifying ML algorithms embedded in public AIoT systems. Some startups provide services to certify that ML algorithms don't suffer from bias, prejudice, stereotypes, unfairness, and other pitfalls. The Institute of Electrical and Electronics Engineers and the International Organization for Standardization are also developing standards for such certification. Google offers AI ethics services that examine multiple dimensions, ranging from the data used to train systems, to their behavior and impact on user well-being. As ML-based services as well as the environments they operate in continue to evolve, governments may find that their technologies do not perform as initially intended. It is therefore crucial that they establish policies and processes to ensure that these technologies behave within appropriate and acceptable limits.

66. U.S. Federal Trade Commission, *Internet of Things: Privacy & Security in a Connected World,* January 2015, https://www.ftc.gov/system/files/documents/reports/federal-trade-commission-staff-report-november-2013-workshop-entitled-internet-things-privacy/150127iotrpt.pdf.

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