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# How Can the Artificial Intelligence of Things Create Public Value? Lessons Learned from Use Cases

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The Artificial Intelligence of Things (AIoT) has the potential to create new public value. However, its application in government is in an early stage. This study identifies three technological capabilities—sensing, analytics, and controlling—as building blocks of an AIoT system and then proposes four value creation models that configure the building blocks differently. This research analyzes four use cases of AIoT systems deployed in the public transport sector that match the value creation models. Based on the analysis of the use cases, this study identifies critical success factors for public AIoT applications and makes recommendations to government leaders for creating public value through the effective deployment of AIoT systems. It concludes with discussion of limitations and future research areas.

CCS Concepts: • **Social and professional topics** → *Government technology policy* • **Computer systems organization** → *Embedded and cyber-physical systems*;

Additional Key Words and Phrases: The Internet of Things, artificial intelligence, machine learning, public value

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5

## 1 INTRODUCTION

The **Internet of Things** (**IoT**) can transform government operations and services significantly [Lee 2019]. Using IoT, governments can create new public value by improving decision-making and optimizing operational conditions [Gao and Janssen 2022, Pang and Lee 2014]. However, the application of IoT in government is still in an early stage. The complexity and scale of public services may hinder the government's attempts to implement IoT systems. Despite this challenge, IoT is already improving some public services, such as public parking, facility management, traffic control, air quality monitoring, and tracking pandemics [DeNardis 2020; Roy et al. 2021].

IoT is defined in this article as a network of physical "things" that are capable of transmitting data and controlling operations with little or no human intervention. IoT has begun to leverage **artificial intelligence** (**AI**) and **machine learning** (**ML**) technologies to further enhance its capability [Wang et al. 2021]. AI/ML takes IoT to the next level by enabling accurate predictions, precise image recognition, and optimal decisions [Beane 2019; Medapati et al. 2020]. This advanced technology is called ***Artificial Intelligence of Things*** (**AIoT**) [Ishengoma

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et al. 2022; Kuguoglu et al. 2021]. The successful implementation of AIoT applications requires a focus on public value, a clear strategy, and new sorts of organizational and technological capabilities [Porter and Heppelmann 2014]. Therefore, government leaders need a framework that can guide their decisions regarding AIoT. A prior study has identified the drivers and barriers for the integration of AIoT in the public sector and called for research that investigates critical success factors for AIoT systems [Ishengoma et al. 2022]. This research aims at filling this knowledge gap.

In what follows, the present study first proposes three technological capabilities, namely sensing, analytics, and controlling, as essential building blocks for creating new public value. Then, it presents a framework of four value creation models for AIoT applications that configure the building blocks differently. It describes the research methods and discusses four use cases of AIoT applications in the public transport sector, which correspond to the four value creation models. Based on the qualitative analysis of the use cases, it identifies critical success factors for AIoT applications in the public sector and presents recommendations for government leaders. Finally, it concludes with acknowledging limitations and proposing future research areas.

## 2 A CONCEPTUAL FRAMEWORK FOR CREATING VALUE WITH AIOT

### 2.1 Building Blocks for AIoT Systems

Public value refers to the value that an organization or activity contributes to society [Moore 1995]. The three building blocks of AIoT for creating public value are described below. AI/ML technologies can enhance the building blocks by preventing errors, improving accuracy, and discovering patterns.

*Sensing*: AIoT systems embed smart sensors. A smart sensor can convert and process data and send it to external devices, edge servers, and cloud servers. It is typically composed of a base sensor, a microprocessor, a memory, a communication module, and a power source. Examples include temperature sensors, proximity sensors, pressure sensors, water quality sensors, chemical sensors, smoke sensors, image sensors, motion detection sensors, accelerometer sensors, gyroscope sensors, and optical sensors. AI/ML technologies can enhance the performance of smart sensors. ML algorithms, for example, can significantly improve the accuracy of image recognition.

*Analytics*: Analytics capabilities turn data into knowledge and insights for better predictions or decisions. They use sensor data for descriptive, diagnostic, predictive, and prescriptive analytics. AIoT analytics tools support data modeling, data filtering, and event scheduling.

*Controlling*: AIoT systems can be controlled to achieve optimal operation. In some cases, advanced analytics is used 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 can act based on its environment to enable the correct operation of the system into which it is embedded.

Figure 1 depicts a conceptual diagram of an AIoT system. The data collected by smart sensors are sent to edge nodes, where they are filtered, cached, buffered, and processed. Some basic analytics and AI/ML algorithms could be used in edge nodes. Edge nodes send a bulk of data periodically to cloud servers for permanent storage and more in-depth analysis. More advanced analytics and sophisticated AI/ML algorithms are used in the cloud servers. The analytics results are sent from edge nodes and cloud servers to end-users. The results are displayed on mobile apps and/or websites.

### 2.2 AIoT Value Creation Models

The three building blocks of AIoT can be configured in different ways to generate four different value creation models. Table 1 shows technological capabilities leveraged for each value creation model and the mechanism by which each model creates public value.

*Model 1* uses only sensing capability. Smart sensors collect data such as image, sound, location, movement, speed, and temperature and send them to the server in the edge or cloud. AI/ML pattern recognition algorithms can improve the accuracy of the data. Once the data is collected, cleansed, and stored, it can be shared with the

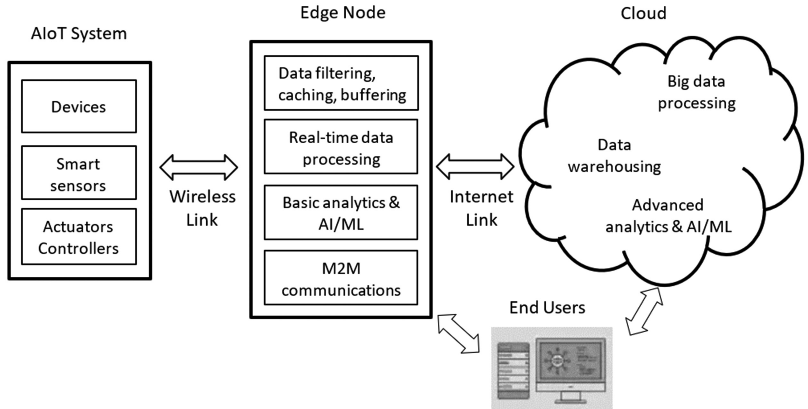


Fig. 1. A conceptual diagram of an AIoT system.

Table 1. Four Models for Creating Value with AIoT

| Model | Building blocks | | | Mechanism for creating public value |
|---|---|---|---|---|
| | Sensing capability | Analytics capability | Controlling capability | |
| Model 1 | √ | | | Awareness of status |
| Model 2 | √ | | √ | Preventing human errors |
| Model 3 | √ | √ | | Predictions and decisions |
| Model 4 | √ | √ | √ | Optimization and adaptation |

public via web browsers and/or mobile apps. The value created by this model is greater awareness of the current state of "things." In public transport, "things" may include parking spots, vehicles, roads, and traffic lights. By making accurate, real-time data available to the public, AIoT systems can help reduce uncertainties when using public transport systems. For these systems, real-time collection and dissemination of data are crucial.

*Model 2* leverages sensing capability and controlling capability. Sophisticated, advanced analytics methods are not used in this model. Instead, simple calculations or rules determine how to control a system. For example, simple calculations of queues of an intersection can help control the interval of traffic lights. One of the public values derived from this model is preventing human errors when controlling public assets. Strong cybersecurity measures are important because hackers could take over the operation of public systems.

*Model 3* utilizes sensing capability and analytics capability. The main value derived from 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 obscure 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 on public transport systems. AI/ML algorithms can improve their prediction accuracy continuously as they are trained with new data.

*Model 4* combines all three capabilities. This model represents the most advanced way of creating public value. The AIoT systems based on this model can deliver significant value as their operation can be continuously optimized by adapting to changing environments. The AIoT system in this category needs to sense and analyze a large volume of data and control the system in real-time. Therefore, zero network latency is a crucial condition. Even if individual technologies may function well, integrating them into an autonomous, adaptive system is a challenging task. For example, autonomous public buses may need to cope with many unknown challenges. AI/ML algorithms can improve the safety of autonomous vehicles by reducing critical errors as they continue to learn anomalies and exceptions.

The four value creation models require different levels of technological and organizational maturity. The logical trajectory is for government agencies 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 or Model 3. Compared to controlling capability, the development of analytics capability tends to take more time and resources. Therefore, agencies are likely to adopt Model 2, followed by Model 3. Agencies may adopt Model 4 after they develop mature capabilities for sensing, analytics, and controlling. However, agencies may adapt the trajectory to suit their capability and priority. The next section discusses four use cases in the public transport sector to demonstrate how AIoT systems create new public value by using the four value creation models.

## 3 RESEARCH METHODS

The public applications of AIoT are an emerging phenomenon. As such, this study takes an exploratory case study approach [Yin 2009]. First, I searched for the relevant cases with the ABI/INFORM database and Google by using combinations of such keywords as Internet of Things, IoT, artificial intelligence, machine learning, public sector, and government. The initial search produced 16 cases from nine countries. Then, I selected four cases based on the following criteria: (1) AI/ML plays important role in the AIoT application, (2) a large amount of information about the case is publicly available, and (3) the AIoT application can be mapped to one of the four value creation models presented in Table 1.

The information about the cases included government publications, project reports, news articles, journal/magazine articles, websites, and blogs. I used open coding and memoing [Agar 1986] to make sense of the case data. A graduate student and I open coded the relevant case documents to extract key facts and identify important themes by using an iterative process [Gioia et al. 2013]. We compared our codes and discussed similarities and differences. We used the memoing method to capture key concepts and ideas from the case data. The memoing method required an iterative process of writing and reflecting salient themes from the data. Finally, we integrated our analysis results into a narrative form for each case.

## 4 USE CASES IN THE PUBLIC TRANSPORT SECTOR

### 4.1 Intelligent Public Parking in Cologne, Germany (Model 1)

Cologne, Germany, is one of the most congested cities in Europe. Drivers in Cologne spend about 70 hours in traffic per year. The search for parking in Europe accounts for 30% of urban traffic and is responsible for 8% of Europe's $CO_2$ emissions. In attempts to reduce traffic congestion and $CO_2$ emissions, the City of Cologne and Rhein–Energie AG launched the **SmartCity Cologne Program** (**SCC**) in 2011.[1] The SCC is a platform for a range of projects on climate protection and energy transition. It conducts innovative product testing at more than 15 locations across the city. Rhein–Energie AG partnered with Cleverciti, a parking solution provider, to develop and deploy smart parking sensors with the goal of decreasing traffic congestion and $CO_2$ emissions.[2]

Eighty-nine sensors have been deployed along Neusser Street in Cologne. Cleverciti does not use ground sensors. Instead, overhead sensors are mounted on existing lampposts along the street to collect data efficiently and unobtrusively. Each sensor can monitor up to 100 parking spots. At the time of this writing, about 90 sensors monitor approximately 800 street-parking spaces. The sensors use AI and edge computing to detect and recognize

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

[2] "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.

the GPS coordinates of available parking spaces. To protect citizens' privacy, the system does not perform license plate recognition. The sensors process image using AI and edge computing and then transmit space availability data to 360-degree LED displays located at road intersections. Drivers at these intersections can know the number of available parking spaces without driving down the road.

As Cleverciti has implemented their technology in Cologne and beyond, they have adapted their intelligent parking technology to cope with the challenges they face. For example, parking sensors required additional light to capture images accurately. In response, additional lights were installed in conjunction with the sensors. While the LED displays reduce drivers' unnecessary roaming, drivers still need to drive by road intersections to read the displays. To address this issue, Cleverciti is testing a mobile app that displays a map of the city with available parking spaces. The LED displays were also installed at the entrances of several large cities to show parking space availability by the city sector.

A study suggests that increased use of AI-based parking technology in German cities could reduce the total hours spent searching for parking by one-third.[3] It is estimated that the deployment of smart parking systems could reduce $CO_2$ emissions by 900,000 tons annually. The early outcomes of the smart parking system in Cologne are encouraging. Citizens experienced less frustration while driving. Furthermore, increasing parking efficiency helps local businesses that rely on high parking turnover.

### 4.2 Intelligent Traffic Control in Pittsburgh, USA (Model 2)

Pittsburgh, Pennsylvania, has been known for its long traffic waits. In response, Pittsburgh implemented the **Scalable Urban Traffic Control** (**SURTRAC**) system in 2012 to better control the city's traffic and reduce commuters' travel time. SURTRAC was initially developed by Carnegie Mellon University and was commercialized later by Rapid Flow Technologies, an intelligent transportation systems provider. SURTRAC's initial trial with nine intersections was successful.[4] SURTRAC was implemented at 50 intersections across Pittsburgh between 2012 and 2015.

One of the advantages of the SURTRAC system is that it 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 data from a distance of 100 meters. AI-enhanced image processing method logs traffic as clusters of vehicles from each direction of the intersection. This enables the system to optimize the lighting plan's direction flow based on the size of vehicle clusters and the distance between clusters. The system maps roadways into distinct zones. The 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. The computer interprets the cameras' data on its surroundings, uses scheduling software to create a lighting plan, and sends this plan to the controller to control the traffic signals. Intersections communicate with adjacent intersections regarding vehicles' locations and the estimated time it will take them to reach the next intersection.

SURTRAC's use of close-circuit television cameras has raised privacy concerns among citizens.[5] The high cost of the system presents a barrier to its widespread adoption as its installation cost is about $20,000 per intersection.[6] Thus far, the estimated cost of the SURTRAC implementation is $4 million. Despite these challenges, the implementation of smart traffic control technology has shown positive outcomes. It has decreased intersection

[3]"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).

[4]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.

[5]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.

[6]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/.

wait times by 40%, vehicle travel time by 25%, and lowered emissions by 20%.[7] The Department of Mobility and Infrastructure of the City of Pittsburgh plans to deploy the SURTRAC system at an additional 150 intersections, specifically along major routes to and from downtown Pittsburgh. Since its initial deployment, the scope of the system has evolved to accommodate older adults and individuals with disabilities. For example, pedestrians can communicate with the intersection, requesting longer crossing times. In the future, the SURTRAC system will enable direct communication between the system and autonomous vehicles. This capability could decrease travel time by an additional 25%.

### 4.3 Intelligent Cycling Routes, London, UK (Model 3)

The City of London in the UK is the sixth most congested city globally. London drivers spend 227 hours per year in traffic, traveling at an average speed of 7 mph.[8] In attempts to reduce traffic and foster environmental sustainability, London is committed to investing in active travel by encouraging citizens to walk or cycle instead of using motor vehicles. The key challenges for this initiative include improving road safety and optimizing cycling routes for cyclists.[9] Data on rates of active travel and road safety for pedestrians and cyclists is essential to the success of the initiative. In the past, **Transport for London (TfL)**, a government agency responsible for transportation operations in London, gathered information on road traffic manually. These manual counts were limited geographically and temporally. In 2018, TfL tested the Cycling Sensors using AI technology to collect anonymized information on road traffic. These sensors developed by Vivacity Labs went through a trial phase, which was highly successful.[10] Given the successful trial, TfL announced the deployment of 43 additional sensors in 20 locations in January 2020.

Leveraging AI technology, Vivacity Labs' sensors gather information and analyze road traffic 24/7 at multiple locations across London with a 98% accuracy rate.[11] The sensor begins by identifying motorists in its field of vision. AI then analyzes each motorist and categorizes them into forms of transportation: Pedestrian, Cyclist, Motorbike, Car, Bus, Van, Truck, and so on. After the transportation was categorized, an Anonymization Filter discards the video and retains only the data. This anonymized data is transmitted to Vivacity Labs for data analysis by AI algorithms. The analysis result is shared with TfL and local governments. The sensors can receive software updates remotely and capture new datasets immediately. With these technologies, London aims at increasing pedestrian and cyclist traffic by improving roadways and prioritizing travel.

In April 2020, it was reported that cycling had increased 250% in certain areas of London.[12] More than 30 UK councils have adopted the technology by August 2020. Data collected from the sensors has already informed changes to roadways to promote active travel. TfL and local governments have used this data to begin redesigning road junctions, with priority given to cyclists.[13] By expanding the sensors' monitoring capabilities, TfL will be able to utilize more data when redesigning roads.

[7] "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.
[8] 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.
[9] 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/.
[10] 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/.
[11] "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/.
[12] 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/.
[13] "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.

### 4.4 Autonomous Public Bus, Singapore (Model 4)

With more than one million vehicles on the roads on the small land, Singapore needs to optimize the efficiency of public transportation. Singapore's Land Transport Authority thinks that autonomous vehicles can improve the accessibility and connectivity of their public transport system.[14] The Ministry of Transport, Sentosa Development Corporation, and ST Engineering Ltd. collaborated on the development of autonomous on-demand vehicles for intra-island travel in Sentosa. During the public trial in August 2019, two autonomous minibuses and two smaller driverless shuttle buses transported passengers along the 5.7 km route.[15]

Commuters can request shuttle rides using a mobile app called "Ride Now Sentosa" or kiosks located at select shuttle stops. The shuttles are equipped with sensors and navigation controls, including light detection and ranging sensors, stereo-vision cameras, and a global navigation satellite system.[16] These mechanisms can give pinpoint accuracy of the shuttle location and capture 3-D images of the surrounding area. The satellite system operates along with a management unit monitoring the shuttle's operations, in terms of speed and movement. This management unit ensures a comfortable ride for passengers even when the shuttle runs on uneven surfaces and around sharp curves. Cybersecurity measures were installed in the operating system to protect the shuttle from cyberattacks.

The autonomous shuttles faced obstacles during the public trial. During the public trial, one bus came to a stop when bushes blown by the wind triggered sensors.[17] The system also faced unexpected challenges when roaming peacocks unexpectedly flew onto the road. Singapore's Ministry of Transport and ST Engineering emphasize safety as their top priority. Each shuttle had a backup driver ready to take the wheel if necessary. The shuttles were also equipped with a vehicle fault system that could detect faults and relinquish control to the backup safety driver if necessary. 80-passenger autonomous electric buses will be deployed in three districts of Sentosa in 2022.

## 5 CRITICAL SUCCESS FACTORS

Based on the analysis of the four use cases discussed above, this research identified the critical success factors for public AIoT systems. These factors are not sufficient conditions but rather necessary conditions for the successful creation of public value using AIoT.

*Focus on public value*: A clear focus on tangible public value increases the likelihood of success for a public AIoT project. Therefore, one of the first steps in any government-led AIoT initiative should be the identification of public value that can be delivered by the new system. It is difficult to get top management support for an AIoT investment if no significant public value is proposed. For instance, London's Intelligent Cycling Routes initiative aims at improving road safety and optimizing cycling routes for commuters.

*Public-private partnerships*: **Public-private partnerships (PPPs)** involve collaboration between a government agency and private-sector companies that can be used to finance, build, and operate projects. All four use cases benefited from PPPs. Private partners included not only established firms but also tech startups and universities. The AIoT solution providers should have the capacity and maturity to fulfill their promises to the projects. The government counterpart needs a project sponsor with the authority to allocate the required budgets and defend the business case.

[14] "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).

[15] 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/.

[16] 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/.

[17] "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/.

*Incremental implementation approach*: The incremental approach uses experiments and pilot tests for a proof of concept before a large-scale rollout. It helps to build momentum and support through fast, small wins. When it comes to the implementation of an AIoT system, an incremental approach, rather than a big-bang approach, appears to be more effective. All four use cases took an incremental approach. For example, Singapore's autonomous public bus was first tested on non-public roads before the public trial on Sentosa Island.

*Quantifying the outcome*: Public value is often difficult to measure quantitatively due to its intangible nature. Nevertheless, it is crucial to show the value of an AIoT system by quantifying the outcome as much as possible. Pittsburgh's intelligent traffic control system demonstrated quantitative 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 concerns*: Citizens are increasingly concerned about their privacy being intruded by government systems. AIoT applications can heighten privacy concerns as they often collect individuals' personal information such as their location at a certain time. Users may not always know how their data are being used or if they are even being collected in the first place. The city of Pittsburgh had to address the privacy concerns raised by the system's use of close-circuit cameras. Cologne's intelligent parking system was designed not to recognize the vehicle's license plate to protect the driver's privacy. An important way to ensure privacy protection for the users of an AIoT system is to adopt the **Privacy by Design** (**PbD**) approach, which incorporates privacy measures into the system throughout the system design process.

*Strong cybersecurity measures*: AIoT networks increase the number of entry points for cyberattacks significantly. As such, AIoT systems must be equipped with strong security measures. It is imperative to strike the right balance between fostering IoT innovation and protecting data security [Lee and Lewis 2018]. Cyber risks for AIoT systems not only affect digital assets but also impact physical facilities, threatening public safety, national security, and even human life. Achieving high-level security starts with safeguarding the transmission of data traveling 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 effective security strategies, including end-to-end encryption, access management, secure provisioning, and open-port management.

*Expecting the unexpected*: No matter how well an AIoT project is planned, the project team is likely to run into unexpected problems. Singapore's driverless shuttle faced several unexpected obstacles during the public trial. Cologne's intelligent parking system had to install additional lights on the street for accurately capturing vehicle images. The project team should be agile to adapt their system to cope with unexpected challenges. Anticipating the unexpected, they should secure project buffers in terms of schedule and budget.

*Using data to create value in multiple ways*: 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's TfL uses cycling sensor data for multiple purposes, such as improving road design, predicting traffic flow, and identifying cyclists' risky behaviors. To realize the full benefits of AIoT data, government agencies should ensure data quality and use advanced analytics and AI capabilities to generate actionable insights.

*Advanced wireless network infrastructure*: Deployment of advanced wireless networks such as 5G and IoT-specific networks (e.g., LoRaWAN) helps to handle the massive traffic generated by AIoT systems. Reliable and fast connectivity is an essential condition for the successful implementation of public AIoT applications. Data collected from sensors embedded in AIoT systems need to flow freely over wireless networks. Wireless networks should have low latency and provide the real-time speed necessary to control and monitor connected devices. Furthermore, the performance of AIoT systems will improve by adopting intelligent gateways and edge servers that aggregate, process, and store data near the edge of the network.

## 6 RECOMMENDATIONS FOR GOVERNMENT LEADERS

Based on the analysis of the four case studies, this study presents the following recommendations for government leaders that are considering AIoT implementation.

*Develop a practical strategy for creating public value using alternative models*: Given their level of organizational readiness, governments should develop a practical strategy that lays out how to create public value using the four different models. Some agencies 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 public value relatively easily and quickly. The strategy should include how to develop organizational and technological capabilities to utilize advanced value-creation models.

*Make your AIoT projects value-driven, not technology-driven*: It is tempting for government leaders to initiate AIoT projects mainly based on new technological capabilities. They should never implement a new AIoT application without a compelling business case. Citizens will be more willing to adopt new technologies and trust in them if they perceive tangible benefits from using them.

*Experiment, validate, and then scale*: 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. 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 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 culture because 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 will not be 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. Government leaders should develop a strategy for identifying, organizing, using, and maintaining data that are relevant to their AIoT applications. To train ML algorithms, governments need a large volume of labeled data. The data strategy should address issues such as how to acquire such labeled data and how to ensure the test data are not biased.

*Promote SbD and PbD approaches*: With their responsibility to protect the public interest, governments are uniquely positioned to help develop a secure IoT while protecting citizens' privacy. The US **Federal Trade Commission** (**FTC**) published guidance on what companies should consider when designing and marketing IoT products [U. S. Federal Trade Commission 2015]. Government leaders should promote SbD and PbD to promote building security and privacy into their AIoT systems from the beginning of the system development process.

*Coordinate with other government agencies*: It is important to establish interagency coordination mechanisms for two reasons. Firstly, as industries and sectors converge, the same AIoT application might have an impact on multiple government agencies and could be subject to conflicting regulations imposed by different agencies. Secondly, as government agencies will go through a learning curve, they will greatly benefit from sharing their best practices and lessons learned with other agencies. To foster interagency coordination, governments may create an interagency AIoT Center of Excellence for coordinating AIoT-related issues and promoting knowledge sharing.

*Promote public-private partnership*: Our analysis of the four use cases suggests that a strong public-private partnership is crucial for the success of AIoT. Government alone cannot do everything well regarding the application of rapidly evolving technologies. Companies benefit from partnering with the government not only for funding purposes but also for building a reputation through successful implementation.

*Monitor and address errors and biases of ML algorithms*: ML algorithms could be biased in terms of race, gender, age, and other aspects. A major source of bias in ML is the training data, and another source is the algorithms themselves. Government leaders should develop plans for certifying ML algorithms used for public AIoT systems so that the algorithms are free from bias, prejudice, stereotypes, unfairness, and other pitfalls. As ML-based

Table 2. Summary of Critical Success Factors and Recommendations

| Critical Success Factors | Recommendations for Policymakers |
|---|---|
| Focus on public value | Develop a practical strategy for creating public value using alternative models |
| | Make your AIoT projects value-driven, not technology-driven |
| Public-private partnerships | Promote public-private partnership |
| Incremental implementation approach | Experiment, validate and then scale |
| Quantifying the outcome | – |
| Strong cybersecurity measures | Promote Security by Design and Privacy by Design approaches |
| Expecting the unexpected | Preventing human errors |
| Using data to create value in multiple ways | Develop a data strategy for AIoT |
| Advanced wireless network infrastructure | – |
| – | Coordinate with other government agencies |
| – | Monitor and address errors and biases of ML algorithms |

services continue to evolve, governments may find that their technologies do not perform as initially intended. They should establish policies and processes to ensure that these technologies behave within acceptable limits.

## 7 CONCLUSIONS AND FURTHER RESEARCH

To the best of my knowledge, this study is the first attempt to identify the critical success factors and present policy recommendations for creating public value with AIoT. Table 2 shows how the critical success factors and policy recommendations are related to each other.

Although the exploratory case studies produced valuable insights, the generalizability of the findings across applications, sectors, and countries needs to be further investigated empirically. As more cases accumulate over time, the AIoT value creation models should be expanded and refined. Another limitation is that this study does not systematically investigate different types of specific public values created by AIoT. A prior study has identified several specific public values that could be delivered from the implementation of AIoT applications [Ishengoma et al. 2022]. But it has not shown how those public values can be created. Building upon the present study, future research should investigate how different AIoT value creation models lead to different specific public values, thus developing a more comprehensive value creation framework. Finally, this study calls for quantitative research that complements the present qualitative study.

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