PARKING SENSOR and CURBSIDE VEHICLE DETECTION

Transportation Innovation Challenge Report

2023

TORONTO

Exhibition Place

ACKNOWLEDGEMENTS

The Transportation Innovation Zone is a collaborative effort between the City of Toronto and Exhibition Place. Led by the City's Transportation Services Division, the Transportation Innovation Challenge (TIC) program is made possible through contributions from a number of City and agency staff as well as academic and industry partners.

For the *Parking Sensor and Curbside Vehicle Detection Challenge* TIC, special thanks are owed to the staff at the following divisions and agencies who participated as Challenge Advisors: Transportation Services, Technology Services, the Office of the Chief Information Security Officer, Exhibition Place, Toronto Transit Commission, Toronto Police Service, Metrolinx and the Canadian Parking Association. Particular thanks are owed to the Toronto Parking Authority for their participation as Challenge Advisors and on-going collaboration to innovate and modernize the City's parking ecosystem.

The TIC was made possible by the participation of the following companies who deployed their technology at Exhibition Place: Automotus, Electromega, eleven-x, Precise ParkLink and Mistall. Arcadis IBI generously provided integration services to link multiple data feeds into the CurbIQ platform.

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TRANSPORTATION INNOVATION IN TORONTO

Urban mobility is rapidly evolving, and the City of Toronto's Transportation Services Division is continuously assessing new approaches and tools that can help its transportation system remain healthy, equitable and safe. Emerging technologies such as micromobility and electric, connected and/or automated vehicles are growing in popularity. Smarter traffic control systems, innovative paving materials, and advanced transportation monitoring methods, while less visible, are also emerging.

Transportation Innovation Zones (TIZs), also referred to as "living labs", are areas where transportation and public realm innovations can be tested in a real-world setting. They offer a controlled testing ground where technologies emerging from academia and industry can be trialed, while monitoring and evaluating their performance. TIZs with various resources and configurations are becoming common around the world, variously operated by government, private, non-profit and academic organizations.

TORONTO'S TRANSPORTATION INNOVATION ZONE

In 2020, the City of Toronto established a TIZ in partnership with Exhibition Place. The TIZ is used to learn about emerging innovations, and to explore their potential benefits, risks, applications, and impacts on factors such as safety, accessibility, and privacy. Exhibition Place has a rich history of showcasing transportation technology, dating back to the first electric streetcar demonstration in 1884. Managed by a City-owned corporation, Exhibition Place is a mixed-use district west of downtown. It was chosen for the TIZ due to its central location and the presence of relevant infrastructure such as roads, sidewalks, bike lanes, traffic signs, and bus stops.

TRANSPORTATION INNOVATION CHALLENGE (TIC) PROGRAM

In 2021, Council approved a challenge-based format for the TIZ with a focus on transportation solutions. The program aims to support research and development, grow local economic activity and talent, and advance the City's mobility-related goals such as **Vision Zero**, **accessibility**, more efficient service delivery, and emissions reductions to meet **TransformTO** goals.

Each TIC is a time-limited trial focused on a specific theme, with defined learning objectives and parameters for how it will run. The TIC program is managed by Transportation Services, with themes and objectives selected collaboratively with Exhibition Place and other City divisions and agencies. An open call is made to solicit private-sector and academic participants to showcase their technologies related to the selected topic. During a TIC, each product is assessed by a committee of Challenge Advisors, representing City divisions and agencies with an interest in the TIC topic. Assessment criteria are based on the TIC's learning objectives and the potential ways in which the technology might be used in Toronto ("uses cases"). Participants in TICs are not scored, ranked, or compared against one another.

The TIC program creates mutual learning opportunities. The City gains a better understanding of the current state of new transportation technologies and the opportunities they offer to resolve or mitigate current transportation challenges. Industry and academic participants benefit from experience deploying their technology in a real-world environment, and learning about the City's policies, priorities, and perspectives in relation to the TIC topic. The TIC model is focused on learning and is detached from any procurement process or indication of future procurement.

For more information, visit the City of Toronto's TIZ and TIC **program website**.

Automated Sidewalk Winter Maintenance TIC - Winter 2021

Micro Utility Devices TIC - Spring 2022

EXECUTIVE SUMMARY

Parking Sensor and Curbside Vehicle Detection Challenge 2023
Access to parking for passenger, delivery, and courier vehicles is vital in a thriving city. People need convenient places to park during their daily commutes or to run errands. Businesses count on curbside parking spaces for their customers, and for the delivery vehicles that service their business. Vehicles parked illegally create hazards for motorists as well as pedestrians and cyclists, delay overall traffic flow, and impede surface transit, deliveries, and other essential curbside activity. It's the job of the City to identify where on-street parking and loading activities can occur and establish rates for on-street parking. The collection of parking fees, provision of off-street parking and operation of the Green P parking app is the responsibility of the Toronto Parking Authority (TPA), which is an agency of the City. Together the City and the TPA manage parking in a manner that supports broader objectives for livability, road safety, traffic management, economic development, and climate. New tools and emerging technologies show some promise for helping cities manage curbside access and help people find appropriate parking.

The purpose of the *Parking Sensor and Curbside Vehicle Detection Challenge* was to learn how vehicle detection technologies used in a parking context could benefit the City of Toronto and the people who live, work, do business in, and visit the city. This TIC allowed City staff to learn about the current state of vehicle detection technology and participants to receive feedback about their systems. The findings will provide input to the forthcoming city-wide Parking Strategy.

In October 2022, four participants were selected: Automotus, Electromega, eleven-x and Precise ParkLink. The detection systems, which included both camera and in-ground sensor systems, were installed in January 2023. Data collection and observation ran until May 2023. This TIC focused on four learning themes:

- Data
- Hardware
- Privacy and Cybersecurity
- Scalability

More information about these themes and learning objectives can be found in Section 1.1 of this report. A series of use cases for this technology were also identified, which anticipated how the systems could benefit both the public and the City. These use cases, detailed in Section 1.4, are:

- Use Case 1: Public information, navigation and reservation
- Use Case 2: Parking and curb use data for planning purposes
- Use Case 3: Enhanced traditional enforcement
- Use Case 4: Automated enforcement
- Use Case 5: Automated payment

Key Findings

Both in-ground sensor and camera-based vehicle detection systems demonstrate potential for application in the five use cases identified in this TIC. As expected, each system offers a unique set of advantages and limitations. In-ground sensor systems demonstrated a high level of accuracy when placed in delineated parking spaces. They do not raise privacy concerns, as they are incapable of collecting personally identifiable information. Each sensor is battery operated, requiring power connections only for a communication box that serves multiple sensors, which enhances the scalability of these systems. However, in-ground sensors have limitations, including the need to modify the road surface during installation, providing less detailed information than cameras, and not allowing for data verification through remote visual inspections. They are not suitable for on-road parking lanes that at times serve as travel lanes, which is often the case in Toronto.

Camera systems offer advantages such as providing detailed data outputs, the ability to verify data through remote visual inspections, hardware portability to enable redeployment in different locations, and not requiring any modification of the road surface. Limitations of camera systems include variable accuracy rates affected by a range of factors, requirements for uninterrupted power connections, and the need for robust privacy protocols.

It is noted that the technology for both in-ground and camera systems is evolving quickly; any of the identified limitations may be resolved in near future generations of the same devices.

Next Steps

- For the near term, Challenge Advisors noted the potential value in deploying a curbside vehicle detection system at a small scale beyond Exhibition Place to collect real-time data in strategic locations.
- For the medium term, there was interest in further exploring automated enforcement of “no-stopping” or “no-standing” zones, as violations of these regulations can have negative impacts on road safety, congestion, and transit operations.
- Further analysis and study of the various use cases are required to better understand the potential applications of this technology before larger-scale deployment.

Overall, this TIC achieved its intended learning objectives, and the project team would like to thank all the participants and Challenge Advisors for their contributions to its success.

1.0 PARKING SENSOR AND CURBSIDE VEHICLE DETECTION TIC

In large cities like Toronto, there are increasing and conflicting demands for curb space and a clear trend of converting surface parking to more developed uses. In this context, well-managed curbside use and vehicle parking are essential to ensure smooth traffic flow, enhance safety for pedestrians and cyclists, support local businesses, and reduce congestion.

The City of Toronto is developing a city-wide Parking Strategy to address growing demands for curb space and to align the City's parking policies with its objectives related to climate, housing affordability, vibrancy, and traffic congestion management. The potential role of technology to help manage the demands for curb space and enable certain parking policies has therefore become an area of interest for the City and other stakeholders of the Parking Strategy.

The *Parking Sensor and Curbside Vehicle Detection Challenge* was developed to gather information about the available technologies designed to provide real-time vehicle occupancy detection in both on-street parking zones and off-street parking facilities. The primary objective was to assess how the data collected by parking sensor and curbside vehicle detection systems could benefit City planning processes, optimize the deployment of enforcement personnel, and improve customer service. Among other things, these improvements could include provision of real-time parking availability information for motorists or enabling automated payment or reservation systems for delivery companies. These and other practical use cases are described further in Section 1.4.

This report outlines the approach that was taken to conduct this TIC, provides an overview of the technologies assessed, and summarizes general findings.

1.1 APPROACH

Learning

Four learning themes were identified to evaluate the potential applications of parking sensor technology in Toronto, as illustrated in the table below. Since the TIC was focused on learning and was not connected to any procurement process, participants were not scored, ranked, or compared. Findings in this report are described based on the system technologies (e.g. in-ground sensor or camera system) rather than the individual participants.

Learning Themes

DATA	HARDWARE	PRIVACY and CYCERSECURITY	SCALABILITY
• Accuracy and reliability in various conditions • Level of detail • Verifiability • Interoperability • Ownership	• Components • Ease of deployment • Roadway impacts • Power supply and portability • Connectivity • Longevity and maintenance • Aesthetics	• Potential for the collection of personally identifiable information • Risk mitigation	• Ability to deploy in any context • Business models • Unintended consequences

Figure 1:
Testing the sensitivity of the in-ground sensors on-site in various conditions

Call for participants

An open call for participants was posted on the City's TIZ webpage and promoted through social media and various relevant industry newsletters in October 2022. The call welcomed any system capable of detecting whether a parking space (or portion of a parking zone) is occupied. Four applications were received, and all four applicants were accepted into the TIC.

Implementation

Once the participants were confirmed, a planning process was initiated to determine the type, quantity, and location for deploying the vehicle detection products. The systems were installed in January 2023 with support from Exhibition Place staff. Data collection began immediately for some products; others first required a validation period, which in one instance lasted for several weeks. Data collection continued until late May when the TIC concluded.

Location

Each participant collaborated with the City's TIC team to determine the exact deployment location of their system. Participants were given the option to deploy on the road in a pick-up / drop-off lane, in a parking lot, or both. Two participants chose to deploy on the road, one chose to deploy in the parking lot, and another participant chose to deploy in both contexts.

Challenge Advisors

Challenge Advisors are individuals representing City divisions and agencies who participate in developing learning objectives for each TIC, and in assessing the technologies based on the potential use cases. For this TIC, the advisors engaged with participants during virtual and on-site meetings, observed the data collection in real time, and ensured that this technology was considered from multiple perspectives.

The advisor team included representatives from the following City divisions, agencies, and external entities:

- Transportation Services Division
- Technology Services Division
- Office of the Chief Information Security Officer
- Exhibition Place
- Toronto Parking Authority
- Toronto Transit Commission
- Toronto Police Service
- Metrolinx
- Canadian Parking Association

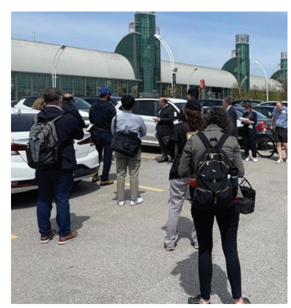

Figure 2:
An on-site meeting with one of the participants and the Challenge Advisors

1.2 PARTICIPANTS

Table 1: Parking Sensor and Curbside Vehicle Detection TIC Participants

	Automotus	Electromega	eleven-x	Precise ParkLink
Nearest corporate location	Los Angeles, CA	Oakville, ON	Waterloo, ON	Toronto, ON
Focus	Curb management; video analytics	Intelligent transportation systems (ITS)	Sensors and IOT (Internet of things) applications	Parking solutions
Partner(s) for the TIC	N/A	Urbiotica, a Barcelona-based parking technology company	N/A	Mistall, a Hamilton-based camera detection company eleven-x, a Waterloo based in-ground sensor company (also an independent participant in this TIC)
Sensing modality	Camera	Magnetometer	Magnetometer and radar	Mistall: Camera eleven-x: magnetometer and radar
System components	Camera with wired connection to a communication box containing a processor unit, mounted to the same pole	In-ground battery operated sensors with a pole mounted communication box	In-ground battery operated sensors with a pole or roof mounted communication box	Mistall: Camera with wired connection to a battery and communication box mounted to the same pole; a solar panel was included for some installations eleven-x: In-ground battery operated sensors with a pole or roof mounted communication box
Data processing and transmission	Edge computing and cellular transmission of de-identified data	Cloud computing: sensors communicate via communication protocol to a communication box, which has a cellular connection to the cloud	Cloud computing: sensors communicate via LoRaWan network to a communication box, which has a cellular connection to the cloud	Mistall: cloud computing and cellular transmission of all data eleven-x: cloud computing - sensors communicate via via LoRaWan network to a communication box, which has a cellular connection to the cloud
Notable deployments	Pittsburgh, PA; Los Angeles, CA; Omaha, NE	Burlington, ON	Oakville, ON	Mistall: University of Guelph eleven-x: Oakville, ON

1.3 ABOUT THE TECHNOLOGY

Parking sensor and curbside vehicle detection technologies are designed to detect the presence, movement, and position of vehicles in parking areas and along curbsides. They use a combination of sensors, cameras, and data analytics to provide this information to a variety of end users, depending on the application or use case. In this TIC, participants brought two types of detection technologies: in-ground sensor systems and camera systems.

In-ground sensor systems use devices that are embedded into the road and detect the presence or movement of vehicles through ultrasonic, electromagnetic, radar, or other sensor technologies.

The in-ground sensor systems in this TIC were comprised of two main parts; i) individual battery-operated sensors which are embedded in the roadway, and ii) a communication box, which could be mounted on a pole or a rooftop.

Camera systems use cameras to capture images and video footage of curbside activities. These camera systems may use advanced data processing to identify vehicle types, licence plates, or other relevant information. The camera systems trialed in this TIC included both low-resolution and high-resolution cameras.

Low-resolution camera systems capture lower-quality still images at set intervals (e.g. every minute or five minutes). The low-resolution camera system used in this TIC produced greyscale images that could not identify licence plates or faces.

High-resolution camera systems capture colour video and can identify licence plates and capture clear facial features. The system trialed in this TIC used edge processing to select relevant still images from the video feed such as a vehicle arriving or departing the parking zone. To protect privacy during this trial, the video, and the full-resolution still images, were neither stored locally nor transmitted from the device. Only lower-resolution images, incapable of revealing personal information were sent to the cloud. While this system can be deployed in applications that require automated licence plate recognition (ALPR), this feature was disabled during the deployment, except for a one-hour test period with staff vehicles in a controlled area.

The camera systems included two main components: i) the camera, and ii), a box containing a modem, SIM card, power connection (plug, battery, and/or solar panel), and, in one case, a processor. During installation, the hardware was mounted onto a pole and cameras were positioned at an optimal angle to capture the target parking zone. Photos of hardware and the installation process are shown in Figure 3.

Figure 3:
Clockwise from top left: Coring for the Electromega installation, Automotus camera installation in progress, eleven-x sensors prior to installation, Precise ParkLink (Mistall) post installation

How the systems work

The effectiveness of a parking sensor system depends on its approach to identifying and locating available parking spaces, as well as its accuracy in performing these tasks. Counting vehicles may seem simple, but it is more complicated, and more useful, to count how many parking spaces are still available. For example, many streets in Toronto do not have parking spaces marked with painted lines; parking availability depends on the size and spacing between vehicles currently parked on the street, the size of the vehicle seeking to park, and the driver's ability to manoeuvre the vehicle. A six-metre gap may work for small vehicles but not for larger ones.

In-ground sensor systems detect vehicles near each sensor, which are typically installed at set intervals for undelineated on-street parking or loading zones, or one per parking space for delineated spaces. The spacing of sensors, size of vehicle, and where the vehicles actually park can lead to errors in detection; there is potential for oversized vehicles to trigger more than one sensor or for smaller vehicles to go undetected, resulting in an inaccurate count of vehicles or remaining spaces. To minimize the risk of these errors, the optimal distance between in-ground sensors must be determined based on the context of each location (e.g. the average length of vehicles expected in the parking zone), as well as the sensitivity of the sensors.

For this TIC, in-ground sensors were deployed 5.5m apart, and the sensors were observed to detect a vehicle when it was within 0.5-1.0m of the sensor. In this context a 4.5m long vehicle (e.g. a Honda Civic) would theoretically never go undetected, but could simultaneously trigger two sensors. Complete accuracy will never be possible, but the probability of errors can be managed with careful consideration of a) the spacing between sensors, b) sensor sensitivity and, c) the most common length of vehicles expected to be parked in that area.

Camera systems count the vehicles in the zone and may be better equipped than in-ground sensors to determine the number of available spaces in areas with non-delineated parking. Vacancy is determined based on the number of spaces in a zone minus the number of vehicles detected within that zone. A camera system may also be able to classify vehicles (e.g. "delivery vehicle" or "bus") and consider their sizes in vacancy calculations.

For this TIC, one of the camera systems was configured to distinguish between vehicle classes, while the other was not. The system configured to identify vehicle classes could correctly identify buses if the entire bus was visible in the detection zone. In this installation, the sample size of delivery vehicles at the deployment location was too small to determine how consistently they could be differentiated.

1.4 POTENTIAL APPLICATIONS ("USE CASES")

There are a variety of potential applications – or "use cases" - for how parking sensor and vehicle detection technology might be used to achieve a specific outcome. The City has identified five use cases of interest; other use cases may emerge as the technology advances, or as new needs and challenges arise.

USE CASE 1: Public information, navigation and reservation
Broadcasting real-time availability data to help motorists, including vehicle-for-hire and delivery drivers, find available parking, loading, or pick-up / drop-off spaces. Future applications could include reservable commercial loading spaces or improved passenger pick-up / drop-off areas at mobility hubs or major event venues.

USE CASE 2: Parking and curb use data for planning purposes
Deploying vehicle detection systems to collect data for planning and analysis, including parking occupancy by time period and average parking duration. Specific applications include input into new parking policies and pricing, complete streets projects (e.g. adding bike lanes), loading or pick-up / drop-off analysis, Business Improvement Area studies, development application review, and transit planning. Some of the systems deployed in this TIC may also be capable in the future of collecting road safety data (e.g. near-miss analysis), offering additional planning insights.

USE CASE 3: Enhanced traditional enforcement
Using vehicle detection systems to identify violations of parking, standing, and stopping restrictions. These could include illegal activity such as stopping in a "no-stopping" zone like cycle tracks, or non-payment in a paid parking area. This information could enable real-time dispatch of nearby enforcement officers or to identify patterns with historical analysis and deploy officers on routes where they are more likely to encounter violations.

USE CASE 4: Automated enforcement
Employing vehicle detection systems with automated licence plate recognition (ALPR) capabilities to automatically issue tickets including: parking overstays, stopping in cycling facilities, misuse of EV charging stations, or stopping in restricted zones such as bus stops.

USE CASE 5: Automated payment
Utilizing ALPR systems to automate payments for permitted activities like parking, EV charging, pick-up / drop-off, or commercial loading. If applied to on-street parking, this could automate a payment system that currently relies on user-payment and enforcement. Automated detection applied to commercial loading zones or pick-up / drop-off zones could provide the means to charge for activities that are currently free.

2.0 FINDINGS

The parking sensor and curbside vehicle detection systems were deployed in the TIZ from January to May 2023. During this time, the performance of each system was monitored and documented through on-site and off-site demonstrations. This section summarizes key findings related to the learning themes identified in Section 1.1.

It is important to note that each of the participating companies is working continuously on product development. As a result, performance and capabilities of each system may improve over time.

2.1 TECHNOLOGY COMPARISON

The following table summarizes the benefits and limitations of each type of vehicle detection system demonstrated in this TIC.

Table 2: Benefits and limitations by system type

		In-ground sensor systems	Low-resolution camera systems	High-resolution camera systems
Data	Accuracy and reliability	High	Variable	Variable
	Level of detail	Low	Moderate	High
	Verifiability	Low	High	High
Hardware	Portability	Low	High	High
	Power Requirements	Sensors are battery operated and communicate with a communication gateway that requires a grid connection.	Can be configured to operate off of solar, intermittent power or continuous power.	Typically requires continuous power at each camera location.
	Roadway impacts	Results in a high number of minor impacts to the roadway surface	No roadway impact	No roadway impact
Privacy and Cybersecurity Concerns		Minimal	Moderate	Very high (but may be mitigated)

2.2 LEARNING THEME FINDINGS

The following tables summarizes key findings from this TIC in more detail.

Table 3: Summary of key findings related to each learning theme

<table>
<tr><th colspan="2">DATA</th></tr>
<tr><th>In-ground sensor systems</th><th>Camera systems</th></tr>
<tr><td>Advantages
• Accuracy was high.
• Accuracy not affected by weather and other external factors.

Limitations
• Provided less detailed information compared to camera systems.
• Unable to independently verify data through remote visual inspections.

Considerations for long-term deployment
• Sensor sensitivity impacts the optimal spacing between sensors, which affects the number of sensors needed and the overall cost of deployment.
• There was no evidence of cold temperatures or snow impacting the accuracy of in-ground sensors, though further winter testing is needed to understand the impact of packed snow and ice on data accuracy.
• Different use cases may require different latency* periods.
• Shorter latencies may impact battery lifespan.

* Latency refers to the time difference between detection at sensor to reception of data by the system</td><td>Advantages
• Provided detailed data outputs, potentially including licence plates, vehicle positioning (e.g. obstructing streetcar tracks), and vehicle type.
• Allowed independent verification of data by remote visual inspections.

Limitations
• Accuracy rates are affected by a range of external factors including weather, low-angle sun, and the presence of trees in the field of view.

Considerations for long-term deployment
• A camera can typically cover a parking zone of up to five on-street spaces (25-30m) without compromising accuracy.
• Cross-street detection may be feasible, depending on traffic volume and other visual obstructions.</td></tr>
<tr><td colspan="2">Data findings for both systems
• Systems that provide both detailed data (e.g. individual park events) and summarized data (e.g. average activity over time periods) are appropriate for more use cases than platforms that only provide summarized data.
• The ability to retrieve data for specific time ranges is valuable for all use cases discussed in this TIC.
• The ability to integrate data into external platforms (i.e. data interoperability) is important for many use cases, including data analysis, parking payment, and parking enforcement.
• Arcadis IBI, the developers of a curbside data platform called CurbIQ, worked with participants to identify best practices to facilitate data integration, including:
  • Provide location coordinates data;
  • Provide unique IDs for all individual sensors, all spaces captured by a sensor, and all relevant aggregation levels (e.g. continuous on-street zones; payment zones, etc.);
  • Utilize a consistent data structure; and
  • Format historical occupancy data in the Curb Data Specification (CDS) Events and Metrics format.
• All participants stored data on their own platforms, with servers located in Canada, USA, and Ireland.
• All participants confirmed that the client would own the data and that they could adjust data retention and cleaning parameters as needed.</td></tr>
</table>

Table 3 (continued): Summary of key findings related to each learning theme

<table>
<tr><th colspan="2">HARDWARE</th></tr>
<tr><th>In-ground sensor systems</th><th>Camera systems</th></tr>
<tr><td>Advantages
• Because each sensor is battery operated, power connections are only required for a communication box, which can typically serve many individual sensors.
• Sensors are not expected to require any maintenance over their 10-year lifespan (though this could not be verified in this TIC).

Limitations
• Installation requires modifications to the road surface.
• Sensors are not portable once installed and are therefore best suited for applications where data is required on a long-term basis.
• Roadway resurfacing requires the removal and reinstallation of sensors, resulting in increased costs if resurfacing occurs over the sensor's lifespan.

Considerations for long-term deployment
• Longer-term testing is needed to confirm if sensors could cause premature pavement damage.
• It is crucial to keep records of the sensor locations, and to share that information with staff coordinating road maintenance and construction.
• Once the sensors reach the end of their lifespan, they should be removed and disposed of properly to avoid inappropriate disposal of e-waste.</td><td>Advantages
• Camera hardware is portable and can be redeployed in different locations as needed.
• Installation does not require any modifications to the road surface.
• The low-resolution camera system could be powered through solar, intermittent power, or direct power connection, which offers flexibility in the application and deployment area.

Limitations
• High-resolution systems require uninterrupted power connections.

Considerations for long-term deployment
• Further testing is needed to confirm if existing poles can support added weight and wind resistance of the solar panel and battery for solar powered systems.
• Cameras may occasionally need lens cleaning or re-positioning.
• Depending on the deployment context, camera systems may require signs alerting people that video is being recorded and identifying the legal basis, purpose and contact information for this collection (see Figure 4).</td></tr>
<tr><td colspan="2">Hardware findings for both systems
• All systems used cellular connections to send data from each camera or communication box to the cloud. Most participants indicated that Wi-Fi could be used if the signal was consistently strong, which could reduce ongoing operational costs.
• All systems were deemed to have minimal or no aesthetic impact on the streetscape. Cameras are typically installed well above eye-level and in-ground sensors are underground. However, aesthetic impacts should be assessed for each deployment area, particularly in Business Improvement Areas, corridors with heritage designations, and in cases where camera notification signage is required.</td></tr>
</table>

Table 3 (continued): Summary of key findings related to each learning theme

<table>
<tr><th colspan="2">PRIVACY AND CYBERSECURITY</th></tr>
<tr><th>In-ground sensor systems</th><th>Camera systems</th></tr>
<tr><td>Advantages
• No/minimal privacy concerns as in-ground sensors do not collect personally identifiable information.</td><td>Limitations
• Robust privacy protocols must be established.

Considerations for long-term deployment
• Any camera deployment on public streets would require a privacy impact assessment and specific strategies to address privacy concerns.
• Privacy concerns were mitigated for the low-resolution camera system by mounting the camera high off the ground, capturing black and white still images (not video) which limits the capture of identifiable behaviors or events, and by using low image resolution to avoid revealing licence plates and detailed facial features.
• Privacy concerns were mitigated for the high-resolution camera system by processing the video feed in real time using an internal device to decode video images. Only metadata (e.g. arrival and departure time of a parked vehicle) and low resolution still images were transmitted or stored.</td></tr>
<tr><td colspan="2">Privacy findings for both systems
• All systems deployed in this TIC use data encryption and have policies regarding data retention and data scrubbing.
• Thorough reviews of privacy, cybersecurity, and data retention policies and practices are necessary before a longer-term, large-scale deployment.
• The strength of the cybersecurity measures should align with the system's ability to collect sensitive information and its significance to City operations.</td></tr>
</table>

Figure 4:
The sign used to alert members of the public about the use of cameras for the TIC

Table 3 (continued): Summary of key findings related to each learning theme

SCALABILITY	
In-ground sensor systems	**Camera systems**
Limitations • In-ground sensors appeared to be unsuitable for on-street locations that serve as travel lanes for several hours of the day and that serve as parking areas during off-peak hours. The high volume of vehicles moving over these sensors (potentially hundreds per hour) could negatively impact sensor battery life.	**Advantages** • The low-resolution camera can utilize existing camera feeds, including security or traffic cameras, if they provide a suitable field-of-view. This could positively impact scalability, if such cameras already exist in appropriate locations, and permissions to use their imagery were obtainable. **Limitations** • The potential obstruction of the camera's field of view by trees or other objects could present limitations on some corridors. • While gaining access to traffic signal and TTC poles is relatively simple, using Toronto Hydro and street lighting poles is more difficult and requires a permitting and approvals process.
Scalability findings for both systems • Ensuring access to uninterrupted power is difficult, and could pose barriers to scalability, especially for camera-based systems. For any solar installation, lack of sunlight due to building or tree shadows could also be a limiting factor. • Since the TIC program is not connected to a formal procurement process, it was not feasible to explore system costs. In general terms, the costs associated with a deployment include hardware acquisition, software licensing, maintenance and troubleshooting, cellular data plans, cloud storage, and platform access and maintenance. TIC participants presented various business models to cover these costs including hardware purchasing, subscription fees, revenue sharing (for enforcement or automated payment applications) or any combination of the above. Prior to selecting a preferred technology, it is imperative that the lifecycle cost of all options are fully assessed and incorporated into the decision-making process.	

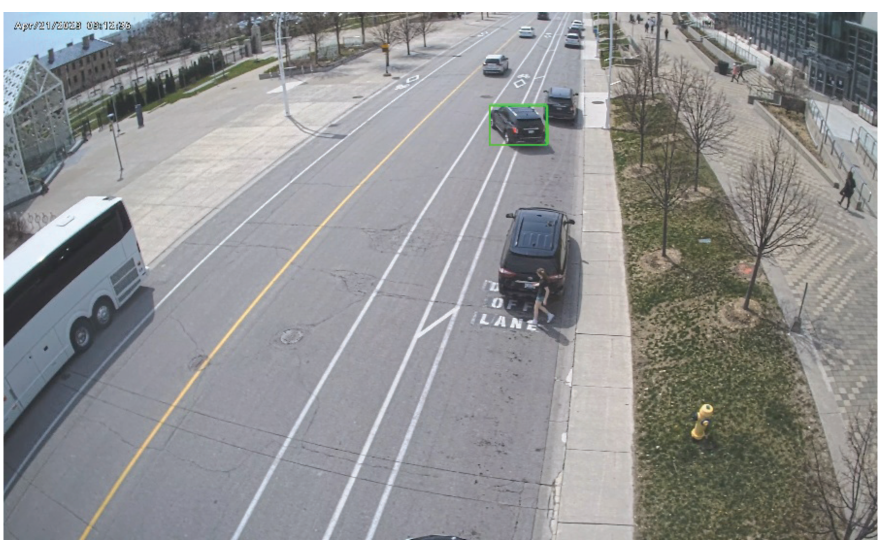

Figure 5:
A full colour image taken from the Automotus platform capturing a vehicle as it departs the parking zone. This system uses AI to process high resolution video data. The data processing takes place in real time in a computer mounted to the pole, and only low-resolution images such as this one are stored and transmitted. This approach helps mitigate privacy and cybersecurity concerns.

Potential Challenges to Implementation

Predicting potential implementation challenges is inherently difficult, and the landscape of potential outcomes for a wide-scale implementation of this technology remains uncertain. Nevertheless, Challenge Advisors identified several unintended consequences that could arise in the context of a large-scale deployment of both in-ground sensor and camera systems.

- Coordination challenges: The risk of underestimating the level of coordination, permitting, and equipment required.
- Streetscape impacts: Possible resistance to tree planting along corridors with camera deployments, to avoid blocking camera views.
- Public perception of over-surveillance: Concerns about over-surveillance may emerge, impacting how the public perceives the technology's presence.
- Enforcement backlash: Applications related to enforcement could be viewed negatively by the public, possibly seen as a "cash grab" and visible hardware could be subject to vandalism.
- E-waste generation: Large-scale deployment may generate a substantial amount of e-waste, necessitating proper disposal, tracking, and management of these devices - particularly for those embedded in pavement - over several years.

Navigating these potential challenges would be essential for the successful integration of this technology on a larger scale.

Figure 6:
A black and white image from the Precise ParkLink (Mistall) platform which captures low resolution images at set intervals. Metadata shown on the image indicates the elapsed time since the vehicle was first detected and the systems confidence that a vehicle is located within the blue bounding box.

3.0 LESSONS FOR SPECIFIC USE CASES

This section provides a summary of how each of the parking sensor and curbside vehicle detection systems in this TIC could perform in relation to the five use cases identified (see Table 4 for quick reference to use cases and Section 1.4 for detailed definitions; see Section 1.3 for definitions of the technology categories).

Each of the companies that participated in this TIC are working to continuously improve their products in this rapidly developing field. Capabilities and

Table 4: Summary of the suitability of the vehicle detection systems for use cases

Use Case	In-ground sensor systems	Low-resolution camera systems	High-resolution camera systems
USE CASE 1: Public information, navigation and reservation	Capable	Potentially capable (depending on contextual factors)	Potentially capable (depending on contextual factors)
USE CASE 2: Parking and curb use data for planning purposes	Capable	Capable	Capable
USE CASE 3: Enhanced traditional enforcement	Capable	Capable	Capable
USE CASE 4: Automated enforcement	Not capable	Not capable	Potentially Capable
USE CASE 5: Automated payment	Not capable	Not capable	Potentially Capable

3.1 SUITABILITY OF IN-GROUND SENSORS FOR USE CASES

In-ground sensors are generally expected to perform effectively for Use Case 1: Public information, navigation and reservation, Use Case 2: Parking and curb use data for planning purposes, and Use Case 3: Making traditional enforcement more responsive.

As discussed in Section 1.3, defining accuracy in a non-delineated on-street context is somewhat subjective and requires careful consideration to determine the optimal spacing of sensors. Further testing is recommended before planning any scaled deployment of in-ground sensors in this context.

Since in-ground sensors are not capable of reading licence plates, they would not work for Use Cases 4: Automated enforcement and 5: Automated payment.

3.2 SUITABILITY OF CAMERAS FOR USE CASES

Camera systems can potentially function in all five uses cases identified in this TIC. However, the suitability of camera systems for Use Cases 1, 2, and 3 depends on specific site parameters, such as available mounting locations, sight-line obstructions such as trees, and the level of accuracy required for the specific goals of the deployment.

In Table 3, camera systems are indicated as 'potentially capable' for Use Case 1 as this application typically demands a high degree of accuracy to be useful and trusted by the public.

Camera systems are indicated as being 'capable' for Use Cases 2 and 3 because the required accuracy levels may be lower than Use Case 1. For example, in certain applications where relative levels of occupancy between zones is the key metric, a certain margin of error may be acceptable if that margin is consistent across zones. If a high degree of accuracy in occupancy data is needed for an application of Use Cases 1, 2, or 3, a camera system may only be appropriate if it can deliver data with precision.

For Use Cases 4 and 5, only high-resolution camera systems have the necessary automated licence plate recognition (ALPR) capability. This trial included very limited testing of the ALPR functionality of one system, involving a one-hour testing period using three staff vehicles. The results of this testing demonstrated the proof of concept, but not enough data was collected to confirm whether the accuracy would be sufficient for those applications.
The participant that offered ALPR functionality indicated that they have deployments that include the functionality described in Use Cases 4 and 5.

3.3. GENERAL USE CASE CONSIDERATIONS

This section outlines high-level considerations for each use case, which are not specific to any of the technology categories. These considerations are based on anecdotal input from the Challenge Advisors and are not indicative of any future actions the City may take.

USE CASE 1: Public information, navigation and reservation
Further analysis is needed to determine whether this technology would bring substantial value to Toronto for public information, navigation, and reservation. This use case may be more feasible for off-street parking lots than for on-street parking zones due to difficulties in providing real-time information to the public. Installing curbside digital signage may not be practical in many locations; if information were to be delivered through a mobile app, it is unclear whether a significant number of people would be inclined to adopt the app. Integration with a third-party app may be necessary to attract enough users, but parking options would have to remain available for motorists who do not use any app.

The value proposition for this use case seems more compelling for commercial loading purposes. The scale of deployment for loading zones is more manageable because they occupy less space than on-street parking zones; and in certain locations, the challenge of securing loading space is more acute than the challenges with general parking.

A reservable loading zone system could improve predictability and availability of loading spaces for nearby businesses. However, such a system would require more than just occupancy detection. It would require a platform to disseminate this information (such as a mobile app), and the widespread adoption of the app among end users, including delivery drivers and the businesses they serve. Managers of the system would need to address whether loading zones would be exclusively reserved for pre-booked users or if they could also accommodate "drive up" users whenever space is available. Communication and enforcement must also be addressed to prevent vehicles from overstaying their booking, or otherwise impeding use of the space by vehicles with legitimate reservations. Digital curbside signage, not currently used in Toronto, could assist with these challenges. Finally, the City's regulatory framework would need updates to enable and enforce this new operation.

Exploring these opportunities and challenges further through a pilot project, possibly in collaboration with a Business Improvement Area, could provide valuable insights.

USE CASE 2: Parking and curb use data for planning purposes

This use case encompasses a range of different applications. Parking sensor and curbside vehicle detection systems could offer much more detailed data than what is currently available from parking transactions in certain locations. These systems could also provide data in locations (or for time periods) where parking is currently free, and no transaction data exists.

The most appropriate technology for this use case would depend on the accuracy requirements and the level of detail needed for each application. In some cases, obtaining some data, even if it lacks perfect accuracy and in-depth detail, may be better than having no data at all. In other situations, like converting parking spaces into loading spaces, getting detailed data such as vehicle type may be essential. For many data collection and planning purposes, data may only be needed for a defined period, making camera systems more suitable due to their portability.

USE CASE 3: Enhanced traditional enforcement

Using a vehicle detection system can help make traditional enforcement more responsive by identifying hotspot locations and optimal times for deploying enforcement personnel. Camera-based systems may excel in locations prone to violations across a large area or where violation frequency is unknown because cameras are portable and can capture a larger area (per device) than in-ground sensors. In-ground sensors are likely better suited to defined locations that are anticipated to be hotspots in the long term, and where there is minimal prospect of deploying automated enforcement (which would require a camera).

A key limitation for both Use Case 3 and 4 relates to the City's accessible parking permit exemptions. These exemptions allow users with an accessible permit to park in designated "no parking" areas and to extend their stay beyond the time limits. As a result, if an occupancy detection system detects a vehicle that is parked in a "no-parking" zone or overstayed the allowable time, it would not necessarily indicate a violation if the vehicle had an accessible parking permit. Since it is virtually impossible for any vehicle detection system to reliably detect accessible permits, enforcement use cases are not currently practical in parking and "no-parking" areas.

A second limitation is that for payment purposes, on-street parking zones are often aggregated together and can span multiple blocks. In theory, real-time occupancy data could be compared with real time payment data to determine how many motorists haven't paid (noting the accessible permit caveat above), but this would not pinpoint the exact location within the payment zone where the violation occurred.

Nevertheless, there may be merit in deploying a detection system in "no-standing" and "no-stopping" areas, which lack accessible permit exemptions. This includes cycle tracks, driveways, most transit stops, and many arterial roads during peak periods. Violations of these regulations are often brief, posing challenges for traditional enforcement methods. Given that violations of these regulations directly impact road safety, transit operations, driveway access, and congestion, the value proposition for this use case (and Use Case #4) appears quite strong.

USE CASE 4: Automated enforcement

The limitations associated with Toronto's accessible parking permit exemptions, as discussed in Use Case3, are also applicable to this use case. Additionally, the City's current pay-and-display system for on-street parking does not require licence plate information to be linked with payment, further restricting the potential for automated enforcement.

As in Use Case 3, automated enforcement appears more promising for "no-stopping" and "no-standing" zones. Automated enforcement is likely more efficient at capturing short and infrequent violations when compared to manual enforcement by an officer. It is crucial for the camera system to accurately detect and document violations, including the capture of licence plate information. Further testing is required to assess the potential effectiveness of current systems for this application, and to consider the probability and consequences of tickets erroneously issued to mis-identified vehicles.

Cameras for automated enforcement are unlikely to capture contextual information relating to exemptions. For example, an enforcement officer can easily identify stopping to allow emergency vehicles to pass, or stopping by utility vehicles involved in permitted work in the right-of-way. These situations may be less obvious from a captured image. Finally, due to the need to capture licence plate information, addressing additional privacy concerns is necessary before deploying for this use case.

USE CASE 5: Automated payment

This use case for automated payment encounters many feasibility limitations when applied to parking. The long-term value for this would depend on the administrative costs and level of accuracy the system can achieve. If launched, an automated payment system would likely be an optional service coexisting with traditional payment methods. This is due to both regulatory and logistical challenges and would significantly reduce the overall value proposition.

In applications like commercial loading or passenger pick-up / drop-off, automated payment may be more suitable. It could be deployed in a smaller area, targeting commercial operators like delivery companies, taxis or Private Transportation Companies (e.g. Uber, Lyft, etc.) rather than individual users. Incentives could be offered to encourage pick-up and drop-off activities on local streets, reserving automated payment for activities on arterial roads.

In any scenario under this use case, privacy considerations would need to be addressed.

SYNERGIES BETWEEN USE CASES

While these use cases are described as separate, standalone applications, there are potential synergies between some of them. Use Case 1, 2 and 3 could conceivably be achieved through almost any application of the technology, provided that the deployed system satisfies the level of accuracy and detail needed. For example, an application to gather planning data could also provide public information or help make traditional enforcement more responsive. Use Case 4 and 5 are unique in requiring ALPR functionality. So, a typical deployment for Use Cases 1, 2 or 3 would not enable Use Case 4 or 5; however, a deployment for Use Case 4 or 5 could enable Use Cases 1, 2, or 3 applications.

Some use cases may serve as steppingstones for others. For example, data collection (Use Case 2) may be an appropriate precursor for enforcement applications (Use Cases 3 and 4), to first gauge the frequency and duration of violations before moving forward with an enforcement approach. For applications that require high levels of accuracy and detail, it may be possible to deploy both in-ground sensors and cameras in conjunction with each other. This approach would require data integration between platforms and would therefore require additional effort or investment to realize the full benefits of a hybrid deployment.

4.0 CONCLUSION

Parking sensor and curbside vehicle detection technology is an emerging and rapidly evolving tool with a variety of potential applications for cities like Toronto with complex transportation networks. While further testing and analysis are necessary to determine if and how to deploy this technology in Toronto, the *Parking Sensor and Curbside Vehicle Detection Challenge* has advanced the City's understanding of its capabilities and limitations. This report has summarized valuable insights about how these systems collect data, their operating hardware, the associated privacy and cybersecurity risks and mitigation strategies, and the potential scalability for various use cases and contexts.

This TIC also provided an opportunity for four leading companies in this field to showcase and trial their vehicle detection systems, and to deepen their understanding of the City's policies and perspectives related to this technology and curbside management.

Key insights from this TIC include:

- Recognizing the complexity of curbside vehicle detection, particularly in non-delineated on-street parking or loading zones;
- Identifying a broad range of potential use cases that are relevant for the City;
- Understanding how these use cases could be operationalized and the opportunities and limitations associated with each use case relative to the demonstrated state of technology;
- Observing that there is no 'one size fits all solution' and better understanding the trade-offs between different technologies; and
- Understanding opportunities to integrate real-time and historical parking occupancy data into a digital curbside management platform.

These insights will help inform the City-Wide Parking Strategy currently under development, and better prepare the City and its agencies to undertake future trialing of vehicle detection technology. The City is grateful for the time, resources, and engagement of the four participating technology vendors, as well as the many Challenge Advisors, all of whom have contributed to the success of this work.