# Unmanned aerial vehicle operations for traffic management

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## Abstract

While the City of Toronto ('City') has an expanding network of arterial traffic cameras, the viewing range of a camera is limited by intersection configuration and the camera mounting height. Unmanned Aerial Vehicles (UAVs) have the potential to offer a large coverage area from a single camera. The City's Transportation Services teamed with the University of Toronto to explore the potential to use UAV for traffic management. The project objectives were to:

1. Evaluate the capabilities and performance of UAVs for real-time traffic management (unplanned incidents and planned special events);
2. Assess the City's Transportation Operations Centre's readiness to make real-time operational changes; and
3. Provide guidelines for potential UAV operations for future transportation services.

The project team deployed a single UAV at two planned events in the fall of 2017. The team gained valuable insight to the capabilities and performance of UAVs for traffic management. The potential benefits to be derived include:

- The ability to manage multiple intersections and links from a single camera's vantage point;
- Being able to more effectively identify new traffic patterns created by temporary road / lane restrictions; and
- The ability to make real-time traffic signal timing changes based on these observations, and be able to monitor the effectiveness of these changes.

The test flights demonstrated traffic management opportunities, but also illustrated flight range and application limitations due to existing battery technology and federal flight regulations. This paper presents the observations and conclusions of the study.

## KEYWORDS

Unmanned aerial vehicle, transportation operations centre, traffic management

## Background

Through recent developments in technology, Unmanned Aerial Vehicles (UAVs), also commonly referred to as 'drones', may be equipped with cameras and GPS to broaden the reach of traffic management beyond what is currently feasible via conventional approaches. In the second quarter of 2016, the City of Toronto Transportation Services ('Transportation Services') initiated a pilot project to investigate the use of UAVs for real-time traffic management. UAVs have the potential to provide a cost-effective means to achieve a "bird's eye view" and enable real-time coverage and rapid response for a wide array of traffic management applications.

In 2015, the University of Toronto (UofT) Institute for Aerospace Studies offered to demonstrate to the City of Toronto ('City') an 'octocopter' UAV shown in **Figure 1** below. This UAV was custom built by UofT and was equipped with

**Figure 1: Octocopter UAV**

a Sony digital camera and a modem to stream the video. The pilot controlled it with a remote control and utilized a laptop to display the live video feed. The laptop recorded the video and uploaded it to a secure web portal. Users in the Transportation Operations Centre (TOC) were able to log in to this portal and view the video stream with a 20 second latency. UofT followed the various flight rules established by Transport Canada within UofT's 'Special Flight Operations Certificate' (a license to operate under Federal flight regulations). During two separate demonstrations, the UAV flew up to 90 m in altitude and captured footage of the Don Valley Parkway, one of two freeways under the jurisdiction of the City of Toronto.

After the promising results from the freeway demos, Transportation Services wanted to explore the feasibility of using UAVs for traffic management on arterial roads. Through the University of Toronto Transportation Research Institute (UTTRI), the City partnered with UofT to conduct a pilot project. The City and UofT met in the spring of 2017 to define their mutual objectives for the project, and in August, a new proposal was drafted identifying the needs and objectives of this project.

## Objectives

The City's outcome objectives of the pilot project were to:

- Evaluate the capabilities and performance of UAVs for real-time traffic management of unplanned incidents;
- Evaluate the capabilities and performance of UAVs for real-time traffic management of planned or special events;
- Assess the TOC's readiness to make traffic signal timing, and other operational changes in real-time, based on UAV inputs to the TOC; and
- Provide guidelines for potential UAV operations for future transportation services.

UofT's outcome objectives were to:

- Gain additional flight experience and flight time under the current Special Flight Operations Certificate (SFOC);
- Observe a practical application of their UAV technology; and
- Demonstrate the range of application for the UAV.

## Pilot project scope

After exploratory discussions with internal stakeholders and UofT, it was determined that the Federal flight regulations would make the application of UAV technology for unplanned incident management impractical at this time. The reasoning is outlined in the section entitled 'Analysis' below (on page 8). Consequently, the project team concentrated specifically on conducting a pilot using a UAV to manage traffic in the vicinity of a planned special event.

The City of Toronto's scope was to provide:

- A selection of candidate events/locations;
- A selection of potential observation points for the event selected;
- On-site support for the pilot team and liaison with the TOC;
- Staffing within the TOC during the event; and
- Hosting a debrief call following the event.

UofT's scope was to:

- Obtain the necessary SFOC from Transport Canada;
- Provide the requisite Notice to Airmen (NOTAM) as applicable;
- Review the candidate event sites for their suitability relative to the provisions of the SFOC;
- Provide the use of UofT's UAV;
- Provide vehicle operational support (a trained UAV pilot) and related operational tools/approvals; and
- Coordinate with the City of Toronto to arrange for a process whereby the video can be streamed into the TOC in real-time during the event.

Going in to each of the pilot test flights, the scope of work that the combined project team would complete included:

- Use the UAV to identify the alternative route(s) for detoured traffic;
- For the traffic control signals along the alternative route(s), identify/assess the performance of the signals in dealing with the added traffic volumes;

- Determine the TOC's capacity for modifying the signal timing in real-time;
- Make any changes necessary to signal timing;
- Monitor for changes in conditions during the event; and
- Return signal timing to normal after the event is complete.

## Regulations and constraints

As operators of the UAV, UofT is bound by the restrictions listed on the SFOC set by Transport Canada. The University's SFOC is valid for one year for the operation of a DJI Mavic or DJI Phantom 3 for the purpose of aerial photography and video acquisition throughout the Province of Ontario. This allows UofT to complete as many flights as they would like as long as the UAV operator complies with the conditions of the SFOC.

Some of the key SFOC conditions placed on UAV flights that impacted the project objectives are as follows:

- The UAV shall only be operated within the pilot's visual line-of-sight;
- The UAV shall only be operated during the day and under favourable weather conditions;
- The UAV shall not fly more than 400 feet (120 meters) above ground level;
- The UAV operator shall coordinate with the air traffic services unit responsible for supplying air traffic services (Nav Canada) for the area of operation well in advance of the proposed operations;
- The UAV operator shall conduct a site survey in accordance with the procedures outlined in the SFOC;
- A notice to airmen (NOTAM) shall be filed for any operation under this SFOC that is within controlled airspace or within three (3) nautical miles of an uncontrolled aerodrome, unless directed otherwise by the Air Traffic Service Provider or the Flight Information Centre;
- No pilot shall operate the UAV at a lateral distance of less than 100 feet (30 meters) unless the persons, building, vehicle or vessel is the subject of the aerial (consent must be obtained from individuals being filmed if they will be in the operation zone). Note – this includes people travelling in vehicles; and
- No pilot shall operate the UAV over a built-up area or over an open-air assembly of persons.

As an extra measure of safety, UofT also chose to use a visual observer as a second set of eyes to help during the operation of the UAV. The observer acted as a spotter to alert the pilot of any other objects in the sky that may be of concern as well as to keep an eye on the UAV for any unusual behaviour. In addition, the observer also kept an eye out for pedestrians who wandered too close to the area of operation.

For the pilot study, UofT used a DJI Mavic, which offers up to 30 minutes of continuous flight with a fully charged battery. The UAV and its camera are controlled with a dedicated remote controller (**Figure 2**) that syncs-up with a

**Figure 2: Remote controller**

smartphone through the DJI app and displays the live video from the camera. The DJI app allows the operator to live stream the video directly to a secure YouTube channel (i.e. the stream was private and not made available to the public); however, there was a latency of 10 to 20 seconds that was introduced to the video when viewed through YouTube.

The app is also used to change operational and safety settings such as maximum altitude, home point, etc. In addition to live video, the app also displays the UAV's stats including current altitude, coordinates, GPS signal and battery strength. Although UofT had four batteries for the UAV, the operator was limited by the battery life of their smartphone. This was because live video and video streaming are resource intensive tasks that drain the phone's battery fairly quickly. Between flights, the smartphone used with the UAV's remote controller had to be charged.

## Pilot study operations

### *Pilot study test 1 (CIBC Run for the Cure)*

The first pilot study was completed on October 1, 2017 for the CIBC Run for the Cure. When surveying possible sites, the project team had to consider locations that would (a) provide a good vantage point for key traffic locations, while (b) satisfying the 30m lateral clearance away from buildings and the public as dictated in the SFOC. Finding an open area in a built-up urban environment proved to be a challenge as the location had to be close to the race route. After considering 5 take off locations, the team decided to use a UofT parking lot located at the southeast corner of Spadina Ave and Bloor St (**Figure 3**). In order to satisfy the SFOC requirements, UofT parking staff cordoned off a 30 m radius away from the UofT building and to prevent motorists from parking in the operation area. The team was working within a tight space, and in order to maintain regulated lateral clearance distances, the UAV was not allowed to make any lateral movements. So, the flight was straight up and then back down.

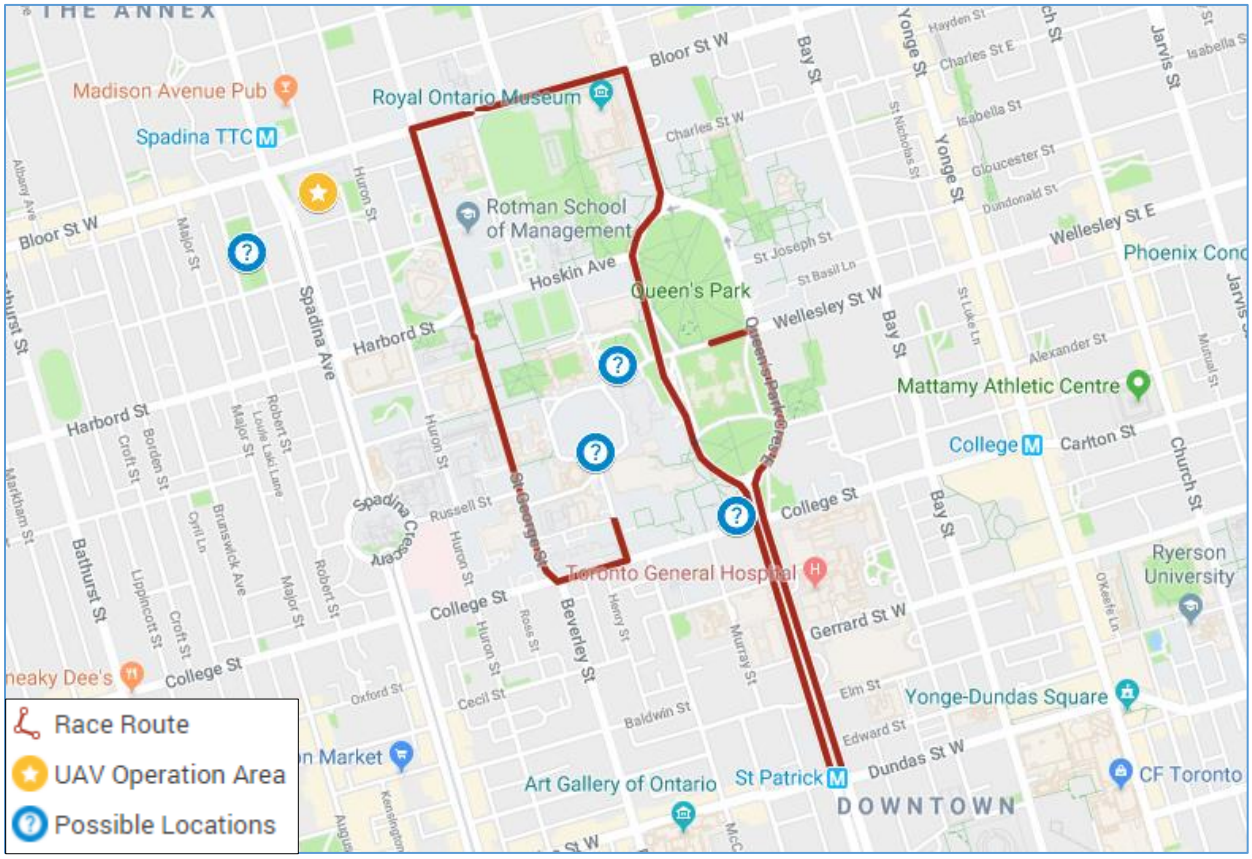


**Figure 3: CIBC Run for the Cure race route**

## UAV operations for traffic management

Within the TOC, operational staff had the following information available:

- The streaming video via YouTube;
- Google Maps with the traffic layer enabled;
- Access to the traffic signal timing for the intersections within the vicinity of the study location;
- TransSuite User Interface (the City's main traffic signal system) to make signal timing changes;
- Map of the race route; and
- CCTV traffic monitoring camera feeds for nearby intersections.

Prior to the UAV flight, the operator added a neutral density filter to the camera's lens. While, the camera automatically adjusts the exposure settings, the neutral density filter helped prevent the video from getting overexposed. The video image was remarkably stable considering how high up in the air it was. This is a function of an electronic stabilizing device attached to the UAV called a gimbal. The initial flight was shot in 4K resolution; however, since City computers do not support 4K, UofT switched to 1080p. After switching to 1080p, the operator was able to utilize the camera's digital zoom feature which provided added information/detail regarding conditions and increased the range of observable view.

This location allowed the team to view Huron St and Spadina Ave which are parallel roadways to the race route to see how traffic behaved due to the closure of St. George St and University Ave. The range of observable view from the UAV was as follows (per **Figure 4**):

- To the north along Spadina Rd to Lowther Ave;
- To the south along Spadina Ave to Willcocks St;
- To the east along Bloor St to Huron St (building occlusion blocked view past Huron St); and
- To the west along Bloor St to Brunswick Ave (also some minor occlusion immediately west of Spadina).

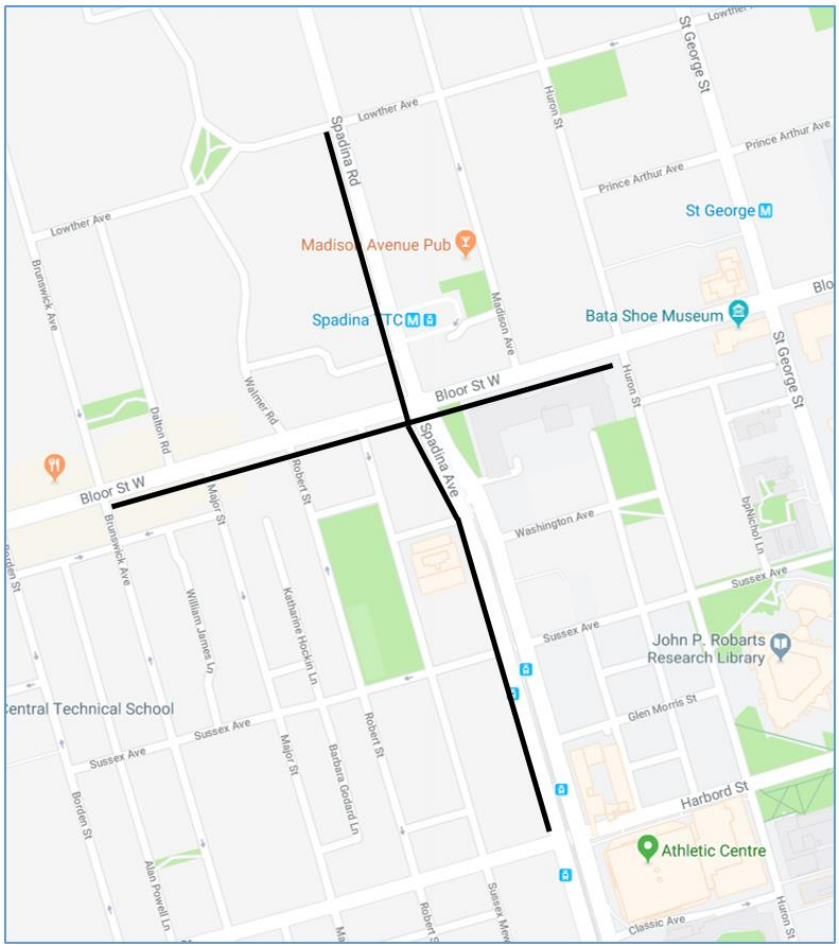


**Figure 4: UAV field of view (black line) during CIBC Run for the Cure**

To prevent traffic congestion near the race route, Toronto Police Services also closed all eastbound exit lanes at the intersection of Bloor St and Spadina Ave (immediately beside our observation point). This forced vehicles travelling east on Bloor St to turn north or south onto Spadina Ave. Around 10AM, using the UAV, we were able to identify higher traffic volumes along Spadina Ave and the northbound through (NBT) movement started to build up at the intersection of Bloor St and Spadina Ave. After consulting the available signal timing plans, operational staff determined that there were available signal timing plans (used to accommodate freeway closures) which adjust the north-south and east-west timing splits to better favour the north-south movements. As there were lighter east-west movements, the freeway closure timing plan was implemented using the TransSuite User Interface to communicate the plan change to the local controllers. The northbound queuing was alleviated shortly after the new plan was initiated.

Shortly after the plan change was made at Bloor St and Spadina Ave, multi-cycle delays and queuing exceeding the storage for the southbound left turn (SBLT) movement at Spadina Ave and Harbord St was observed. Again, operational staff had the opportunity to observe a real-time need, and make appropriate adjustments. However, a signal controller maintenance issue was identified that prevented our remote downloading of new signal timings to that site. As a result, operational staff in the TOC were unable to adjust the timing splits to assist the SBLT movement.

There was also a higher than expected amount of westbound left turn (WBLT) traffic from Bloor St to Huron St which might have been used as an alternative route to access the UofT campus. This caused presumably heavier than normal traffic on Huron St. No signal timing changes were needed at Bloor and Huron as the rest of the movements had low traffic volume so there were no significant delays for the WBLT traffic.

### *Pilot study test 2 (Scotiabank Toronto Waterfront Marathon)*

The second pilot study was completed on October 22, 2017 for the Scotiabank Toronto Waterfront Marathon. In addition to the SFOC conditions, the project team wanted to find a location for the UAV operation area with less tree canopy and fewer high rise buildings in order to get a better sense of the viewing ability of the UAV. To satisfy this need, the team had to consider various parts of the race route in the east (near Woodbine Park) and in the west (near High Park) as shown in **Figure 5**.

**Figure 5: Scotiabank Toronto Waterfront Marathon race route**

Measurement Park, near the southwest corner of Queen St E and Northern Dancer Blvd, was the location chosen (**Figure 6**). The project team expected that Kingston Rd and Queen St would be utilized as an alternative route to get into the City since Lake Shore Blvd was closed.

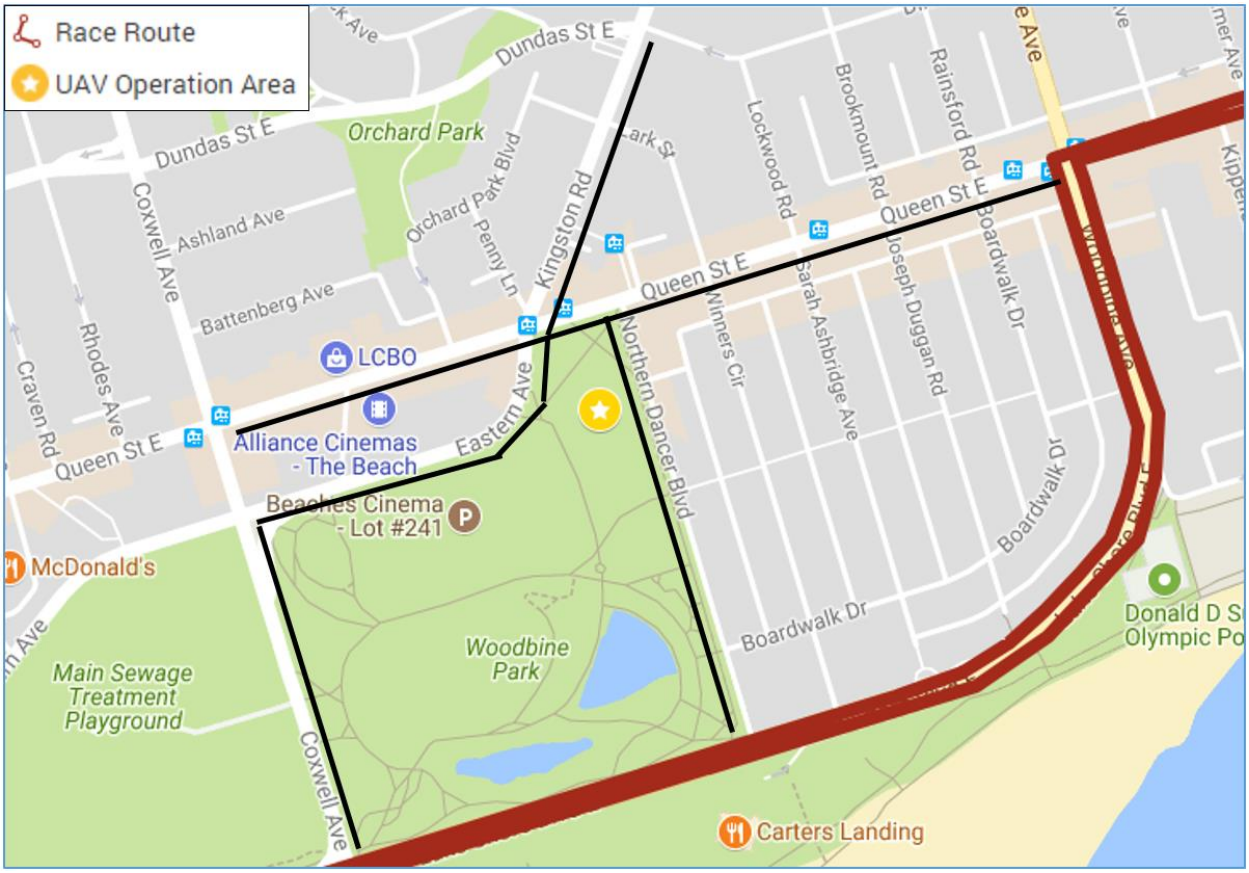


**Figure 6: UAV field of view (black line) from Measurement Park during Waterfront Marathon**

Due to the proximity of the proposed UAV operation to Billy Bishop Airport, UofT had to obtain special permission from Nav Canada prior to the flight. On the day of the event, City staff were in charge of coning off the UAV operation area to prevent the park users from entering this area. Since an open field was used, a larger area was coned off and this enabled the operator to move laterally up to 10 meters. The observation spot afforded a view of four key intersections, specifically Kingston Rd & Dundas St, Kingston Rd & Queen St, Coxwell Ave & Queen St and Coxwell Ave & Eastern Ave. However, as with the first pilot study date, the UAV was not able to travel along the roadway due to the restrictions listed in the SFOC. Operationally, the same processes from the first flight were followed in the field and in the TOC. One additional objective on top of the ones previously listed, was to compare the UAV feed with the City's live HERE traffic probe data, and with the City's Waze maps, to help cross-validate the data received.

This location offered a larger observable area than the first flight and even though the area had no high rise buildings, there was some occlusion caused by trees and low rise buildings especially near the extents of the observable area. The range of observable view from the UAV was as follows:

- To the north along Kingston Rd to Dundas St E;
- To the south along Coxwell Ave and Northern Dancer Blvd to Lake Shore Blvd;
- To the east along Queen St E to Woodbine Ave; and
- To the west along Eastern Ave and Queen St E to Coxwell Ave.

Due to the closure of Lake Shore Blvd for the race, the project team expected there to be heavy traffic turning right from southbound Kingston Rd to westbound Queen St. However, none of the flights observed issues with this

movement. Consequently, congestion at Queen St and Coxwell Ave did not materialize and there were no signal timing changes made in this area.

During these flights, the team in the TOC made use of the live HERE and Waze maps to monitor traffic conditions in the area. The Waze map provided information that supplemented what was observed by the UAV in regards to road closures and traffic in the observable area. Waze provided real-time status for areas where there was no camera coverage. Waze provided a sense of the real-time impacts (i.e. showed the portions of roadway as they actually closed versus when they were scheduled to close) and appeared to be user-driven. It showed where people were getting through (or not) in a way not readily apparent in the HERE data.

## Analysis

### *Unplanned events*

Given the unpredictability of unplanned traffic incidents it is currently not feasible to use UAVs to manage these type of events. This is because:

- Given the size and operational authority of the City, 'blanket coverage' would not be feasible.
- The unpredictable nature of unplanned events prevents the City from dispatching UAVs from a central location in a timely manner.
- Today, the range for the UAVs used is relatively small due to battery life and the requirement for line-of-site operation. Therefore, to achieve broader coverage, the City would have to deploy UAV at many sites across the City. However, Transportation Services would not be able to deploy enough vehicles, with enough pilots, for meaningful coverage.
- Current regulations prohibit the operation of UAV over an open roadway, and within 30m of an occupied building or members of the public in an outdoor setting. Therefore, the mobility of the UAV is mostly restricted to vertical take-off and landing at this time. It cannot (for example) travel along a roadway to either reach the site of an unplanned event, or to observe the area surrounding an unplanned event to assess area impacts.

### *Planned events*

**Table 1** summarizes the team's experience in using UAVs to fulfil the project objectives (outlined in the section entitled 'Objectives' on page 2) related to managing traffic during planned special events.

**Table 1: Project objectives for planned special events**

| Objective | Ability to Meet Objective |
|---|---|
| Evaluate the capabilities and performance of UAVs for real-time traffic management of planned or special events. | The current flight regulations prevent flights along a roadway and require line-of-sight. Battery life limitations restrict practical flight times to 15-20 minutes. Flights are essentially restricted to vertical take-off and landing movements. It cannot (for example) travel along a roadway to either reach the site of an unplanned event, or to observe the area surrounding an unplanned event to assess area impacts. It is, therefore, not possible to 'dispatch' UAV to a site from the TOC or another remote location.<br><br>However, if a reasonable site can be identified, a UAV can offer some promise for traffic management of events, and allow for area-wide operational decision making. Within the pilot project flights, the team was able to observe congestion as it built, developed operational response strategies, and implemented them in real-time.<br><br>The limitations concerning set-back from people and open roads still limits the potential benefits to be derived, and – within the pilot project flights – significantly limited the area that could be managed by an UAV. |

## UAV operations for traffic management

| Objective | Ability to Meet Objective |
|---|---|
| Assess the TOC's readiness to make traffic signal timing, and other operational changes in real-time, based on UAV inputs to the TOC. | With one notable technological exception, the TOC was well positioned to use the UAV images for the purposes of real-time traffic management. Specifically:<br>▪ The TOC was able to identify alternative route(s) for detoured traffic;<br>▪ The TOC was able to identify/assess the performance of the signals in dealing with the added traffic volumes;<br>▪ For some of the traffic control signals along the alternative routes, the TOC was able to modify traffic signal timing updates to suit changing traffic patterns; and<br>▪ The ability to change traffic signal timing was limited (at one site) by the firmware version used in the controller. This is a known limitation that Transportation Services is working to resolve. |

Therefore, in contrast to the project team's observations concerning unplanned events, it is feasible to utilize UAVs for planned / special event traffic management. As demonstrated through this pilot project, UAVs can be used to identify alternative routes and visually assess traffic signal performance at intersections in the immediate area during the event. Alternative signal plans can be activated and changes in traffic can be managed using UAVs.

Revisiting the project objectives established prior to the pilot, the team was able to gain an understanding of the current operational limitations, restrictions and capabilities of utilizing UAVs to monitor traffic. For the purpose of viewing real-time traffic incidents, the conditions in the SFOC limited where the UAV could be used. Finding open space that met the conditions in the SFOC in a built-up urban environment like Toronto was a challenge.

While each location had large observable viewing areas, there were varying levels of occlusion from trees and buildings. When observing the extents of the observable viewing area, occlusion was more prevalent due to the viewing angle. It would be beneficial if the UAV were allowed to move laterally to reduce the effects of occlusion and to expand the observable viewable area, however, with current restrictions on UAVs, this is not possible.

### Future potential

Currently, there are two factors that significantly limit the benefits to be derived from using UAVs for the subject applications:

a) The Federal regulations governing UAV flight capabilities; and
b) The battery life limitations.

#### *UAV flight regulations*

Transportation Services has been attending the City of Toronto UAV Regulations Working Group, which is comprised of several City Divisions that have a special interest in how UAVs can be used in the City. This group discusses updates and changes to UAV regulations and how they may affect the City. Members from this group who are more involved with Transport Canada have suggested that regulations are starting to loosen. UofT echoed this sentiment. The hope here is that this would allow for a larger observable viewing area and would resolve some issues caused by occlusion.

#### *UAV battery life*

Current UAV battery life limits flight time to about 20 minutes (with a practical observation time for a vertical 'up and down' flight) closer to 15 minutes in length. For 'stationary' flights, this is a minor limitation if additional batteries are available. However, should the regulations relax such that the UAV can travel along a roadway (with or without line of sight), the battery life length will become a limitation, as the time available to monitor remote locations will be limited by the travel time to/from the site.

There are strong expectations that advancements in battery life are a focus for this industry, and the flights time capabilities are improving rapidly. In the future, it is reasonable to expect that UAVs will eventually be able to make round trip flights.

*Privacy impact assessment*

The City has completed a Privacy Impact Assessment (PIA) for traffic monitoring cameras, but recent discussion with the City Clerk's Office suggests that the PIA should be updated to more explicitly address UAVs, and to put in place policies and best practices related to the use of the video by operational staff.

Should the City pursue developing a program to operationalize UAVs for traffic management, the City would also consider strengthening its current encryption for the streaming video. This will ensure that the data is secure to prevent unauthorized parties from accessing the stream.

## Conclusions and next steps

Based on the analysis above, the major conclusions reached include:

a) It is not currently feasible to use UAVs to detect, monitor and manage unplanned traffic incidents due to the unpredictable nature (location, time, and distance from base) of these events; but
b) There is some merit in using UAVs to monitor unusual traffic patterns surrounding special events, though current flight regulations significantly limit the potential that this technology might otherwise offer.

Further pilot flights with UofT are being considered subject to completing the above noted PIA. There is some indication that the regulations relating to flying over roadways and buildings may be relaxed in the future. This would significantly increase the applicability and benefits to be derived from the use of UAVs for traffic management. Consequently, City staff will monitor these changes in the UAV regulation by staying actively involved in the City's UAV Working Group. Should these regulations relax, additional rounds of pilot tests will be conducted to assess the traffic management benefits to be derived within the new regulatory environment.

**References**

1. Government of Canada. (2018). *Flying your drone safely and legally*. Ottawa, ON: Transport Canada.