massDOT
Massachusetts Department of Transportation

May 2022

Report No. 22-032

Charles D. Baker
Governor

Karyn E. Polito
Lieutenant Governor

Jamey Tesler
MassDOT Secretary & CEO

Use of UAS for Surface Transportation Emergency Response

Principal Investigator (s)
Dr. Danjue Chen
Dr. Yunachang Xie

University of Massachusetts Lowell

Research and Technology Transfer Section
MassDOT Office of Transportation Planning

U.S. Department of Transportation
Federal Highway Administration

Technical Report Document Page

1. Report No. 22-032	2. Government Accession No. n/a	3. Recipient's Catalog No. n/a
4. Title and Subtitle Use of UAS For Surface Transportation Emergency Response		5. Report Date May 2022
		6. Performing Organization Code 22-032
7. Author(s) Danjue Chen Yuanchang Xie		8. Performing Organization Report No. n/a
9. Performing Organization Name and Address Department of Civil and Environmental Engineering University of Massachusetts Lowell Lowell, MA 01854		10. Work Unit No. (TRAIS) n/a
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address Massachusetts Department of Transportation Office of Transportation Planning Ten Park Plaza, Suite 4150, Boston, MA 02116		13. Type of Report and Period Covered Final Report May 2022 [March 2021 - May 2022]
		14. Sponsoring Agency Code n/a
15. Supplementary Notes Project Champions - Jeffrey DeCarlo and Chester Osborne, MassDOT		

16. Abstract

This project examines the potentials of developing a network of unmanned aerial systems (UAS) for highway incident response in Massachusetts. The project first conducted a thorough analysis of incidents from 2013 to 2019 and the impacts of COVID-19. Based on that, the project identified fire, environment/hazmat, and roadway/traffic incidents to benefit the most from a UAS network. The project then reviewed the typical types of UAS for a UAS network, with a focus on drone-in-a-box. Thereafter, the project identified three incident scenarios most likely to benefit from a UAS network and evaluated the effectiveness of typical UAS types. A tabletop simulation of pilot flights was conducted to assess how a drone could help if it were available. Chapter 6 developed a UAS network for incident response accounting for the incident frequencies, operation features of UAS, and existing CCTV cameras. It was found that existing CCTV cameras can cover 43% of incidents, and a UAS network will cover 25% of the uncovered incidents with four superstations and another 24% with nine key stations. Three state agencies were interviewed on their UAS usage and feedback for future UAS development. Finally, the project has provided recommendations for MassDOT on the development of UAS.

17. Key Word UAS, emergency response, network		18. Distribution Statement n/a	
19. Security Classif. (of this report) unclassified	20. Security Classified. (of this page) unclassified	21. No. of Pages 82	22. Price n/a

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

This page left blank intentionally.

Use of UAS For Surface Transportation Emergency Response

Draft Report

Prepared By:

Danjue Chen, PI
Yuanchang Xie, Co-PI
Muhammad Zaeem Sheikh, Research Assistant

Department of Civil and Environmental Engineering
University of Massachusetts Lowell
Lowell, MA 01854

Prepared For:

Massachusetts Department of Transportation
Office of Transportation Planning
Ten Park Plaza, Suite 4150
Boston, MA 02116

May 2022

This page left blank intentionally.

Acknowledgments

Prepared in cooperation with the Massachusetts Department of Transportation, Office of Transportation Planning, and the United States Department of Transportation, Federal Highway Administration.

We would like to acknowledge the MassDOT Highway Operations Center for providing the data and the Massachusetts Emergency Management Agency for providing feedback.

Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Massachusetts Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

This page left blank intentionally.

Executive Summary

This study of the Use of UAS For Surface Transportation Emergency Response was undertaken as part of the Massachusetts Department of Transportation Research Program. This program is funded with Federal Highway Administration (FHWA) State Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies.

This project has further examined the potentials of developing a network of unmanned aerial systems (UAS) for highway incident response in Massachusetts. We have investigated the following three important questions related to the development of a UAS network:

- Question 1: Which types of highway incidents are most suitable for using UAS?
- Question 2: What are the key UAS operational parameters for successful highway emergency response applications?
- Question 3: How can UAS be effectively integrated into highway emergency response practices?

To address the questions, a thorough analysis of the incidents in Massachusetts from 2013 to 2019 was conducted, and incident features before and after COVID-19 are compared. The analysis and comparison are described in Chapter 2, in which we identify the three types of incidents that can potentially benefit from the applications of UAS—namely, fire, environment/hazmat, and roadway/traffic incidents. These incidents were used later to develop the UAS network.

In Chapter 3, we review the typical types of UAS that can potentially be used to build the UAS network. Our review focused on the latest drone-in-a-box technology and its counterparts. Based on the pros and cons of the different types of drones, in Chapter 4 we identify three application scenarios for use of UAS in highway emergency responses and evaluate the potentials of each type of drone for each application scenario. Drone-in-a-box (including drone-in-a-box in a truck) is particularly attractive for Scenario 1 (recurring bottlenecks, incident hotspots, and scheduled events) and Scenario 2 (nonrecurring incidents such as fire, hazmat, injury, and extreme weather).

In Chapter 5, we document the tabletop simulation of the pilot flights. Based on a historic incident, we analyzed the response of current MassDOT surveillance systems and deployed a drone to the incident site to see how a drone could help if it was available. MassDOT HOC experts participated in the tabletop simulation, and the entire team had an extensive discussion on the potentials of UAS for incident response.

In Chapter 6, we update the UAS network for incidents response by considering the operational features of UAS (based on the results of Chapter 3) and the impacts of CCTV cameras. We found that current CCTV cameras cover 43% of incidents considered. If a UAS network is available, four super stations (with two or more incidents per month) will cover

25% of the incidents uncovered by CCTV cameras, and the nine key stations (incident frequency is between one and two incidents per month) will cover another 24% of the uncovered incidents.

Regarding the future development of a UAS network, we interviewed three state agencies to understand their UAS usage and collect their feedback on future development of UAS. The outcomes are summarized in Chapter 7.

Finally, based on what we have learned from the analysis of incidents in Massachusetts, the literature review, the tabletop simulations, and the feedback from the stakeholders, the University of Massachusetts Lowell (UML) research team has the short-term and long-term recommendations for MassDOT on the development of UAS.

Table of Contents

List of Tables

This page left blank intentionally.

List of Figures

List of Acronyms

Acronym	Expansion
BVLOS	Beyond visual line of sight
FAA	Federal Aviation Administration
HOC	Highway operations center
KPI	Key performance indicators
MBTA	Massachusetts Bay Transportation Authority
MEMA	Massachusetts Emergency Management Agency
MSP	Massachusetts State Police
SAMS	Smart aerial monitoring systems
SB	Southbound
SER	Special emergency response
TSMO	Transportation systems management and operations
UAS	Unmanned aerial systems
UML	University of Massachusetts Lowell

This page left blank intentionally.

1.0 Introduction

In recent years, unmanned aerial systems (UAS, or "drones") have demonstrated great potential for surface transportation applications, including transportation systems management and operations (TSMO). Many state departments of transportation (DOTs) have shown strong interest in harnessing the potential of this new technology and leveraging it to inspect transportation infrastructure, monitor traffic, provide situational awareness, and so forth. In 2017, MassDOT initiated a project "The Application of Unmanned Aerial Systems in Surface Transportation" to explore the new opportunities for the use of UAS in transportation management as well as to identify the challenges associated with UAS, referred to as the Phase 1 study. One task of that project was to conduct an analysis and to develop a conceptual framework for implementing a UAS emergency response network for both highway incidents and natural disasters. As a result of that analysis, a basic framework of the emergency response network has been proposed. MassDOT has expressed an interest in moving this effort into the implementation stage, which requires a deeper understanding of the practical utility, operational constraints, and emergency integration steps required to transition the UAS for transportation emergency response concepts into reality. Our goal is to answer some important operational questions, particularly the three raised in section 1.1, which must be addressed before UAS could be widely deployed to respond to highway emergencies.

1.1 Objectives

UAS can be very helpful in emergency incident response, particularly when the incident scenes are too dangerous for first responders to get close to (e.g., fire and hazmat spills). Recognizing this need, the MassDOT Aeronautics Division has already conducted a study via the project "The Application of Unmanned Aerial Systems In Surface Transportation Volume II-D: Development of UAS Emergency Service Drone Network for Use in Surface Transportation" *(1)* and developed a conceptual drone emergency response network for both highway incidents and natural disasters in Massachusetts. To enable practical UAS applications in the near future, this project will address the following three critical questions:

- Question 1: Which types of highway incidents are most suitable for using UAS?
- Question 2: What are the key UAS operational parameters for successful highway emergency response applications?
- Question 3: How can UAS be effectively integrated into highway emergency response practices?

In the following chapters, Chapter 2 presents an analysis of the incidents in Massachusetts that can potentially benefit from the applications of UAS. Chapter 3 presents a review of the typical drones with a focus on drone-in-a-box and its alternatives. The main purpose of the review is to guide the selection of drones for use in the pilot flights and potential UAS network deployment. Chapter 4 has identified three potential scenarios that will benefit from using UAS. Chapter 5 documents the tabletop simulation of the pilot flights. Chapter 6 updates the UAS network for incident response by considering the operational features of UAS and the impacts of CCTV cameras. Chapter 7 summarizes the feedback from the relevant stakeholders regarding UAS applications and future development. Chapter 8 presents recommendations on integrating UAS into highway emergency response in Massachusetts. Conclusions follow in Chapter 9.

2.0 Analysis of Massachusetts Incidents

This chapter presents our analysis of the incidents in Massachusetts. This will lay a foundation for the development of a UAS network for incident response. We first introduce the incident selection criteria and then present the analysis of historical trends. After that, we introduce the results from the comparison of before and after COVID to show the impacts of the pandemic.

2.1 Incidents Selected for Analysis

In our previous Phase 1 analysis in the project "The Application of Unmanned Aerial Systems In Surface Transportation Volume II-D: Development of UAS Emergency Service Drone Network for Use in Surface Transportation" *(1)*, we conducted an initial analysis of the incident features in Massachusetts. In the current project (i.e., Phase 2), we have conducted a more in-depth analysis of the incidents. Table 2-1 below details our selection criteria. Particularly, we focused on three incident types (fire, environmental/hazmat, and roadway/traffic) that are mostly likely to benefit from drone applications. For these event types, we also require that the severity level is 2 (per definition of the MassDOT Headquarter of Operation Center) and above and the duration is between 30 and 300 min, similar to our Phase 1 analysis. Severity level 2 and above is used so that the incidents are likely significant and of duration 30–300 min so that it is likely enough for drones to reach the incident scene considering the preparation time. (When we develop the UAS network, we also try a stricter filter for duration, 60–300 min, to see how the network layout changes.) We also require that a year should have valid data for the whole period so that we can study the seasonal and yearly trends. With these criteria, we have identified 8,650 incidents from 2013 to 2019.

Regarding the three incident types selected, we believe that they are most likely to benefit from drone applications. Particularly, in fire incidents, drones can provide firefighters and first response teams with a preliminary assessment before they enter the area. During the incident, they can improve the safety of responders and incident victims by tracking the personnel through the smoke/fire and monitoring the incident scene in low light conditions using drones equipped with thermal imaging cameras *(2)*. In environmental/hazmat incidents, drones can provide immediate and real-time assessment of the type of hazmat and the impacted areas to enable faster and safer response. Drones with thermal imaging sensors can also be used to assess the situation and provide support to the team on ground *(3,4)*. Roadway/traffic incidents can benefit from drones equipped with special sensors (e.g., infrared sensors and sensors that can detect oil spills) to quickly assess the impacted area, monitor the status of incident clearance, estimate potential delay to guide traffic detours, and estimate incident clearance time. Drones can also be used in day-to-day traffic management such as incident hotspots and work zone monitoring *(5)*.

Table 2-1*: Incident selection criteria*

Feature	**Criteria**
Event type	Fire Environmental/hazmat Roadway/traffic
Severity level	Level 2 and above
Time duration	30–300 mins*

* In practice, this can be the estimation of the incident commander as the exact incident duration is unknown until it's cleared.

2.2 Historical Analysis from 2013 to 2019

Based on our analysis of the 8,650 incidents identified per criteria in Table 2-1, fire incidents were 10.05% (869), environmental/hazmat incidents were 1.45% (125), and roadway/traffic incidents were 88.5% (7,656) (Figure 2-1). For each incident type, we have analyzed the event frequency, severity, and the trends across the year, season, day of the week, and time of the day.

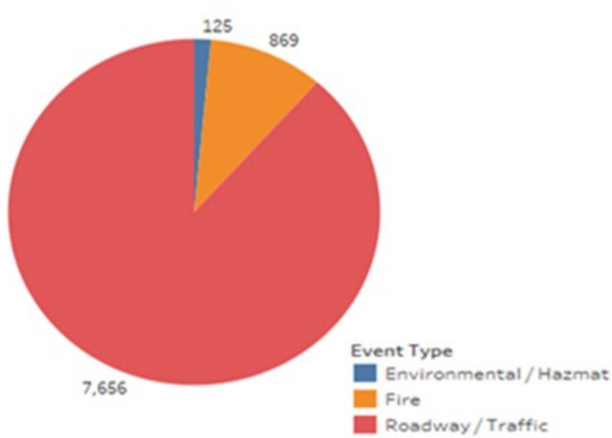

Figure 2-1: Proportion of the three incident types

2.2.1 Key Features Across the Three Incident Types

Next, we summarize the key features of each incident type. Detailed plots of the analysis are provided in Appendix 1.

- Roadway/traffic incidents dominate across the event types: 1,094 events/year (average across the 7 years analyzed) compared to 124 fire incidents/year and 18 environmental/hazmat incidents/year.
- Annual trend (HOC adjusted the classification of incidents in the system in 2016, which affects the number of incidents shown in these statistics): Figure 2-2 shows the combination of three incident types, and Figures 2-3, 2-4, and 2-5 show each incident type.
- Seasonal trend: Fire incidents are slightly higher in the summer and winter (pattern varies across year), environmental/hazmat incidents are slightly higher in the fall (pattern varies across year), and traffic incidents are higher in winter.
- Day of the week: Event frequency is higher on weekdays than weekends for all three types.
- Time of the day: Event frequency is slightly higher in the afternoon than morning and it is low in the evening; similar trends occur for all three incident types.

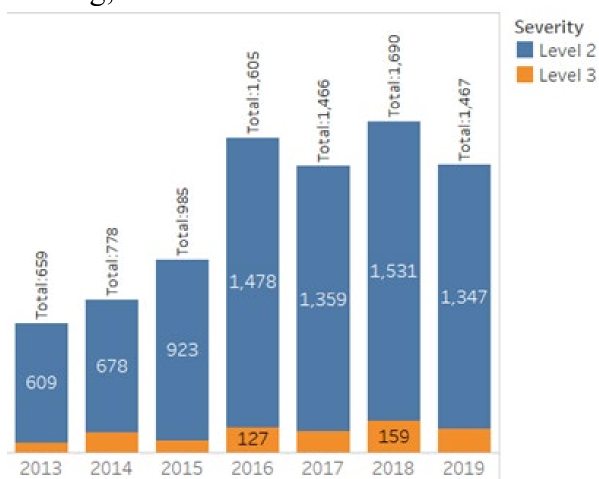

Figure 2-2: Combined incidents per year by severity level

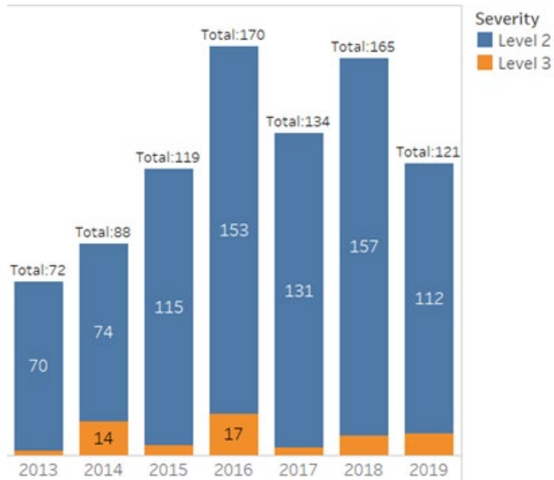

Figure 2-3: Fire incidents per year by severity level

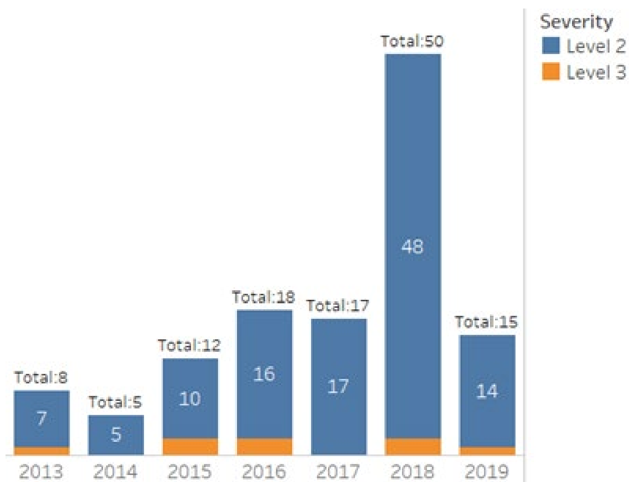

Figure 2-4: Environmental/Hazmat Incidents per year by severity level

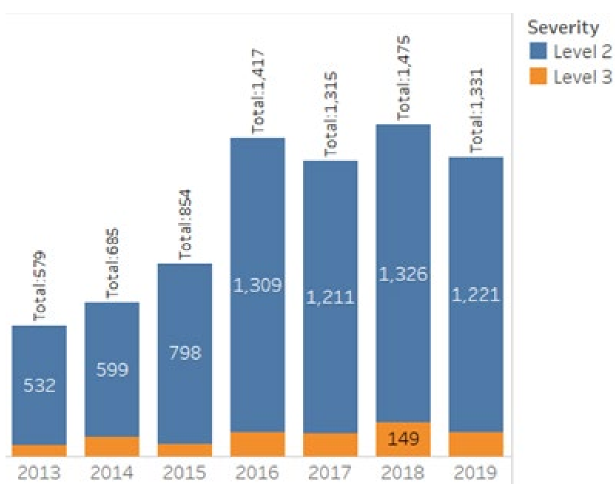

Figure 2-5: Roadway/traffic Incidents per year by severity level

2.2.2 Fire Incidents

- On average, there are 124 fire incidents per year shown in Figure 2-3.
- Incidents are mostly at level 2 severity with a small proportion of level 3 (6.56%, average across the years).
- Event frequency is slightly higher in the summer and winter seasons.
- Incidents are higher on the weekdays than the weekends.
- Event frequency is slightly higher in the afternoon (12 p.m. to 8 p.m.) than the morning (4 a.m. to 2 p.m.), and it is low in the evening (8 p.m. to 4 a.m.).

2.2.3 Environmental/Hazmat Incidents

- On average, there are 18 incidents per year (Figure 2-4).
- Incidents are mostly of level 2 severity with 6.4% (on average across the year) level 3 severity incidents.
- Events are slightly higher in the fall and summer seasons.
- Incidents are higher on the weekdays than the weekends.
- Event frequency is slightly higher in the afternoon than the morning and it is low in the evening.

2.2.4 Roadway/Traffic Incidents

- There are 1,094 roadway/traffic incidents per year (Figure 2-5).
- Incidents are mostly of level 2 severity with 8.62% level 3 severity incidents (average across all years considered).
- Events are slightly higher in the winter season and the other three seasons have similar frequencies.
- Incidents are higher on the weekdays than weekends.
- Event frequency is slightly higher in the afternoon than the morning, and it is low in the evening.

2.3 Comparison Before and After COVID

We conducted a comparison of the incident before and after COVID-19 to understand the impacts of the pandemic. For this purpose, we selected the incidents for a continuous 10-month period before and after the COVID outbreak. This is the best data coverage based on the current data availability. We applied the same incident selection criteria as in the historical analysis for the following time periods:

- Pre-COVID: June 2018 through March 2019
- Post-COVID: June 2020 through March 2021

The total numbers of incidents (across the three types) filtered out are as follows:

- Pre-COVID records: 1,145

- Post-COVID records: 867

In the post-COVID period, on the change of fire incidents, the event frequency was similar in summer and slightly higher in the fall, but it decreased significantly in winter 2020 (post-COVID; see Figure 2-6, particularly the months labeled in the dashed box). For the environmental/hazmat incidents, the incident frequency significantly decreased in the post-COVID period (Figure 2-7). For roadway/traffic incidents, the incident frequency was similar in summer, slightly higher in the fall, and significantly lower in the winter (Figure 3-8. For the aggregation of the three incident types, the incident frequency was similar in summer, slightly higher in the fall but significantly decreased in winter 2020 (Figure 2-9). We found that the large incident reduction concurred with COVID-19 surges (i.e., the second wave). The lockdown associated with the second wave may have significantly reduced the travel and therefore the incidents (Figure 2-10) *(6)*. The results here show that the pandemic has a profound impact on the incident frequency, particularly in fire incidents and roadway/traffic incidents.

We would like to caution that, limited by data availability, our analysis only used data of 10 months for the before and after period. It is unclear whether the changes in traffic patterns will continue in the mid- and even long-term. Further research with more extensive data coverage is needed. Additionally, future research will benefit from incorporating other data (e.g., traffic volume, travel behaviors) to understand the underlying factors that cause the changes.

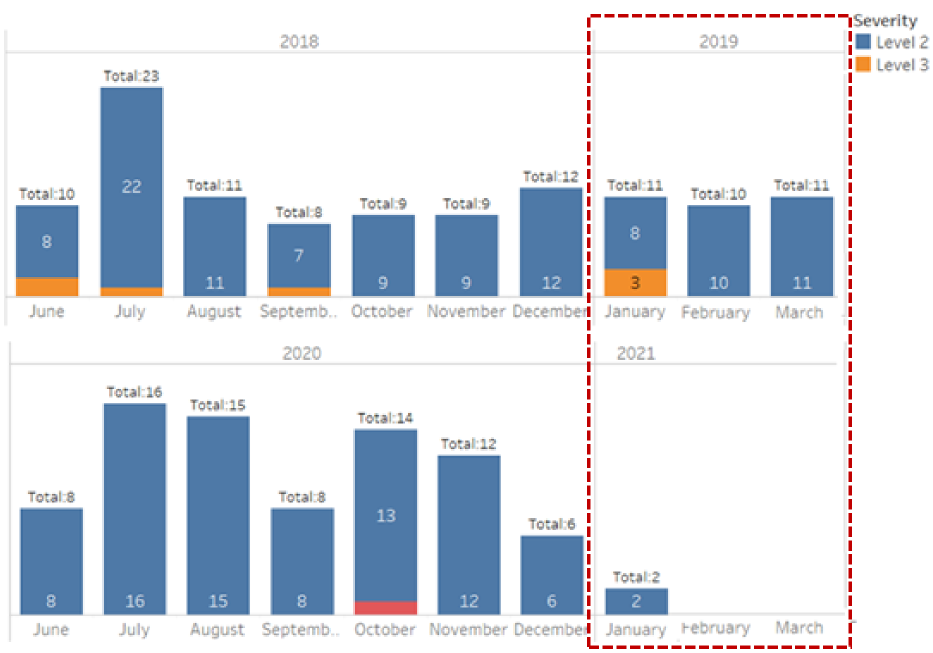

Figure 2-6: Pre- and post-COVID comparison of fire incidents

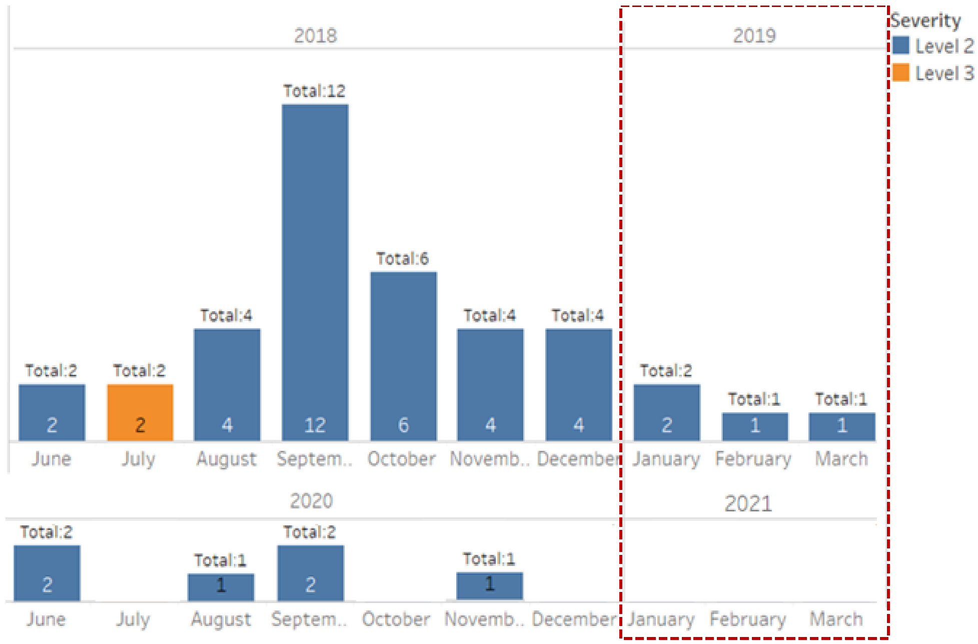

Figure 2-7: Pre- and post-COVID comparison of environmental/hazmat incidents

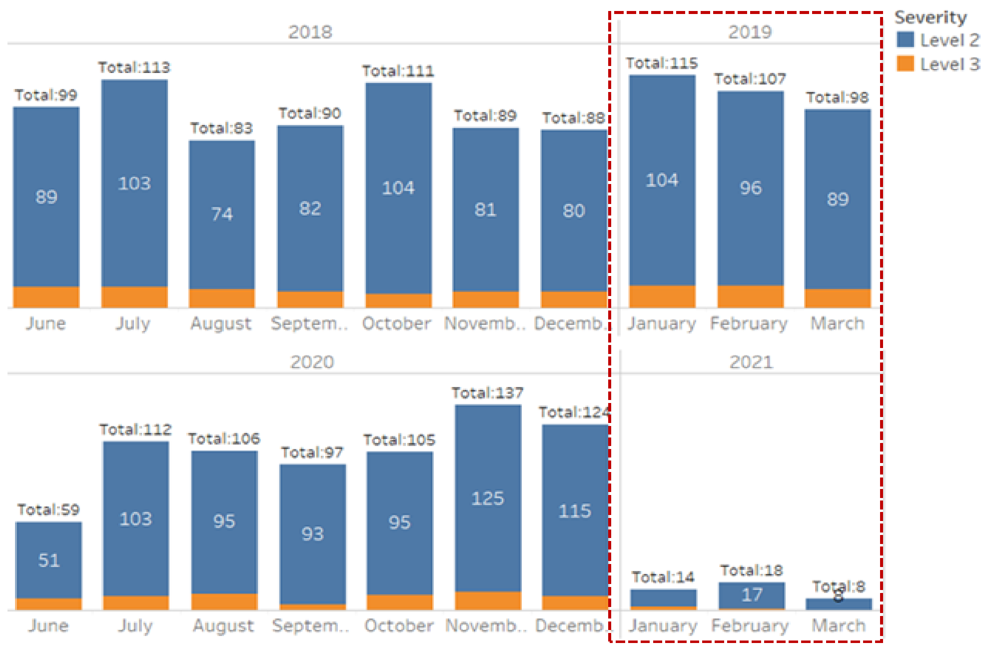

Figure 2-8: Pre- and post-COVID comparison of roadway/traffic incidents by season

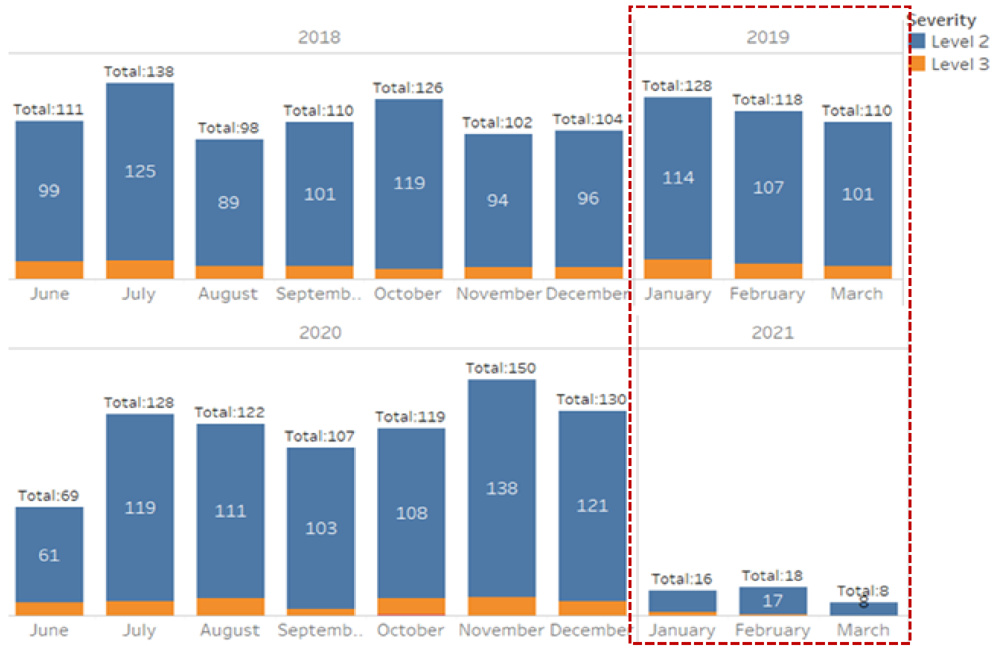

Figure 2-9: Pre- and post-COVID comparison of three incident types combined

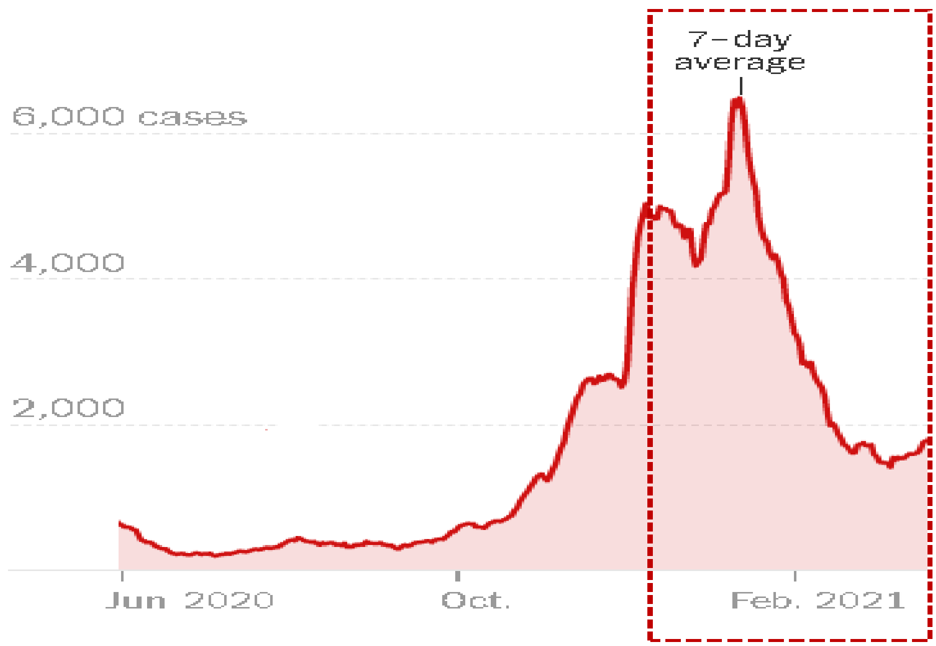

Figure 2-10: COVID cases in Massachusetts during post-COVID period of study

3.0 Review of Typical UAS Types

This chapter presents a review of the typical drone types, with a focus on drone-in-a-box and its alternatives. The main purpose of the review is to guide the selection of drones in the pilot flights and potential UAS network deployment. We reviewed five types of drones and summarized the key features of each type. A detailed review of some specific drones is provided in Appendix 2.

We reviewed five types of drones with a total of 21 specific drone brands: drone-in-a-box, drone-in-a-box with fixed wings, rotary drones, fixed-wing drones, and tethered drones. Table 3-1 summarizes the key features of the five types of drones.

Table 3-1: Operational features of typical types of drones

Features	Drone-in-a-box	Drone-in-a-box with fixed wings	Rotary drone	Tethered drone	Fixed-wing drone
Takeoff/landing	Autonomous[a]	Autonomous	Pilot present	Pilot present or automated[b]	Pilot present or autonomous[c]
Ranges	1.5–13 miles	Network dependent	1–12 miles	Not provided	1–100 miles
Max speed	Mostly in 30–40 mph	60 mph	35–50 mph	Not available	45–90 mph
Flight time	Mostly in 40–50 min	50 min	20–35 min	24 h	45 min–4 h

Power charging	Battery swap/ 30–40 min charge time	Internal charging	Charging cable and/or battery swap	Chargeable during tethered state	Not listed
Payload	Usually adaptable and interchangeable	Not Provided	About 1 kg	Not provided	0.7–4.5 kg
Sensors	EO/IR	EO	EO, EO/IR	EO/IR	EO/IR
Takeoff time[d]	5 min	5 min	10 min	unknown	15 min
Service ceiling	400 ft AGL	400 ft AGL	400 ft AGL	400 ft AGL	400 ft AGL

Notes: EO/IR = Electro-optic/infrared; AGL = above ground level.
[a] "Autonomous" takeoff/landing means that the drones can be operated remotely.
[b] Some tethered drones claim to have the capability of automated takeoff/landing for certain missions, but a pilot may still be needed nearby.
[c] Some fixed-wing drones claim to have the autonomous mode, but a pilot is needed to operate it remotely.
[d] The takeoff time does not include the time needed to acquire permission approval.

In our comparison, we focused on a set of operational features, including takeoff/landing capability, flight range (in distance), maximum operation speed, flight time, power charging requirement, payload, sensor compatibility, takeoff time, and service ceiling. In general, each type of drone has pros and cons. The selection of drone type will depend on the specific needs.

Specifically, the drone-in-a-box type has autonomous takeoff and landing capabilities (but a pilot is needed to remotely operate them) but also can be controlled via ground station. The drone (a rotary drone) often is stored in a box, and the box automatically opens when the drone is to take off (e.g., Figure 3-1). The box is often made bulky and resilient against tough weather. Depending on the design, the entire suite (the drone and the box) can be placed in a fixed location or in the trunk of a truck. For the latter, we call it "drone-in-a-box-on-truck." This type of drone is relatively new to the market and only a few brands are available. For those surveyed, the operation temperature range is wide (around −10 to 50°C or 14 to 122°F), and some can go to −30°C (−22°F). For drone-in-a-box, the flight range (measured from the box of the drone) is between 1.5 and 13 miles with a maximum speed mostly in the range of 30–40 mph. The flight time is mostly between 40 and 50 min. The drone often has the option to swap batteries or fly back to the box to recharge automatically (about 30–40 minutes of charging time). The payload of this drone type is usually adaptable and interchangeable. The drones can be equipped with electro-optic/infrared (EO/IR) sensors.

Figure 3-1: Drone-in-a-box by American Robotics

For such autonomous drones (i.e., those that can be remotely operated), current FAA rules for flying beyond visual line of sight (BVLOS) requires additional approvals. Such approvals are feasible but are still challenging to acquire. Therefore, routine use of such systems may need some time. Nevertheless, with the operation permission acquired, it takes about 5 min for the drone-in-a-box to take off. The service ceiling (i.e., maximum height the drones can go) is 400 ft above ground level per FAA regulation. Drone-in-a-box is particularly suitable for surveillance that follows a regular timetable and consistent surveillance paths because the drone can be preprogrammed to autonomously carry out the task. Some providers such as American Robotics *(7)* and Perceptro *(8)* have already acquired the permission to fly BVLOS.

Notably, for drone-in-a-box-on-truck, the practical range can be significantly extended because someone can drive the truck to a location and then let the drone fly. Of course, this will increase the response time (i.e., from receiving the task until the drone reaches the target location). If longer response time is allowed, the reachable range also can be greater.

The drone-in-a-box with fixed wings type of drone has similar features with the regular drone-in-a-box with rotary drones, such as autonomous takeoff/landing and very short takeoff time (about 5 min), but it is network dependent. The drone also has a larger maximum speed (up to 60 mph) and longer flight time.

Regular rotary drones share similar features with drone-in-a-box except that the drones do not have the autonomous takeoff/landing capabilities, and a pilot needs to be present. The takeoff time is longer than drone-in-a-box (10 min vs. 5 min). This type of drone can use the charging cable and/or battery swap.

Fixed-wing drones are built like small-sized airplanes with longer flight times and operating range, greater speeds, and more payload capacity as compared to other types of drones. Particularly, the flight time is substantially longer than other types of nontethered drones. Some fixed-wing drones can also have the autonomous takeoff/landing capabilities (pilot is needed for remote control), such as Believer *(9)*. The downside is that they are expensive, do not have the hovering capability, require a run-up for takeoff as well as landing, and have a longer takeoff time. This type of drone is more suitable for large area coverage with low maneuverability requirements, such as surveillance of a large area after flooding.

Tethered drones are similar to rotary drones except that they are connected to a tether and have continuous power supply. The advantage is that the flight time is unlimited as long as it is in operation. The disadvantage is that it has limited range (due to the tether) and is immobile, but it is suitable for fixed location incidents such as work zones and forest protection. Although tethered drones often need a pilot present operate them, some claim to have the automatic operation capabilities (pilot is likely needed to remotely operate them), such as Orion 2 *(10)*.

4.0 Application Scenarios Using Different Types of Drones

Based on the technical features of the drones reviewed, the UML research team identified four potential highway emergency response scenarios that will benefit from using drones. A summary of the scenario description is provided in Table 4-1. The detailed pros and cons of each drone type are provided in Appendix 3. Based on the pros and cons, we provide a rating for each type of drone (Table 4-2). Our rating uses a 5-star scale (5-stars being the best), which is a subjective evaluation that considers the technical capabilities, cost-effectiveness, and technology readiness.

- Scenario 1: recurring bottlenecks, incident hotspots, scheduled events
- Scenario 2: nonrecurring incidents (e.g., fire/hazmat/injury/extreme weather)
- Scenario 3: incidents affecting an extensive area (e.g., flooded roads)

4.1 Scenario 1

Scenario 1 pertains to bottlenecks, incident hotspots, and scheduled events, which are recurring in fixed locations (for scheduled events, they are recurring during the scheduled time and the location varies across events). For this scenario, a drone can be used to provide regular surveillance to study the factors that cause the events, monitor the event development, and predict potential incidents. The surveillance task can be completed in less than an hour. For such missions, current technologies provide some solutions. For example, CCTV cameras may exist for some road spots. In places where CCTV cameras do not cover, cameras can be installed if a pole (or another device) is available to mount the camera, but the installation and maintenance are not easy and could be labor/time consuming. Use of CCTV cameras and cameras mounted on poles are typically at a fixed location and can cover only a small area (e.g., a radius <200 m or 656 ft), which may not be sufficient for the monitoring of bottlenecks/incident hotspots that involve a more extensive area. Another current method is the probe vehicle data (e.g., from Bluetooth or onboard devices on vehicles such as INRIX data), which can provide traffic information (e.g., speed) but the resolution is not sufficient to diagnose the cause of the event and the accuracy is not sufficient for event prediction.

(a) 300 ft slanted view (d) 300 ft top-down view

(b) 350 ft slanted view (e) 350 ft top-down view

(c) 400 ft slanted view (f) 400 ft top-down view

Figure 4-1: Typical view sheds of a drone at different elevations

Compared to the current methods, drones have some unique advantages for this recurring bottleneck, incident hotspots, and scheduled event scenario. Specifically, drone-in-a-box (in a fixed location or on a truck) can provide a more extensive view (because it can move in a certain range) and can complete the mission autonomously without a pilot present if BVLOS is permitted. It can also livestream the events if needed. For example, drone-in-a-box can be used to monitor traffic before and after a construction project and further optimize future construction planning. Figure 4-1 provides the typical view sheds of a drone at different elevations. The cons are associated with the high cost and the short surveillance time. Overall, we rate drone-in-a-box 4 stars for this scenario. Drone-in-a-box with fixed wings have similar functions with drone-in-a-box using rotary drones, but they are network dependent and very limited information about this type of drones is available so far. Rotary drones are also quite suitable for such missions, but they require pilots, although they are cheaper. Thus, we also give them 4 stars. For tethered drones, the coverage range is very small, which is a significant con for this type of mission. We rated them as 2 stars. Fixed-wing drones can cover a large area, sufficient for this scenario, but they are more expensive than rotary and tethered drones, so they were given 3 stars.

4.2 Scenario 2

Scenario 2 pertains to nonrecurring incidents (such as fires, fatal injuries, incidents involving hazmat, and road blockage due to extreme weather). The locations of such events are uncertain, and the incident scenes may pose a risk for emergency response personnel. In this scenario, it is desirable to use drones to provide preliminary incident assessment before the first responders enter the scene, monitor incidents for safety, record the incidents for reconstruction and post-incident damage assessment, and estimate incident clearance time. In the current practice, CCTV cameras, if available, can provide initial assessment. Otherwise, incident response relies on the presence of emergency response personnel at the scene to estimate the incident severity and clearance time. In these incidents, emergency responders are exposed to significant risks due to the incidents themselves (e.g., fire/hazmat) and/or from secondary traffic crashes. Additionally, the arrival of the first responders can be significantly delayed if traffic congestion is severe.

For Scenario 2, drone-in-a-box-on-truck can be particularly useful to serve the desired missions because one can easily drive the truck to the desired location and then launch the drone, which can perfectly address the issue of unpredictable incident locations. Additionally, with BVLOS permission, the initial assessment can be done quickly before the first responders arrive and to help first responders plan a safer and more effective response. Thus, we give it 4 stars for the application potentials. Rotary drones are slightly less effective than drone-in-a-box-on-truck because they require a safe spot for the pilot to launch the drones. We give it a 3-star rating. Other types of drones have the similar pros and cons when they are applied to Scenario 1.

4.3 Scenario 3

Scenario 3 pertains to incidents affecting an extensive land area (such as flooded roads). For this scenario, it is desirable to use drones for damage assessment. Current practice uses satellite image, which may not provide the resolution desired. Fixed-wing drones have great potential for such a scenario. They can provide high-resolution data of the area and are able to access unsafe or difficult-to-reach areas. Their surveillance is also efficient and accurate (more stable than rotary drones). The major con compared to satellite image is that they may have weather restrictions. Other types of drones, drone-in-a-box (rotary or fixed wings), rotary drones, tethered drones, are not very suitable for this scenario.

Table 4-1: Potential application scenarios

Scenario number	Scenarios	Features	Drone task	Current technology
1	Recurring bottleneck, incident hotspot, scheduled events	Fixed location, recurring	Regular surveillance at the event site to monitor safety and traffic conditions; it must finish the task within 40 min	CCTV camera might exist for some road spots; camera on a pole (needs installation); probe data (not very accurate)
2	Nonrecurring incidents (e.g., fire, hazmat, injury, extreme weather)	Uncertain location; could be risky for personnel	Preliminary incident assessment before first responders arrive; monitor incident for safety; recording incident for reconstruction; estimate clearance time	CCTV camera might exist for some road spots; rely on human experts on scene to estimate incident severity and clearance time
3	Incidents affecting an extensive area (e.g., flooded roads)	Involve an extensive area	Damage assessment of incidents	Satellite image (resolution may not be sufficient)

Table 4-2: Star rating for different drone types

Scenario number	Scenarios	Drone in-a-box/drone-in-a-box-on-truck	Drone-in-a-box with fixed wings	Rotary drone	Tethered drone	Fixed-wing drone
1	Recurring bottleneck, incident hotspot, scheduled events	4 stars	4 stars	4 stars	2 stars	3 stars
2	Nonrecurring incidents (e.g., fire/hazmat/injury/extreme weather)	4 stars	3 stars	3 stars	2 stars	3 stars
3	Incidents affecting an extensive area (e.g., flooded roads)	1 star	1 star	1 star	1 star	4 stars

5.0 Pilot Flight Tabletop Simulation

This chapter documents the tabletop simulation for the pilot flight. The main purpose was to understand the potential challenges of drone deployment and the potential benefits.

5.1 Introduction

The objectives of the tabletop are to (1) understand how the current surveillance system at MassDOT responds to an incident, and (2) how the UAS would have helped with the response of an incident.

5.2 Tabletop Setup

For the tabletop, the UML team worked with the project champions to identify a historic incident for the simulation. Then, the UML team analyzed the response of MassDOT had to this incident when it occurred. Additionally, the drone team at the MassDOT Aeronautics Division deployed a drone to the incident site to collect additional data. The UML and drone teams completed the design of the tabletop simulation on April 11, 2022, and MassDOT Highway Operations Center (HOC) experts participated in the tabletop simulation to provide feedback.

5.2.1 Incident Overview

The incident used in the simulation involved an over-height truck striking the Roosevelt Circle bridge overpass on I-93 southbound (SB) near Exit 24, in Medford, Massachusetts. The incident occurred around 3:22 p.m. on July 19, 2021, and lasted until July 23, 2021. The incident severity was L2. During the incident, two to three lanes (at different stages of the incident) on I-93 SB were closed for bridge inspection and repair. Roosevelt Circle bridge was closed for some of the time for repair. The incident caused significant delay on both I-93 southbound and northbound and nearby roads.

For this incident, MassDOT had three systems deployed that provided surveillance. The first one was the CCTV camera system. As shown by Figures 5-1 and 5-2, this incident was captured by a CCTV camera, which provided images of the incident scene and even a view of traffic further upstream. The traffic slowdown caused by this incident was well captured by the second system, the INRIX data. As shown in Figures 5-3 and 5-4, INRIX data detected the traffic slowdown right after the incident (the incident was initially reported at 3:22 p.m. on July 19, 2021). Comparing the traffic condition on the day before and two days after the incident (Figure 5-3), one can clearly see that the incident caused significant delay on I-93 and queue spillover to I-95 (Figure 5-4). Because of the incident, travelers were detoured to nearby routes, which was captured by the third system, StreetLight data (Figure 5-5) in which the nearby routes had an increase in the trip sharing after the incident.

For this particular incident, the three systems together provided good images of the incident cite and captured the traffic slowdown. However, if a drone had been available, it could have provided additional valuable information to complement the current systems. More details will follow in the next section.

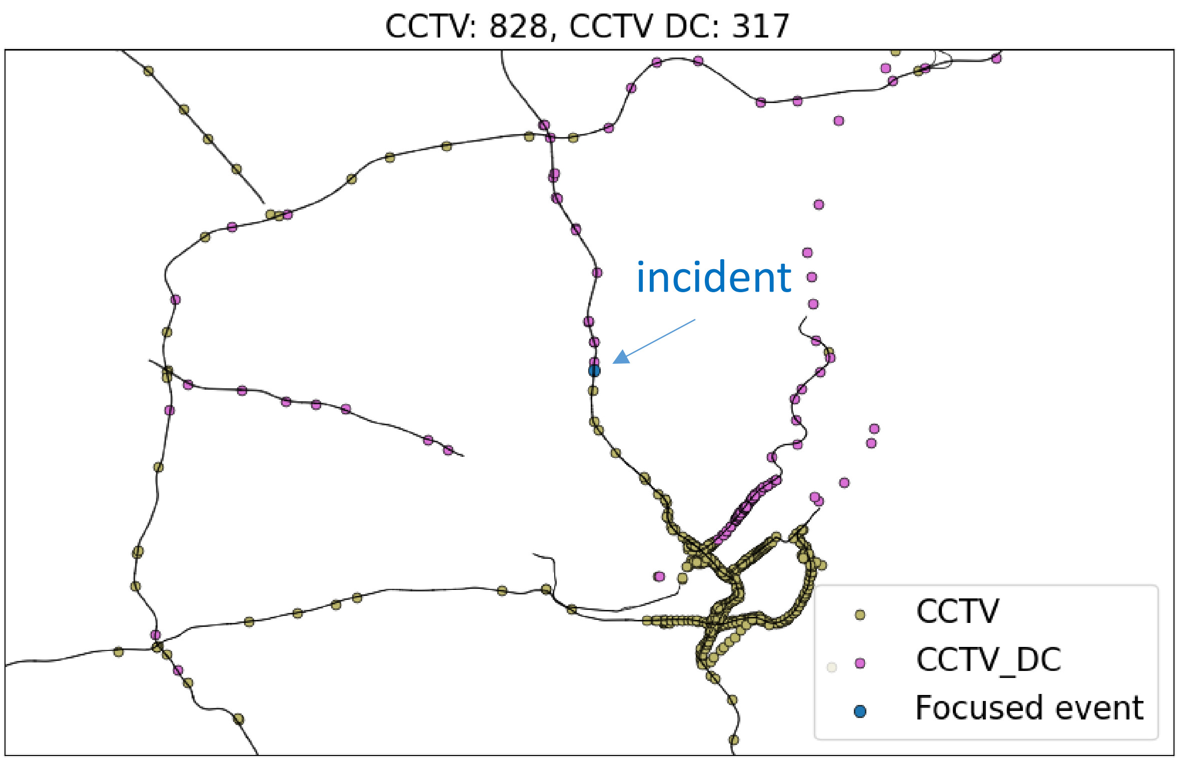

Figure 5-1: CCTV system capturing the incident identified

Figure 5-2: Images captured via CCTV camera system

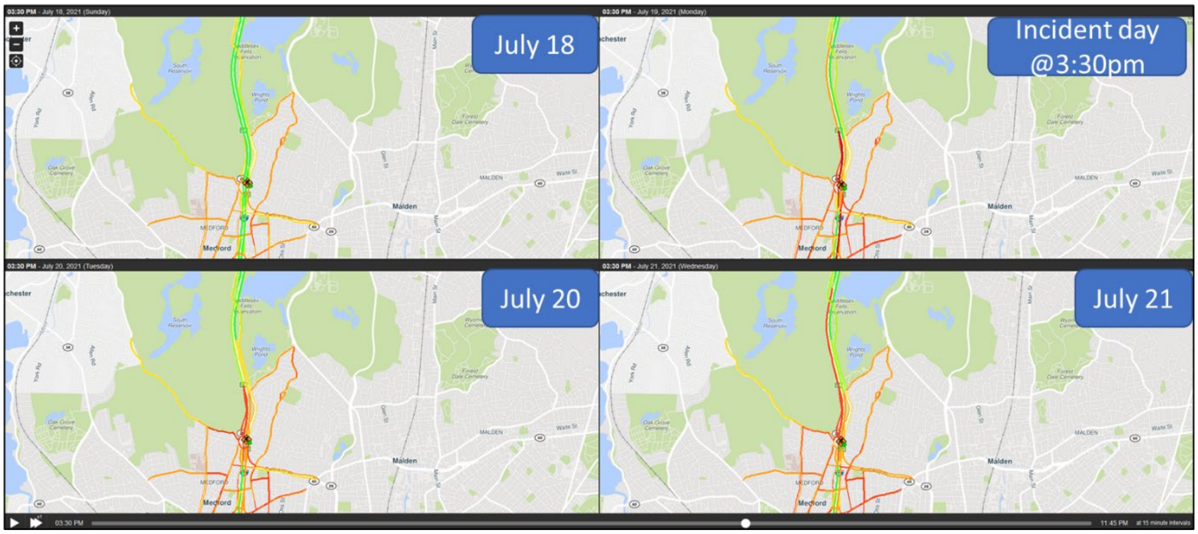

Figure 5-3: Traffic around incident time (3:30 pm) before and after the incident dates

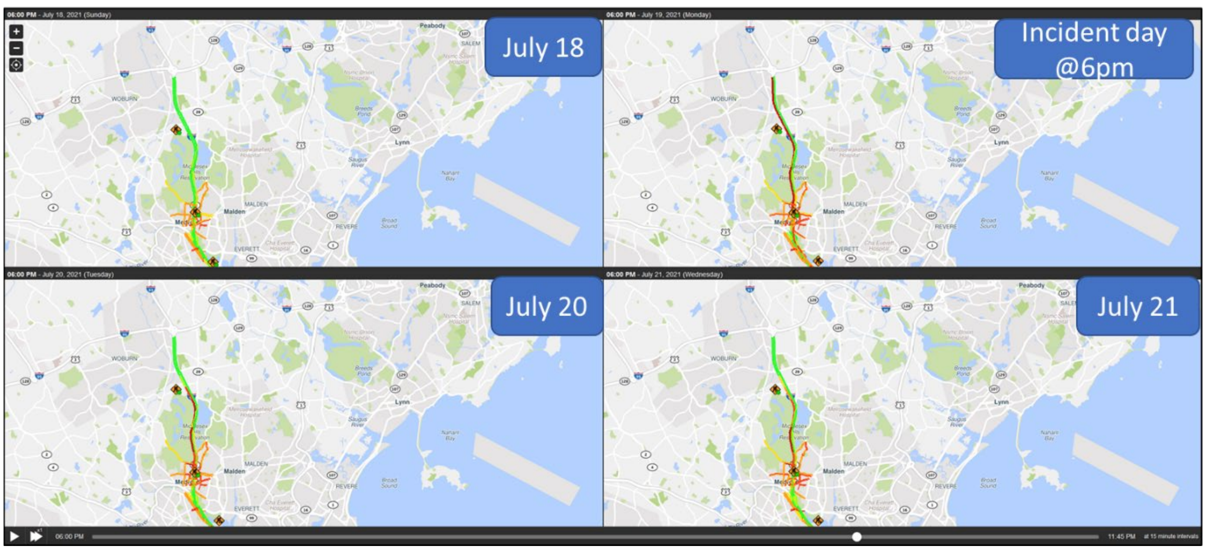

Figure 5-4: INRIX data detecting queue spillover to I-95 due to the incident

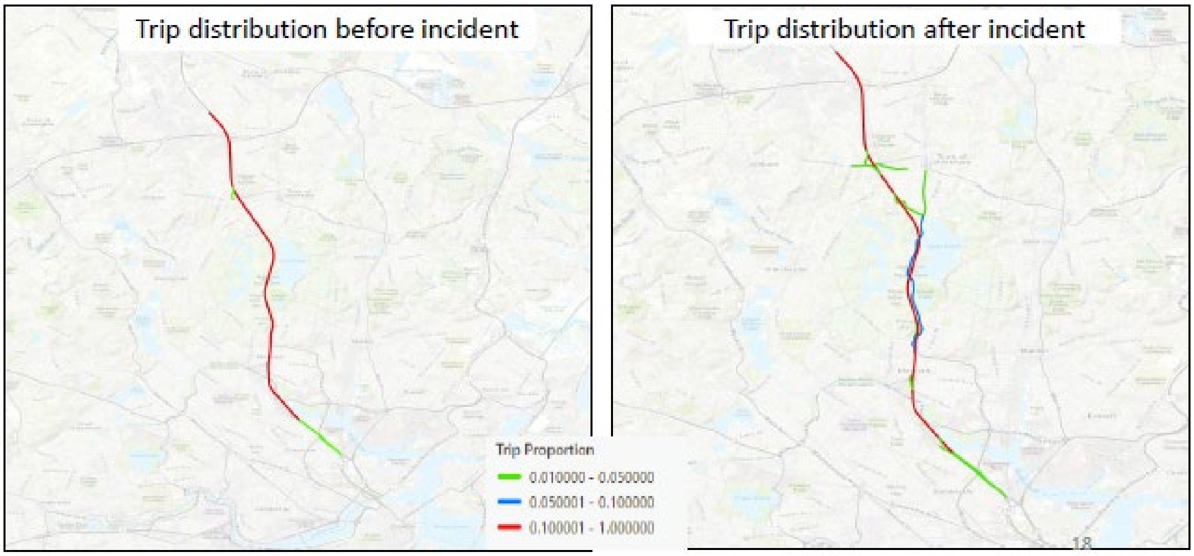

Figure 5-5: Changes of trip distribution before and after the incident captured by StreetLight data

5.2.2 Drone Technologies at the MassDOT Aeronautics Division

MassDOT Aeronautics Division has a variety of drones available. Particularly, American Robotics *(7)*, a partner of MassDOT Aeronautics, makes drone-in-a-box and has received the FAA permit to operate automated drones without humans on site, that is, it can fly beyond visual line of sight (BVLOS). The system, Scout, is featured with a weatherproof charging and edge computing station, and the drone can run autonomously to collect, process, and analyze data (Figure 5-6). Additionally, drones often can carry different kinds of sensors, including HD cameras, LiDAR, and infrared sensors, which can provide a variety of imaging and detecting capabilities.

Figure 5-6: Autonomous drone-in-a-box by American Robotics

Figure 5-7: Sensors carried by drones

5.2.3 Drone Flight for the Incident Scene

MassDOT Aeronautics Division deployed a drone to the incident site to collect data. Figure 5-8 shows the view of the Roosevelt Circle bridge (left) and the view of traffic further upstream of the incident site (right). Figure 5-9 shows the view of I-93 southbound, looking north (left) and a view of I-93 southbound, looking south and feeder routes (right). The images captured by a M210 RTK with X4S sensor (a rotary drone) provided detailed views of the incident site, and more importantly, an extensive view of relevant routes. Although the drone used was a rotary drone, the imaging capabilities are similar to those of a drone-in-a-box. If a drone is deployed, it can reach an incident 5 miles away about 15–20 min after a request (assuming that drone maximum speed is 30 mph, and it takes 5 min to acquire FAA approval, and another 5 min for other preparation). This means that a drone could have reached the scene and provided data before the bridge was closed, the very early stage of the incident response process; see Figure 5-10 for the incident response cycle based on data provided by HOC. Additionally, a drone could be used in later stages of the incident response cycle, such as monitoring the traffic slowdown on roads that do not have CCTV cameras.

Figure 5-8: Roosevelt Circle Bridge and traffic upstream

Figure 5-9: I-93 southbound and feeder routes

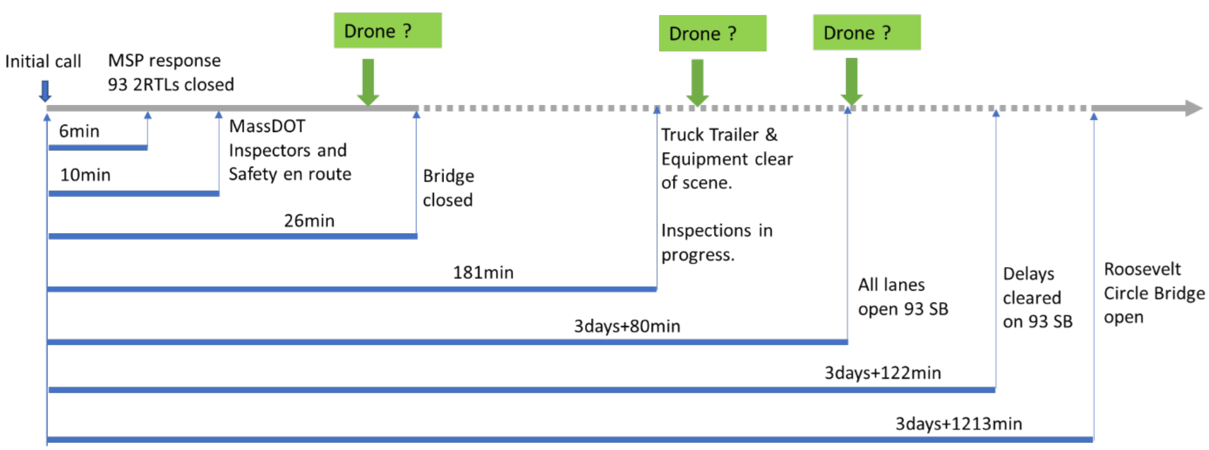

Figure 5-10: Incident response cycle

When drones are equipped with other proper sensors and software, the research team believe that drones can serve three purposes: (1) to inspect the damaged bridge/road before inspection crew enter the incident scene, which helps to improve safety of the inspection crew and shorten inspection time; (2) to provide detailed and timely images for the public and the media; and (3) to help with traffic management, including monitoring traffic in an extensive range to enable more active detours and to assess secondary crashes. For incidents on road segments that do not have CCTV camera coverage, purposes (2) and (3) would be particularly important. In fact, the current CCTV cameras cover only 43% of the incidents (assuming a 0.05-mile radius of camera coverage).

Had a UAS network been deployed, it would have covered the incident selected as shown by Figure 6-2. Additionally, it would cover the remaining 57% incidents not covered by the current CCTV cameras. More detailed analysis is provided in Chapter 6.

5.3 Review of the Tabletop Simulation

The entire simulation team, along with invited experts from MassDOT HOC, discussed the potential applications of drones for incident response. The main remarks are summarized as follows:

- Per HOC's main responsibilities (such as providing traveler information), the three current systems (CCTV cameras, INRIX, and StreetLight) meet the needs. For road segments that do not have CCTV cameras, drones could be useful (e.g., providing images of incident scenes). In general, incidents at severity level 2 may not benefit significantly from drones, but level 3 and above may benefit from their use.
- Drones have some appealing advantages, such as being mobile, easy to set up and maintain, able to carry different sensors to detect hazmat or oil spill *(11)*, and able to work in the nighttime. Drones can help to serve road segments without CCTV cameras. However, for the deployment feasibility, further research on cost-effectiveness is needed.
- Drones could help with some incidents (like fire and hazmat), but it would be at the discretion of the first-responder agencies (e.g., bridge team, MassDEP for hazmat, state police for fatal accidents) to decide whether to use drones.
- Based on the research team's analysis, 57% of incidents at level 2 and above are not covered by current CCTV cameras (assuming 0.05-mile camera coverage radius). A UAS network with four super stations (two or more incidents per month) can cover 25% of those incidents not covered by CCTV cameras.

This page left blank intentionally.

6.0 Analysis of a UAS Network for Highway Emergency Response in Massachusetts

In this chapter, we update the UAS network by considering the operational features of drones and the impacts of CCTV cameras as they can be used to provide incident surveillance.

For the UAS network analysis, we used the filtered data in Chapter 2 (i.e., incident severity 2 and above, duration between 30 and 300 min, and incident type is fire, environmental/hazmat or roadway/traffic). Some incidents satisfy the criteria but do not have coordination information and therefore are excluded. We have obtained 7,984 incidents in total.

Massachusetts has an extensive CCTV camera system. Figure 6-1 shows the existing and planned cameras. These cameras can cover a significant proportion of the incidents. In our analysis, we use both the existing and planned cameras. The proportion of incidents covered varies with the coverage radius of the CCTV cameras. In general, a camera is able to cover a radius of 0.05 mile with good image quality. With that, the CCTV cameras can cover 43% of the incidents. If the cameras are at a higher quality and can cover a radius of 0.1 mile, 52% of the incidents can be covered.

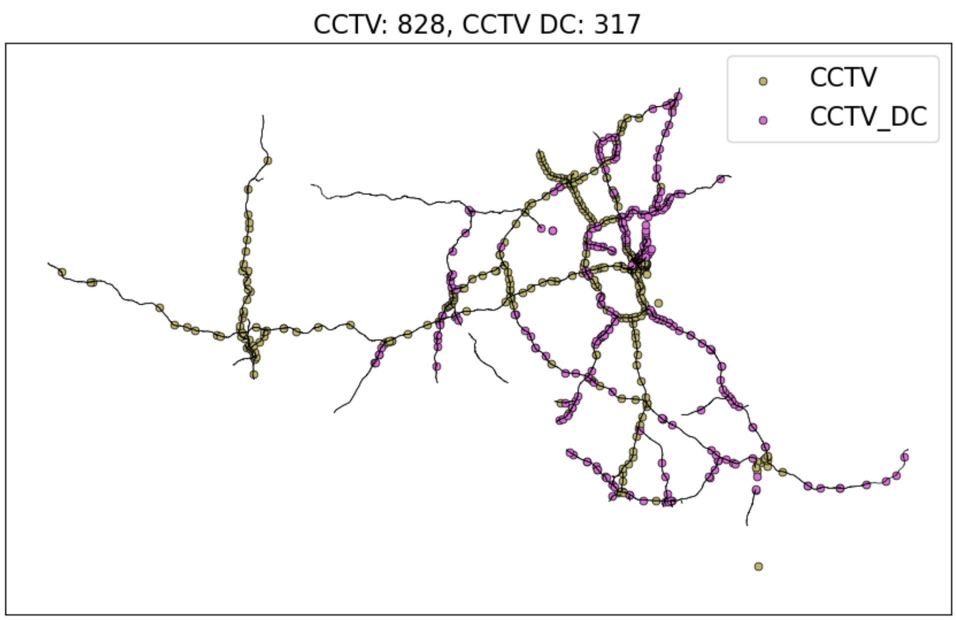

Figure 6-1: CCTV cameras in Massachusetts

In our UAS network analysis, we considered the utilization of CCTV cameras and assumed that the UAS network only needs to serve the uncovered incidents. Based on the drone operation features in Table 3-1, we assume that a typical drone can fly at 30 mph and has the flight time of 40 min or more. We used a 5-mile radius for the UAS stations, which implies that a drone would need to spend up to 20 min to reach and come back from an incident (Assume that drone flight speed is 30 mph; it takes 20 min [=10 miles/30 mph] to fly to an incident 5 miles away and then fly back to the station). That will leave at least 20 min to collect data at the scene. We assume that the CCTV cameras can cover a 0.05-mile radius (Figure 6-2). Under these settings, the UAS network will have four super stations (two or more incidents per month) and nine key stations (incident frequency is between one and two per month). The four super stations will cover 25% of the uncovered incidents not covered by CCTV cameras, and the nine key stations will cover another 24% of the uncovered incidents. If the CCTV cameras can cover a 0.1-mile radius, their network requires only two super stations and 10 key stations (Figure 6-3). In Figures 6-2 and 6-3, the bold circles indicate super stations, solid circles indicate key stations, and dashed circles designate regular stations, and the underlying heat map indicates the incident frequency.

We tested a stricter duration filter, 60–300 min. The number of super stations and key stations decrease slightly, but the results do not change significantly.

We also tested the UAS network for a single incident type (such as fire or hazmat). It was determined that the frequency of fire and hazmat incidents is not high and the utilization frequency of the UAS network would be low. Therefore, we believe that it is more cost-effective to use a single UAS network to serve multiple incident types. That implies that the drone stations may need to have different sensors available so that the drones can change the sensors to serve the different needs of the incidents.

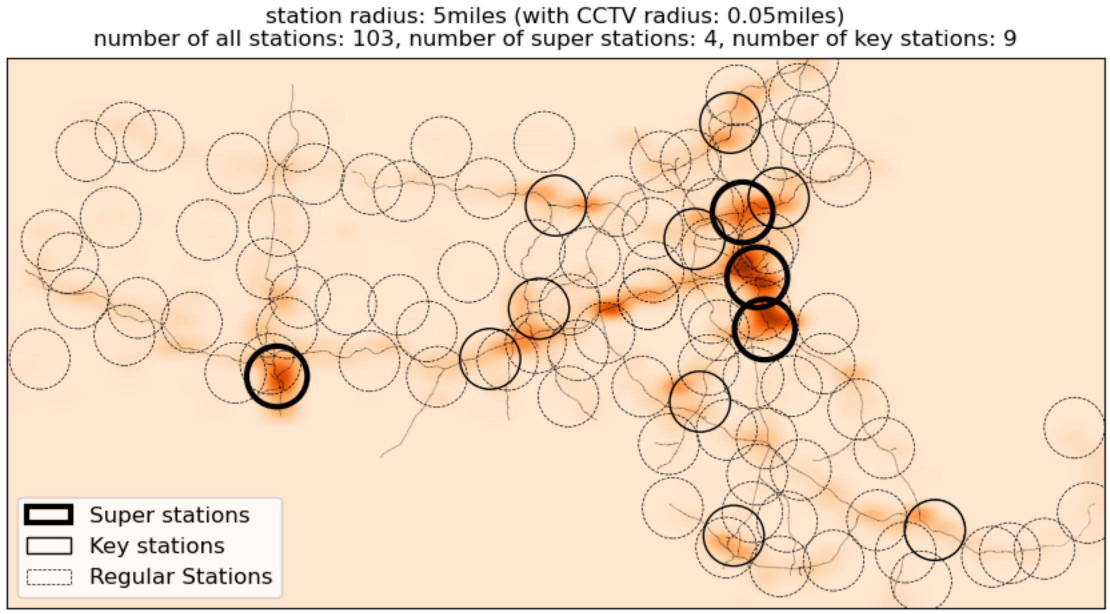

Figure 6-2: UAS network with 0.05-mile radius coverage of CCTV cameras

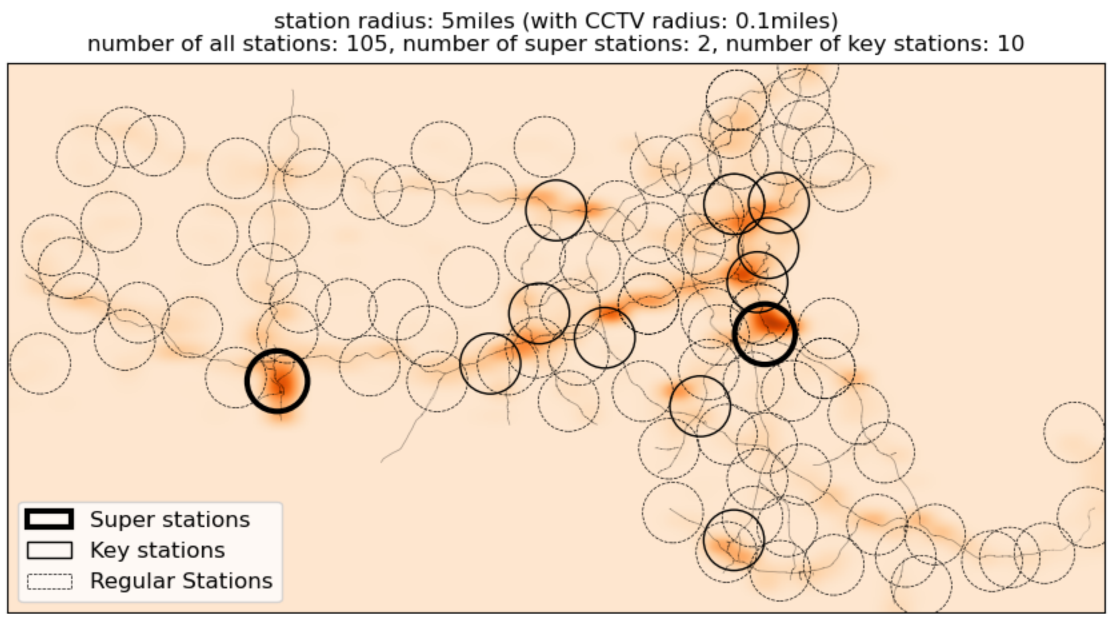

Figure 6-3: UAS network with 0.1-mile radius coverage of CCTV cameras

This page left blank intentionally.

7.0 Recommendations from Agency Stakeholders on the Future Development of UAS Network in Massachusetts

This chapter presents the outcomes of interviews with three relevant stakeholders regarding their practice and needs of UAS applications and their recommendations on the future development of UAS.

7.1 Introduction

In December 2021, the UML team interviewed the following three Massachusetts state agencies to understand their current drone usage and collect their feedback on the future development of the deployment of a drone network for highway emergency response activities:

- Massachusetts Emergency Management Agency (MEMA)
- The Office of Security and Emergency Management
- Massachusetts State Police (MSP): the Incident Management Assistance Team and specifically the Unmanned Aerial Section, referred to as the MSP-UAS.

7.2 Recommendations from the Stakeholders on the Future Development of a Drone Network in Massachusetts

We consolidated the interviewees' recommendations on the future development of a drone network for emergency response. These recommendations are closely related to each stakeholder's role and experience of incident response, which are introduced in more details in Appendix 4. The detailed report of interviews is provided in Appendix 5. The stakeholders made the following recommendations:

- To have drones that can be rapidly deployed from fixed locations and can operate beyond visual line of sight to rapidly get sensory and image data from incidents.
- To reach out to local agencies and communities to demonstrate the capabilities of the drones and make them aware of such resources. Even simple demonstrations can be useful. Emergency managers of towns would be the priority agencies for such outreach. By far, there are few requests (for drone service) from local communities because they are not yet aware of such resources.
- To have MassDOT Aeronautics Division serve as the central point of UAS operations, coordinate the drone purchases and utilization across different entities,

help to make the best use of the drones (e.g., the drones can serve multiple missions across different agencies), and provide the service to the agencies needed (such as the Office of Security and Emergency Management and local communities).

- To have the drone inventories across the agencies consolidated and managed by the MassDOT Aeronautics Division in a centralized manner.
- To enhance the air operations plan: (1) add a specific drone network as an element of the air operations plan to specify the drone operations; (2) enhance the drone inventory (e.g., to have a complete and real-time list of the capabilities of the drones, the locations of the drones/pilots, operational conditions, and the equipped sensors and software); and (3) have an alert layer that can alert all the relevant stakeholders about the incidents in a timely manner (e.g., to alert a certain agency that can rapidly deploy drones for the incidents).
- To consider collaborating with local entities and the private sectors to utilize their drones and/or data they have collected, but the privacy, liability and security issues should be addressed beforehand. Prequalified private drone operators (e.g., contractors, hobbyists) can be used in emergency scenarios as a layer of redundancy, if they have prior background/security clearance as well as insurance.
- To make the better use of drones, such as doing pre-event imaging for pre- and post-damage assessment for rescue as well as restoration.
- To equip drones with proper sensors and software to covert the data into useful information to inform decision making.

8.0 Recommendations for Integrating UAS into Highway Emergency Response in Massachusetts

Based on what we have learned from the analysis of incidents in Massachusetts, the literature review, the tabletop simulations, and the feedback from agency stakeholders, the UML research team developed for MasDOT's consideration a number of short-term and long-term recommendations for the development of a UAS highway emergency response network in Massachusetts.

8.1 Short-Term Recommendations

We recommend that MassDOT consider the following short-term actions:

- Establishing a small-scale UAS network consisting of the super stations and gradually extending to the key stations. The network will serve multiple purposes, such as regular roadway traffic surveillance, MBTA incidents, and extreme weather. The stations of the UAS network can change based on incident frequency (e.g., the stations can be prioritized for extreme weather response in winter but switch to vegetation or other services in the summer).
- Equipping the UAS stations with different types of sensors (e.g., infrared, thermal sensors, LiDAR) that drones can choose to use to serve different types of incidents (e.g., fire vs. hazmat vs. severe traffic injuries). It is also recommended that MassDOT investigate sensors that can detect hazmat or oil spill on surface roads.
- Implementing a few mobile UAS platforms (e.g., placing drone-in-a-box on a truck) to serve the on-demand needs, such as response to severe traffic incidents on roads without CCTV cameras.
- Conducting outreach to local communities (e.g., emergency managers of towns) to demonstrate the capabilities of the drones and make them aware of the air operations plan. MassDOT Aeronautics Division could partner with MEMA in the outreach because MEMA has a lot of interactions with local communities.
- Exploring opportunities to enhance the air operations plan: (1) to add a specific drone network as an element of the air operations plan to specify the drone operations; (2) to continue to update the drone inventory (e.g., to have a complete and real-time list of the capabilities of the drones, the locations of the drones/pilots, operational conditions, and the equipped sensors and software); and (3) to have an alert layer that can alert all the relevant stakeholders about the incidents in a timely manner (e.g., to alert a certain agency that can rapidly deploy drones for the incidents).
- Exploring opportunities for collaboration with other Massachusetts state agencies to optimize the use of drones, including working with MEMA to use drones for pre- and post-incident assessment and restoration of flooding and working MBTA for rail inspection and response to derailment.

- Expanding the capabilities of the UAS through the use of software and algorithms that can convert the data into useful information to inform decision making. It is also recommended that MassDOT look into products that allow drones to stream in real-time.

8.2 Long-Term Recommendations

We recommend that MassDOT consider the following short-term actions:

- Evaluate the cost-effectiveness of building an extensive UAS network to cover the entire state. For example, in the mid- to long-term, if drones become cheaper and more robust against different types of weather, drone stations may be used for traffic surveillance to gradually replace CCTV cameras. A comparison of cost-effectiveness among different types of drone technologies is also beneficial.
- Evaluate the effectiveness and feasibility of collaborating with local entities and the private sectors to utilize their drones and/or data they have collected. Particularly, the relevant privacy, liability, and security issues should be investigated.
- Evaluate opportunities to incorporate prequalified private drone operators (e.g., contractors, hobbyists) into its air operations plan as a layer of redundancy for highway emergency response activities.

9.0 Conclusions

In this report, we have further examined the potentials of developing a UAS network for highway incident response in Massachusetts. We investigated three important questions related to the development of a UAS network:

- Question 1: Which types of highway incidents are most suitable for using UAS?
- Question 2: What are the key UAS operational parameters for successful highway emergency response applications?
- Question 3: How can UAS be effectively integrated into highway emergency response practices?

To address the questions, in Chapter 2 we conducted a thorough analysis of the incidents in Massachusetts from 2013 to 2019 and we compared incident features before and after COVID-19. From the analysis, we identified the three types of incidents that can potentially benefit from the applications of UAS: fire, environment/hazmat, and roadway/traffic incidents. These incidents were used later to develop the UAS network.

In Chapter 3, we reviewed the typical types of UAS that can potentially be used to build the UAS network. Our review focused on the latest drone-in-a-box technology and its counterparts, including rotary drones, tethered drones, and fixed-wing drones. Based on the pros and cons of the different types of drones, in Chapter 4 we identified three application scenarios for UAS and evaluated the potentials of each type of drone for each application scenario. Different scenarios favor different types of drones. Drone-in-a-box (including drone-in-a-box in a truck) is particularly attractive for Scenario 1 (recurring bottlenecks, incident hotspot, and scheduled events) and Scenario 2 (nonrecurring incidents such as fire/hazmat/injury/extreme weather).

In Chapter 5, we documented the tabletop simulation of the pilot flights. Based on a historic incident, we analyzed the response of the MassDOT surveillance systems, and deployed a drone to the incident site to determine how a drone could have helped had it been available. MassDOT HOC experts participated the tabletop and provided valuable feedback.

In Chapter 6, we updated the UAS network for incidents response by considering the operational features of UAS (based on results of Chapter 3 and the impacts of CCTV cameras. We found that current CCTV cameras cover 43% of incidents. If a UAS network is available, we determined that four super stations could cover 25% of the incidents not covered by CCTV cameras and the nine key stations will cover another 24% of the uncovered incidents.

Finally, we interviewed three Massachusetts state agencies to understand their current UAS usage and collect their feedback on the future development of a UAS network for highway emergency response activities in Massachusetts. The outcomes are summarized in Chapter 7.

Based on what we have learned from the analysis of incidents in Massachusetts, the literature review, the tabletop simulations, and the feedback from the stakeholders, the UML research team developed a list of short-term and long-term recommendations to assist MassDOT in identifying opportunities to develop a UAS network for assisting its highway emergency response activities (Chapter 8). Lastly, we provided conclusions in Chapter 9.

10.0 References

1. Chen, D., Xie, Y., Schweik, C., Li, T., Qiu, H. L., Friedman, A., and Flores-Marzan, R. The Application of Unmanned Aerial Systems in Surface Transportation—Volume II-D: Development of UAS Emergency Service Drone Network for Use in Surface Transportation. Rep. No. 19-010, Massachusetts Dept. of Transportation, 2019.
2. MacNeil, A. Firefighting from New Heights in Peabody. Salem News, August 27, 2017. https://www.salemnews.com/news/local_news/firefighting-from-new-heights-in-peabody/article_74502fe9-0f47-5771-8e3b-706445e3df65.html. Accessed July 21, 2022.
3. Teledyne FLIR. FLIR Announces Industry's First Multi-Gas Detector for Unmanned Aerial Systems. September 24, 2019. https://www.flir.com/news-center/public-safety/flir-announces-industrys-first-multi-gas-detector-for-unmanned-aerial-systems/. Accessed July 21, 2022.
4. FlytNow. How FlytNow Enhances the Capabilities of Drones for HAZMAT. https://flytnow.com/drone-for-hazmat-response/#How_FlytNow_Enhances_the_Capabilities_of_Drones_for_HAZMAT. Accessed July 21, 2022.
5. Stevens, C. R., and Blackstock, T. Demonstration of Unmanned Aircraft Systems Use for Traffic Incident Management (UAS-TIM) Final Report. Texas A&M Transportation Institute, 2017. https://static.tti.tamu.edu/tti.tamu.edu/documents/PRC-17-69-F.pdf
6. Tracking Coronavirus in Massachusetts: Latest Map and Case Count. *New York Times*, https://www.nytimes.com/interactive/2021/us/massachusetts-covid-cases.html. Accessed Dec. 15, 2021.
7. American Robotics. https://www.american-robotics.com/. Accessed Jun. 24, 2021.
8. Perceptro. https://percepto.co/. Accessed Jun. 24, 2021.
9. UAV Systems. https://uavsystemsinternational.com/. Accessed Nov. 17, 2021.
10. Elistair. https://elistair.com/orion-tethered-drone/. Accessed Nov. 17, 2021.
11. De Kerf, T., Gladines, J., Sels, S., and Vanlanduit, S. Oil Spill Detection Using Machine Learning and Infrared Images. *Remote Sensing*, Vol. 12, No. 24, 2020, 4090.
12. Mass. State Police Using Drone to Reconstruct Crashes. YouTube, Dec. 2, 2016. https://www.youtube.com/watch?v=SMyBOHtnm7I&ab_channel=WPRI. Accessed Dec. 13, 2021.

This page left blank intentionally.

Appendix 1: Detailed Plots of Incident Analysis

Fire incidents:

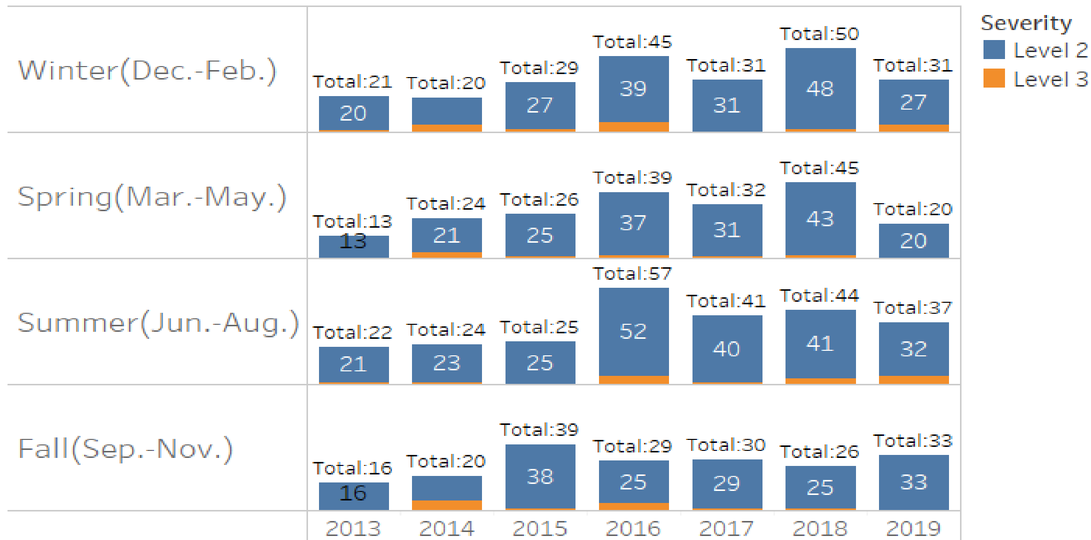

Figure A1-1: Fire incidents per year by season

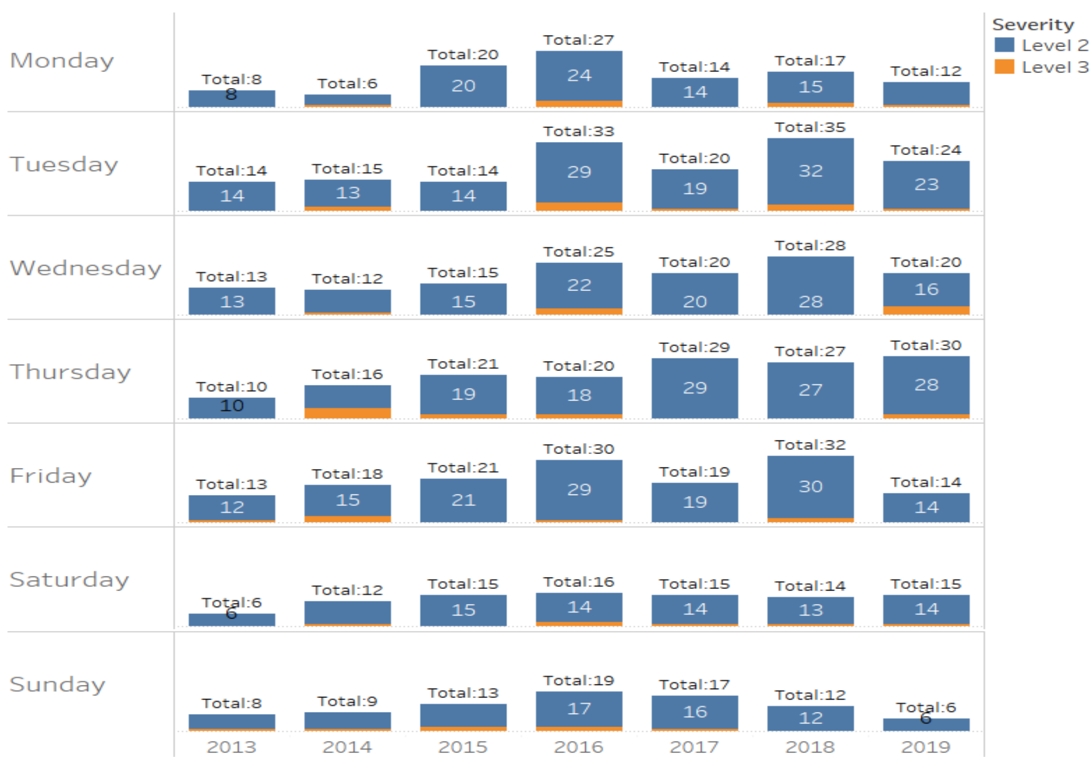

Figure A1-2: Fire incidents per year by day of the week

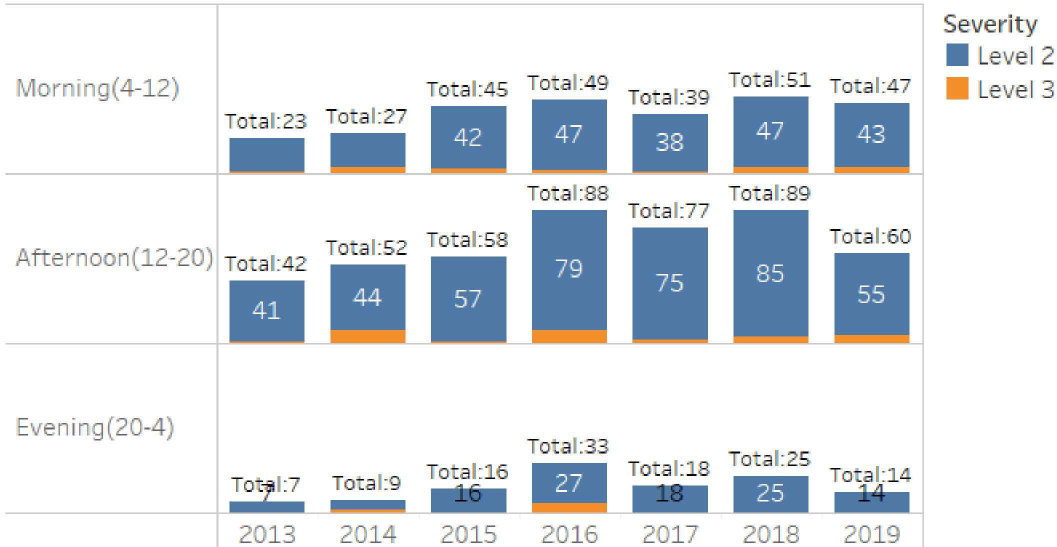

Figure A1-3: Fire incidents per year by time of day

Environmental incidents:

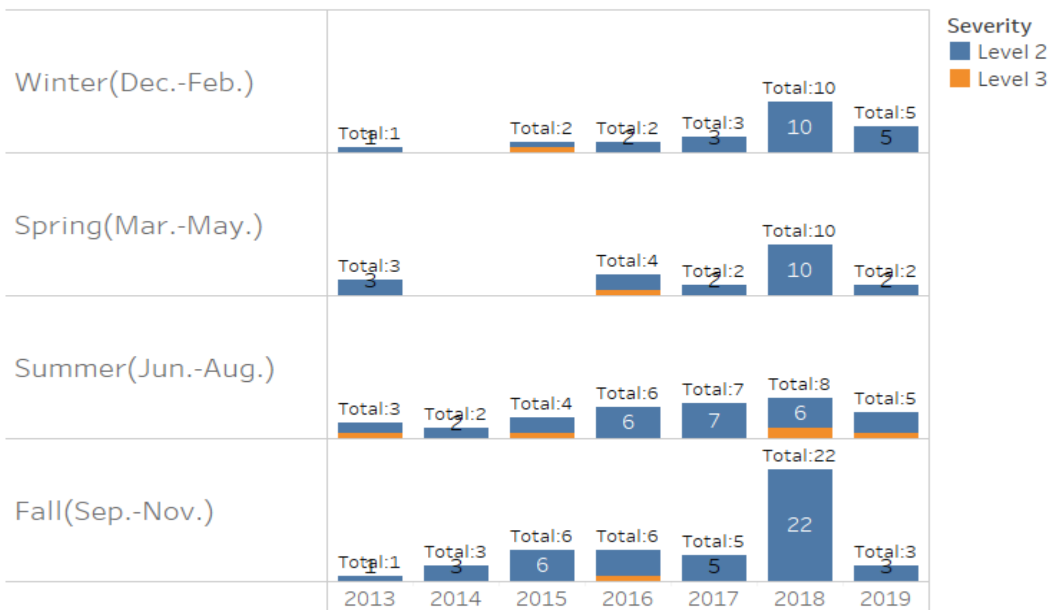

Figure A1-4: Environmental/hazmat incidents per year by season

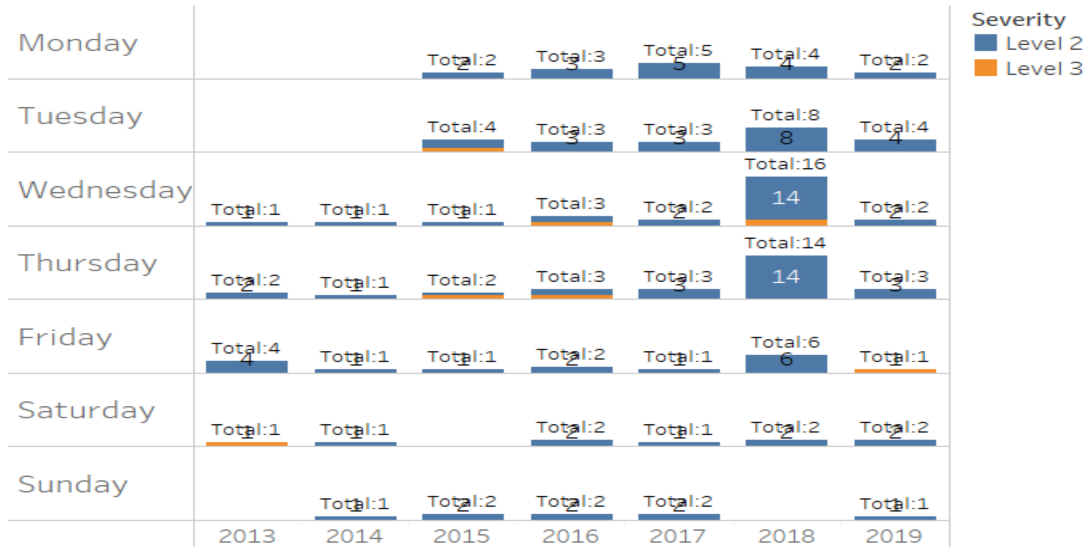

Figure A1-5: Environmental/hazmat incidents per year by day of the week

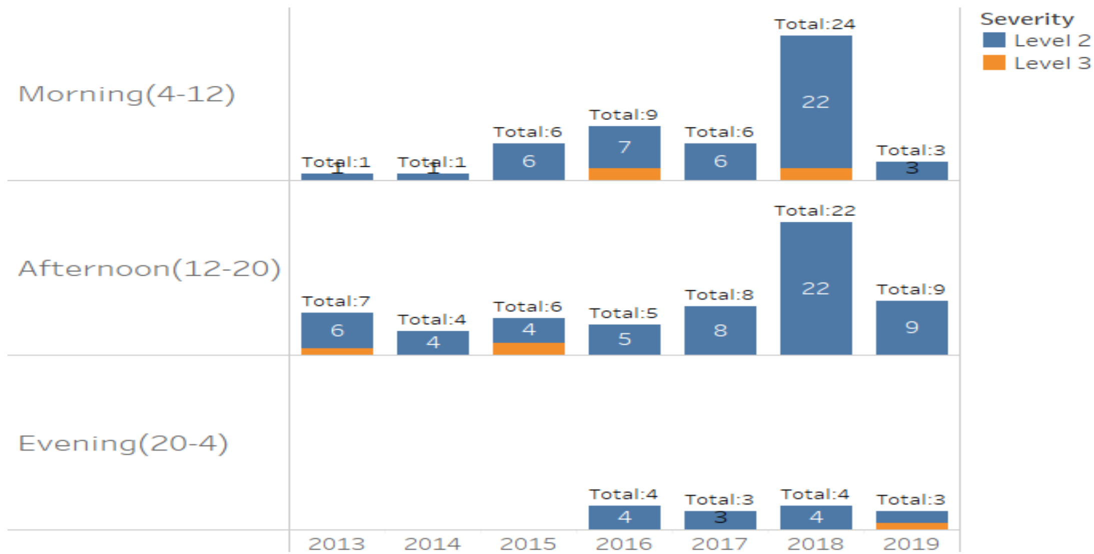

Figure A1-6: Environmental/hazmat incidents per year by time of day

Roadway incidents:

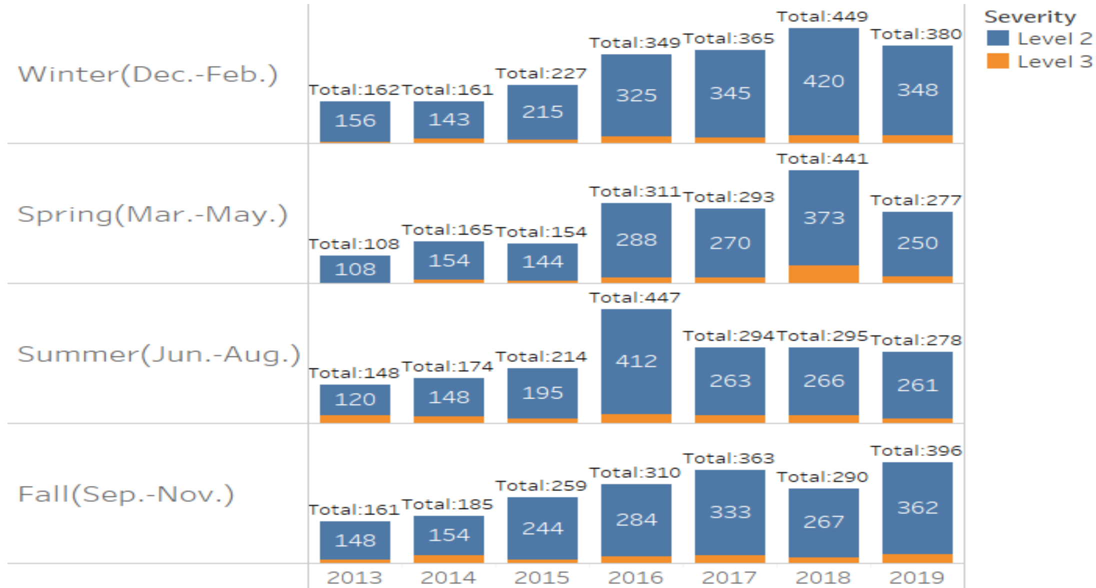

Figure A1-7: Roadway/traffic incidents per year by season

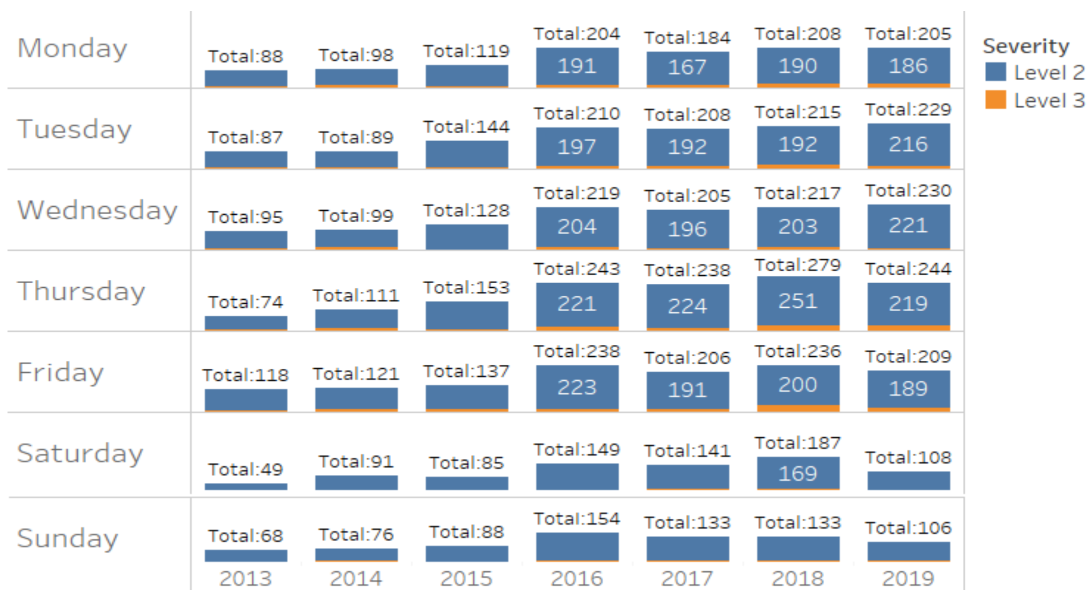

Figure A1-8: Roadway/traffic incidents per year by day of the week

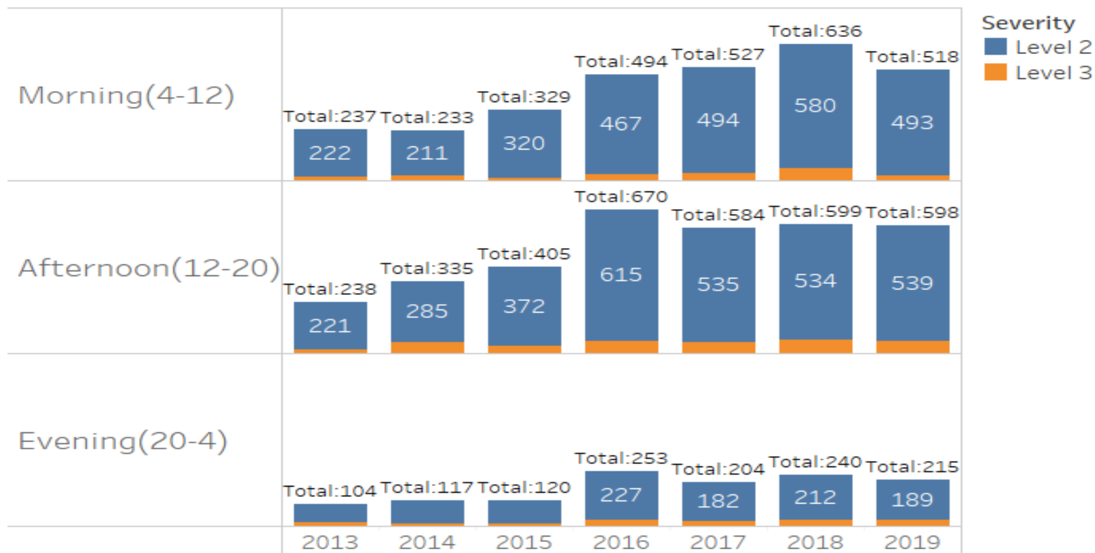

Figure A1-9: Roadway/traffic incidents per year by time of day

Combined three incident types:

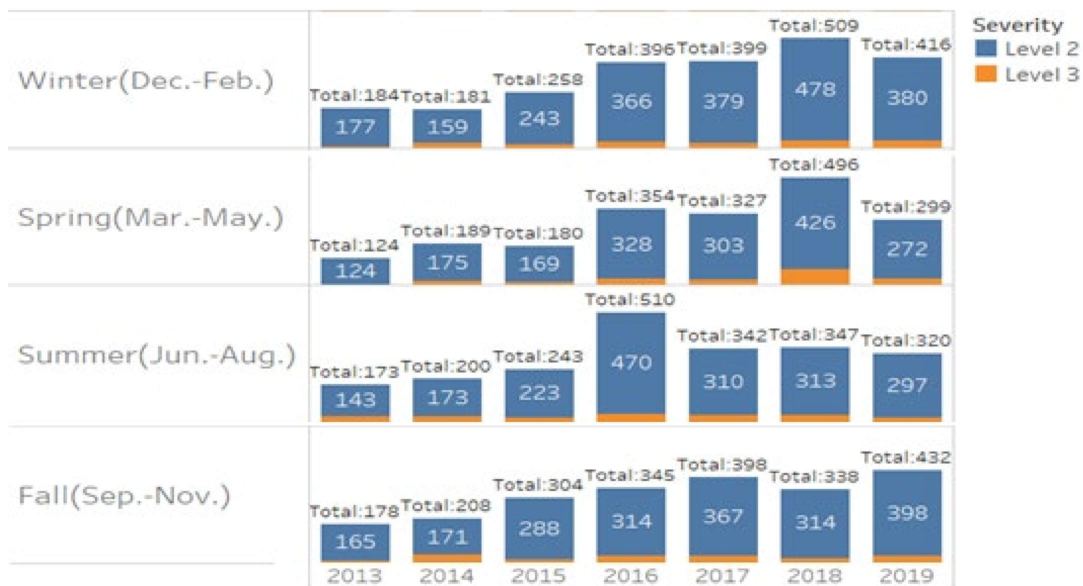

Figure A1-10: Combined three incident types by season

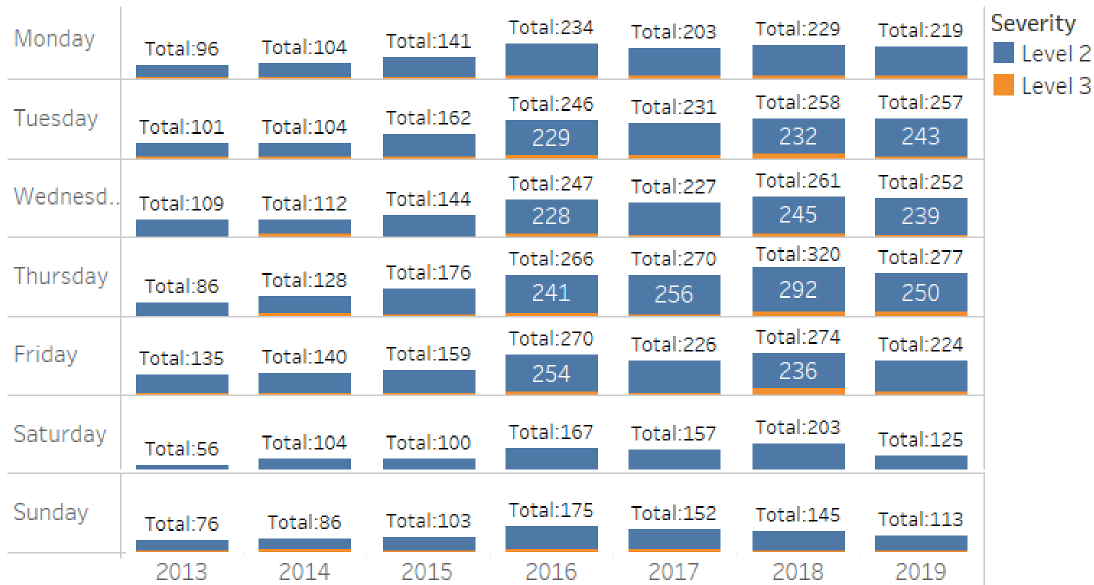

Figure A1-11: Combined three incident types by day of the week

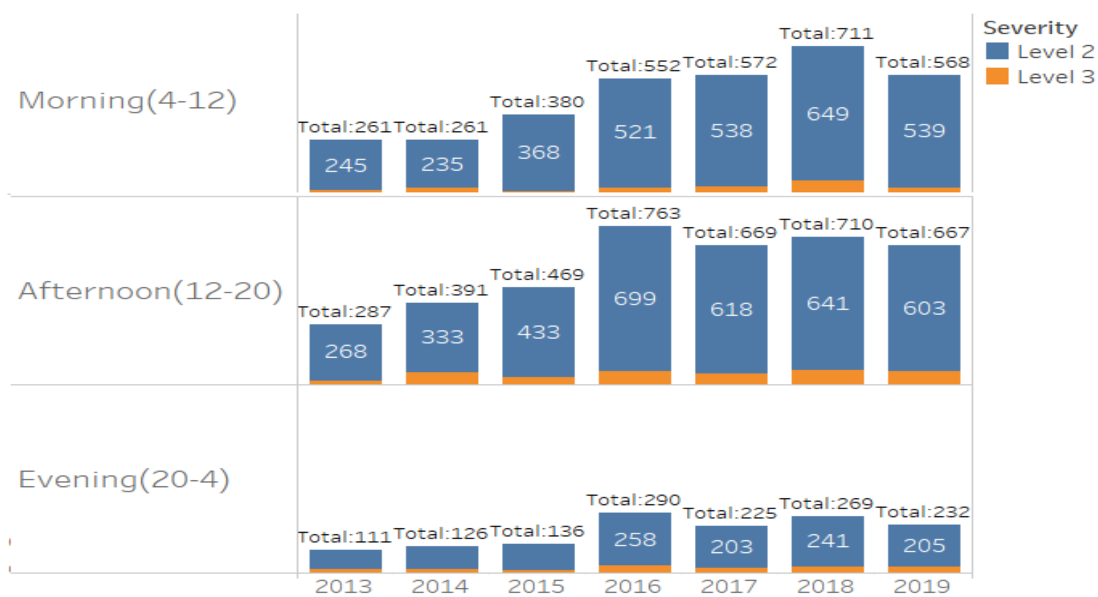

Figure A1-12: Combined three incident types by time of day

Appendix 2: Technical Details of Drones

Table A2-1: Technical features of drones reviewed

Number	Drone type	Drone name	Launching/Landing	Range (miles)	Max speed (mph)	Flight time (min)	Power charging	Payload capacity[a]	Weight	Sensors	Takeoff time (min)[b]	Service ceiling (ft)[c]
1	Drone-in-a-box	Airobotics	Automatic deploy and landing	3.2	22	45	Uses robotic arm to swap batteries	1.2 kg	—	EO/IR	5	400
2	Drone-in-a-box	Percepto drone in a box	Automatic deploy and landing	10.3	40	40	Charge on field	Dual payload	9.5 kg	EO/IR	5	400
3	Drone-in-a-box	Easy Aerial (Icaro Osprey drone in a box)	5 sec from trigger to airborne, fully autonomous landing and charging, ability to fly autonomously with SAMS (smart aerial monitoring systems)	12.4	62	55	30–40 min charge time	3.0 kg (6.6 lb)	5.5 kg (12.12 lb)	EO/IR	5	400
4	Drone-in-a-box	Sky drone mk1 drone in a box	Takeoff, fly and in-flight control via ground control station	Unlimited	50 (Fast Mode); 28 (Position Mode)	45	Not applicable	Not applicable	2.4 kg	EO/IR	5	400
5	Drone-in-a-box	Easy aerial SAMS	Not applicable, depends on drone	Not applicable	Not applicable	Not applicable	30–40 min for full charge	Not applicable, depends on drone	Not applicable, depends	—	5	400

Number	Drone type	Drone name	Launching/Landing	Range (miles)	Max speed (mph)	Flight time (min)	Power charging	Payload capacity[a]	Weight	Sensors	Takeoff time (min)[b]	Service ceiling (ft)[c]
									on drone			
6	Drone-in-a-box	Aeryon Skyranger (R 70)	Automatic takeoff and landing	5	31	50	Rapidly charge batteries via intelligent power management kits	3.5 kg	4.7 kg	EO/IR	5	400
7	Drone-in-a-box	Leptron Quad copter	Automatic deploy and landing	1.5	35	20	Use charging cable; two batteries on field	0.68 kg	2.26 kg	—	5	400
8	Drone-in-a-box	American Robotics (Scout System)	No pilot needed, fully autonomous	10	—	—	Autonomous charging on Scoutbox	—	—	EO/IR	5	400
9	Drone-in-a-box with fixed wing	First IZ Drone System Fixed Wing	Automatic deploy and landing	Network dependent	60	50	Internal charging	Not applicable	Not applicable	EO	5	400
10	Rotary	DJI phantom 4 RTK	Pilot needed	4.3	36	28	Charging cable is used and 6,000 mAh LiPo 2S battery	1 kg	1.3 kg	EO	10	400

Number	Drone type	Drone name	Launching/Landing	Range (miles)	Max speed (mph)	Flight time (min)	Power charging	Payload capacity[a]	Weight	Sensors	Takeoff time (min)[b]	Service ceiling (ft)[c]
11	Rotary	DJI phantom 4 pro V2	Pilot needed	4.4	45	28	Charging cable is used	1 kg	1.35 kg	EO	10	400
12	Rotary	DJI mavice series	Pilot needed	11.25	40	34	Charging cable is used	1.2 kg	0.9 kg	EO/IR	10	400
13	Rotary	DJI phantom series	Pilot needed	4.3	45	28	Charging cable is used	1 kg	1.3 kg	EO	10	400
14	Rotary	DJI inspire 1 UAV	Pilot needed	1.25	50	18	Charging cable is used	6.4 kg	2.8 kg	EO/IR	10	400
15	Rotary	S500 quad copter	Pilot needed	—	—	20	Charging cable is used	1 kg	0.4 kg	—	—	400
16	Rotary	Skydio 2	Pilot needed	2.2	36	23	Charging cable is used	0.77 kg	0.85 kg	EO	10	400
17	Fixed wing	Parrot Disco FPV	Automatic takeoff and landing, assisted piloting controls, antistall system, and return home functionality	1.2	50	45	Not listed	Not applicable	0.7 kg	EO	15	400
18	Fixed wing	The Albatross (Applied Aeronautics)	Fully autonomous, requires runway	100	90	240	Not listed	4.4 kg	10 kg	EO/IR	15	400

Number	Drone type	Drone name	Launching/Landing	Range (miles)	Max speed (mph)	Flight time (min)	Power charging	Payload capacity[a]	Weight	Sensors	Takeoff time (min)[b]	Service ceiling (ft)[c]
19	Fixed wing	Believer UAV Ready To Fly	Throw in the air once, propellers are running at maximum capacity	12	45	120	Not listed	0.7 kg	5.5 kg (12.12 lb)	EO/IR	15	400
20	Tethered	Orion 2	Autonomous takeoff and landing	6	—	1,440	Chargeable during tethered state	Not applicable	Not applicable	EO/IR	Not applicable	400
21	Tethered	Hoverfly–Livesky sentry	One push button takeoff and landing	Not applicable	—	1,440	Chargeable during tethered state	Not applicable	Not applicable	EO/IR	Not applicable	400

Notes:

EO/IR = Electro-optic/infrared.

[a] Payload capacity is usually adaptable and interchangeable.

[b] Takeoff time is measured once on station.

[c] 400 feet above ground level per FAA.

Appendix 3: Application Scenarios of Drones

Table A3-2: Current technologies for the three scenarios

Scenario number	Scenarios	Features	Drone task	Current technology
1	Recurrent bottleneck, incident hotspot, scheduled events	Fixed location, recurrent (recurrent during scheduled time but location can vary with events)	Regular surveillance at the event site to monitor safety and traffic conditions. It must finish the task within 40 min	• CCTV camera might exist for some road spots, but the maintenance cost is high • Temporary camera on a pole can be used but they need installation • Probe data can be used but it is not very accurate and only provide limited information
2	Nonrecurrent incidents (e.g., fire/hazmat/injury/extreme weather)	Uncertain location; could be risky for personnel	Preliminary incident assessment before first responders arrive; monitor incident for safety; recording incident for reconstruction; estimate clearance time	• CCTV camera might exist for some road spots, but the maintenance cost is high • Rely on human experts on scene to estimate incident severity and clearance time
3	Incidents involving an extensive area (e.g., flooded roads)	Involve an extensive area	Damage assessment of incidents	Satellite image

Tables A3-2 through A3-6 provide evaluation of the different types of drones on the three scenarios.

Table A3-3: Drone-in-a-box/drone-in-a-box-on-truck

Scenario number	Pros	Cons	Overall potential
1	• Autonomous takeoff/landing (no pilot presence needed, but a pilot may be needed to operate it remotely) • Can cover an extended area (e.g., 2 miles) • Can livestream to a variety of key stakeholders, giving real-time assessment of scope and severity of situation • Can fly at a higher altitude and may produce accurate results • Varying camera angles for more complete incident analysis • No need for infrastructure	• Short surveillance time • Expensive	4 stars
2	• Pros of drone-in-a-box • Drone-in-a-box-on-truck is particularly useful: it has pros of drone-in-a-box but with a larger response radius and more portable	• Not feasible if the drone-in-a-box is placed at a fixed location • For drone-in-a-box-on-truck: response time may be subject to traffic condition • Cons of drone-in-a-box	4 stars
3	• Not very applicable due to the battery capacity	• Not very applicable due to the battery capacity	1 star

Table A3-4: Drone-in-a-box with fixed wings

Scenario number	Pros	Cons	Overall potential
1	• Similar to drone-in-a-box (and rotary drone), but has larger max speed and longer flight time	• Network-dependent; our knowledge of it is limited	4 stars
2	• Pros of drone-in-a-box	• Not feasible if the drone-in-a-box is placed at a fixed location	3 stars
3	• Not very applicable due to the battery capacity	• Not very applicable due to the battery capacity	1 star

Table A3-5: Rotary drones

Scenario number	Pros	Cons	Overall potential
1	• Cheaper than drone-in-a-box • Similar pros of drone-in-a-box but without the autonomous takeoff/landing function	• Pilot presence is needed • Similar cons of drone-in-a-box but cheaper	4 stars
2	• Pros of rotary drone	• Cons of rotary drone	3 stars
3	• Not very applicable due to the battery capacity	• Not very applicable due to the battery capacity	1 star

Table A3-6: Tethered drones

Scenarios number	**Pros**	**Cons**	**Overall potential**
1	• Unlimited surveillance time • Larger coverage than camera on a pole but smaller than drone-in-a-box and rotary drone	• In general, pilot presence is needed • Smaller coverage than rotary or drone-in-a-box • More expensive than camera on pole but cheaper than drone-in-a-box • High maintenance cost	2 stars
2	• Pros of tethered drone	• Cons of tethered drone	2 stars
3	• Not very applicable due to the limited flight range	• Not very applicable due to the battery capacity	1 star

Table A3-7: Fixed-wing drones

Scenario number	Pros	Cons	Overall potential
1	• Autonomous takeoff/landing (a pilot may be needed to operate it remotely) • Can cover a very large area • Long surveillance time	• In general, pilot presence is needed • More expensive than rotary and tethered drones • Maintenance may be needed • May need runway • Bulky	3 stars
2	• Pros of fixed-wing drone	• Cons of fixed-wing drone	3 stars
3	• Efficient; accurate (more stable) • Can access unsafe or difficult-to-reach areas • Pros of fixed-wing drones	• Cons of fixed-wing drones • May have weather restrictions	4 stars

This page left blank intentionally.

Appendix 4: Drone Usage at Three Agencies

MEMA

MEMA is the warning point for the state of Massachusetts. MEMA is involved in (1) major weather events (e.g., flooding, snow incidents), (2) system failure (e.g., panels fallings in tunnels causing injuries/death), and (3) other disruptive events, such as large debris events. In such events, MEMA deploys physical and technological resources to support the incident commander and helps with the emergency management and provides situational awareness by disseminating information to partners/public. In the process of managing incidents, the incident commander or the relevant agencies could go to MEMA to request air support. MEMA then works with the relevant partners to find the right tools via the air operations plan and provides the support. MEMA can also recommend a resource other than requested.

The air operations plan provides the air asset inventory and a coordination framework across the agencies when there is a state emergency.

The Office of Security and Emergency Management

The Office of Security and Emergency Management aims to support highway, MBTA, and other agencies in handing larger-scale crises. The Security and Emergency Management Office can provide (1) physical and technological security support in collaboration with local/state law enforcement and transit security; (2) security assessment of facilities, and (3) emergency management for organizations like MBTA and response coordination and recovery support. Events that could involve the Office of Security and Emergency Management include (a) weather events that cause substantial disruption to the services (e.g., major snowfalls, tropical storms), (b) derailments and collisions of rail systems, (c) events that will involve regional evacuation, and (d) rapid incident clearance on highways per request of the highway division. For the Office of Security and Emergency Management, the most significant benefit of drones is that they can help to fill the biggest gap right now—situational awareness. Drones, equipped with proper sensors, can fly beyond visual line of sight to rapidly show what is going on there. Additionally, drones can be used to assess incidents, conduct inspection, or provide aid in difficult-to-reach, dangerous-to-reach, or expensive-to-reach facilities/locations (e.g., deliver safety and/or medical materials to save lives).

Massachusetts State Police

MSP uses drones for crash investigation frequently (about 15 times per week) *(12)*. MSP has 20 drones. The Collision Analysis and Reconstruction Section (CARS) team is the primary agency for crash investigation, and the MSP-UAS team is the backup for the CARS team. MSP-UAS is involved in substantial incidents that likely involve crimes. The MSP-UAS uses drones for their crime scene investigation (e.g., to collect evidence and assess the situation and clear the damage). The CARS team has four full-time pilots, and MSP-UAS has eight full-time pilot. Each MSP-UAS pilot has his/her own drone(s) and is responsible for the drone operation. The MSP-UAS pilots/drones are distributed in eight locations. MSP-UAS aims to have the drone network cover any location within an hour of travel time in the commonwealth. The current drone inventory at MSP mostly satisfies the needs, but the incident response time could be improved.

On drone usage, MSP requires that drones are to be operated within visual line of sight and never BVLOS. For the injuries/fatal crashes, it is at the pilot's discretion to decide when to use the drones. No prior approval is required. After using the drones, the operation will be documented. For other missions, permission is approved by the Lieutenant. On drone operations, the drone can be in the air within 10 minutes for planned events. For unplanned events, the time varies (about 15–20 min after the pilot arrives at the scene).

Appendix 5: Interview Reports with Stakeholders

Introduction

In December 2021, the UML team interviewed the following three Massachusetts state agencies to understand their drone usage and collect their feedback on the future development of the drone network:

- Massachusetts Emergency Management Agency (MEMA)
- The Office of Security and Emergency Management
- Massachusetts State Police (MSP): the Incident Management Assistance Team and specifically the Unmanned Aerial Section, referred to as the MSP-UAS.

Next, we first summarize each agency's involvement in incident management and their usage of drones. After that, we have consolidated the interviewees' suggestions on the future development of drones.

Drone Usage at The Three Agencies

MEMA

MEMA is the warning point for the state of Massachusetts. MEMA is involved in (1) major weather events (e.g., flooding, snow incidents), (2) system failure (e.g., panels fallings in tunnels causing injuries/death), and (3) other disruptive events, such as large debris events. In such events, MEMA deploys physical and technological resources to support the incident commander and helps with the emergency management and provides situational awareness by disseminating information to partners/public. In the process of managing incidents, the incident commander or the relevant agencies could go to MEMA to request air support. MEMA then works with the relevant partners to find the right tools via the air operations plan and provides the support. MEMA can also recommend a resource other than requested.

The air operations plan provides the air asset inventory and a coordination framework across the agencies when there is a state emergency.

The Office of Security and Emergency Management

The Office of Security and Emergency Management aims to support highway, MBTA, and other agencies in handing larger-scale crises. The Security and Emergency Management Office can provide (1) physical and technological security support in collaboration with local/state law enforcement and transit security; (2) security assessment of facilities, and (3) emergency management for organizations like MBTA and response coordination and recovery support. Events that could involve the Office of Security and Emergency

Management include (a) weather events that cause substantial disruption to the services (e.g., major snowfalls, tropical storms), (b) derailments and collisions of rail systems, (c) events that will involve regional evacuation, and (d) rapid incident clearance on highways per request of the highway division. For the Office of Security and Emergency Management, the most significant benefit of drones is that they can help to fill the biggest gap right now—situational awareness. Drones, equipped with proper sensors, can fly beyond visual line of sight to rapidly show what is going on there. Additionally, drones can be used to assess incidents, conduct inspection, or provide aid in difficult-to-reach, dangerous-to-reach, or expensive-to-reach facilities/locations (e.g., deliver safety and/or medical materials to save lives).

Massachusetts State Police

MSP uses drones for crash investigation frequently (about 15 times per week) *(12)*. MSP has 20 drones. The Collision Analysis and Reconstruction Section (CARS) team is the primary agency for crash investigation, and the MSP-UAS team is the backup for the CARS team. MSP-UAS is involved in substantial incidents that likely involve crimes. The MSP-UAS uses drones for their crime scene investigation (e.g., to collect evidence and assess the situation and clear the damage). The CARS team has four full-time pilots, and MSP-UAS has eight full-time pilot. Each MSP-UAS pilot has his/her own drone(s) and is responsible for the drone operation. The MSP-UAS pilots/drones are distributed in eight locations. MSP-UAS aims to have the drone network cover any location within an hour of travel time in the commonwealth. The current drone inventory at MSP mostly satisfies the needs, but the incident response time could be improved.

On drone usage, MSP requires that drones are to be operated within visual line of sight and never BVLOS. For the injuries/fatal crashes, it is at the pilot's discretion to decide when to use the drones. No prior approval is required. After using the drones, the operation will be documented. For other missions, permission is approved by the Lieutenant. On drone operations, the drone can be in the air within 10 minutes for planned events. For unplanned events, the time varies (about 15–20 min after the pilot arrives at the scene).

Recommendations for the Future Development of a Drone Network

- To have drones that can be rapidly deployed from fixed locations and can operate beyond visual line of sight to rapidly get sensory and image data from incidents.
- To reach out to local agencies and communities to demonstrate the capabilities of the drones and make them aware of such resources. Even simple demonstrations can be useful. Emergency managers of towns would be the priority agencies for such outreach. By far, there are few requests (for drone service) from local communities because they are not yet aware of such resources.

- To have MassDOT Aeronautics Division serve as the central point of UAS operations, coordinate the drone purchases and utilization across different entities, help to make the best use of the drones (e.g., the drones can serve multiple missions across different agencies), and provide the service to the agencies needed (such as the Office of Security and Emergency Management and local communities).
- To have the drone inventories across the agencies consolidated and managed by the MassDOT Aeronautics Division in a centralized manner.
- To enhance the air operations plan: (1) add a specific drone network as an element of the air operations plan to specify the drone operations; (2) enhance the drone inventory (e.g., to have a complete and real-time list of the capabilities of the drones, the locations of the drones/pilots, operational conditions, and the equipped sensors and software); and (3) have an alert layer that can alert all the relevant stakeholders about the incidents in a timely manner (e.g., to alert a certain agency that can rapidly deploy drones for the incidents).
- To consider collaborating with local entities and the private sectors to utilize their drones and/or data they have collected, but the privacy, liability and security issues should be addressed beforehand. Prequalified private drone operators (e.g., contractors, hobbyists) can be used in emergency scenarios as a layer of redundancy, if they have prior background/security clearance as well as insurance.
- To make the better use of drones, such as doing pre-event imaging for pre- and post-damage assessment for rescue as well as restoration.
- To equip drones with proper sensors and software to covert the data into useful information to inform decision making.

Detailed Interview Reports with Stakeholders

MEMA (December 17, 2021)

Mike Russas: Assistant Director Operations at MEMA; 15 years of work experience with MEMA in areas of communications network, logistics, and emergency security.

MEMA is the state's warning point and a dispatch and communications center for statewide incident monitoring and information circulation. It is responsible for dispatching state agencies to disaster areas, notifying federal government in case of a disaster and broadcasting federal government warning messages to local partners.

Transportation Events That May Involve MEMA

- Major events like flooding, tropical storms, snow incidents, larger debris events, severe icing (e.g., a major ice event on I-290 caused a vehicle pile-up in December 2013).
- System failure: for example, panels falling in tunnels and causing casualties.

- Weather events that cause multiple highway breakdowns, severe winds, rainfalls, and snow incidents.

MEMA's Involvement

- On highway incidents: MEMA is only included in large-scale highway incidents that have major disruptions and/or mass casualties per the mass casualty plan. In such events, MEMA will support the incident commander with resources and provide situation awareness to local, state, and federal partners. For example, multi-incident events and significant snowfall may involve MEMA, and MEMA will support agencies (e.g., state DOT and state police) with resources and public messaging to warn the public to avoid the risky locations. MEMA has been working with Waze to send out the public warning.
- In general, MEMA deploys physical and technological resources to support the incident commander and help with emergency management. MEMA also provides situational awareness by disseminating information to partners and the public. MEMA manages the emergency alert system, which can be used for public messaging.
- Currently MEMA uses drones and helicopters of other agencies and coordinates with other agencies for drone deployment. When air asset is needed, MEMA leverages the air operation plan managed by the MassDOT Aeronautics Division.

<u>*Note:*</u> MEMA does not own drones and assets but coordinates with other agencies that have resources via the air operation plan.

Air Operations Plan

- The air operations plan provides the air asset inventory and a coordination framework across the agencies when there is a state emergency. The plan *has started to take note of the resources at individual agencies and coordinate with them.* Since 2020, the air operations plan has started to collect inventories of the drones owned by state agencies. There are local entities and private sectors that have drones too, but they are not incorporated into the state air operations plan yet.
- Other support plans that supplement the air operations plan are:
    - Helicopter aquatic rescue team support (a coordination plan of helicopter-based river and coastal rescue), and
    - Wildfire aviation support (deploying helicopters to drop water on wildfires).

Note: Could add another support plan for drone usage in existing plan.

Logistics of Resource Allocation (Can Be Used for Drone Air Operations Plan)

- The process to request air support is "one-stop shopping": agencies go to MEMA to make the request (e.g., what they need and where they need it), and MEMA works with the relevant partners to find the right tools via the air operations plan and provide the support. MEMA is the "go-to" agency for the air resource request. Currently, state highway and local agencies/communities go to MEMA for such requests, even for lower-level events.

- Threshold of drone usage: it varies a lot with the missions and the agencies. At MEMA, it is at the discretion of MEMA and local agencies.
- For MEMA's job, it is important to maintain the drone inventory. Currently it is updated annually. MEMA has started to scratch the surface on the inventory but there is a lot more to do (e.g., to update the information in real-time, to add the information of drones).
- MEMA can recommend a resource other than requested, for example, if the original request is for a helicopter, a drone may be suggested based on the situation.

Point Agency for Drones

Aeronautics Division should be the point agency for drone usage for incident situational awareness as well as rescue. MEMA will decide drone usage feasibility.

Future Improvements in Drone Plan/Air Operations Plan

- To consider the collaboration with local entities and the private sectors to utilize their drones and/or data they have collected, but the privacy, liability, and security issues need to be accounted for beforehand. Real estate and major utility companies are already using drones for their operations and have collected a lot of data. Those resources can be used in the event of a major disaster.
- To significantly enhance the conservation, collaboration, and coordination on the inventories of drones, the capabilities, the missions, and the collected data to make the best use of the drones. Case studies can be used to practice the coordination.
- To do pre-event imaging for pre- and post-damage assessment for rescue as well as restoration. MEMA has been using helicopters and fixed-wing drones for the assessment.
- To enhance the drone inventory: determine what is the proper frequency to update the drones and to add the information of drones.
- To inform agencies on what is available there (related to air assets), the capabilities, and when the drones are available. By far, there are few requests (for drone service) from local communities yet as they are not aware of such resources.
- To reach out to local agencies to show the capabilities of the drones and make them aware of such resources. Emergency managers of towns would be the priority agencies for such outreach.
- To add a specific drone network as an element of the air operations plan to specify the drone operations.

DOT Office of Security and Emergency Management (December 13, 2021)

- <u>Greg T. Brunelle:</u> Previously worked as the Director of county emergency management organization in New York. Managed the recovery after Hurricane Sandy and provided emergency management consultancy throughout the United States.
- <u>Michael P. McCabe:</u> Currently Deputy Director of MBTA Security Operations. He has experience related to design security.

Main Responsibilities of the Security and Emergency Management Team

- Provide guards (physical security) and cameras, card readers, badges, and door access (technological security) in collaboration with local law enforcement, transit security, and state law enforcement
- Security assessment of facilities
- Emergency Management for organizations like MBTA, training exercises, response coordination, and recovery support

Note: The Office of Security and Emergency Management has existed for a while, but its role has been evolving. It aims to support highway, MBTA, and other agencies in handing larger-scale crises. If local cities need assistance from highway division, request comes to Security and Emergency Team through the Emergency Support Function (ESF-1) program, which includes logistics, evacuation, and heavy equipment movement.

Entities with which the Security and Emergency Management Team Collaborate

- Registry of Motor Vehicles (RMV)
- Massachusetts Bay Transportation Authority (MBTA)
- Highway Division
- Aeronautics Division
- State and local law enforcements

Possible Events That Involve the Security and Emergency Management Team

- Weather events that cause substantial disruption to the services, like major snowfalls, and tropical storms
- Derailments and collisions of rail systems
- Rapid incident clearance on highways per request of highway division; support on training, policies, technologies, and so forth
- Events that will involve regional evacuation

In Case of Fire and Hazmat Incidents

- The Security and Emergency Management Team is currently working with HOC and Aeronautics to devise plans on disaster management.
- Most of the current hazmat incidents can be handled by the HOC and other highway teams properly.
- Substantial events, like those that may involve regional evacuation, will involve the Security and Emergency Management Team, but in such events, MEMA will be the primary contact. One such example was the gas explosions in Lawrence, Massachusetts.

Terrorism Involving Transportation

Security and Emergency Team will be coordinating MassDOT response and be the primary point of contact for Massachusetts emergency management for transportation services collaborating with Department of Homeland Security (DHS).

Possible Benefits That Drones Can Provide

- The biggest gap right now is situational awareness. We have thousands of cameras now, but they are static. It is desirable to know where we have the sensors, where we should put more sensors, and how to leverage UAS platforms that can fly beyond visual line of sight to rapidly tell us what is going on there. UAS is not a complete solution, but it needs to be a solution that can be rapidly deployed from fixed locations and can operate beyond visual line of sight or cross systems so that we can rapidly get sensory and image data from incidents.
- In fire and hazmat incidents: Drones can be used to assess the invents without putting human life in danger.
- Inspect rails in extreme heat, flooding, or wind damage.
- Could be automatically deployed based on certain events, for example, motion detection.
- Inspection in difficult-to-reach, or dangerous-to-reach, or expensive-to-reach facilities (such as tunnels): to check obstructions on tracks, people, and check for water and heat damage on tracks and within the tunnel.
- Rescue/aid in hostile environment: provide support to affected people in a hostile environment, such as delivering safety and/or medical materials to save lives, two-way audio communication.
- Post-disaster infrastructure assessment combined with software solutions—a great advantage on safety and security.

Features of Drones That Affect the Applications

- The applications of UAS mainly depend on the capabilities, such as conditions under which they can operate, where can we use them (indoors, outdoors, elevation of assessment region), and what sensors (e.g., image, audio, EO/IR motion detection) are available.

<u>Note:</u> MEMA provides quick assessment of disaster damage right after the incident. Highway division constantly evaluates and monitors their transportation systems for road operation. Highway division is often able to handle disasters pertaining to their transportation system. Security and management team is only involved in large-scale disasters.

Features the Security and Emergency Management Team Would Like to See in the MA UAS Network

- The network can alert all the relevant stakeholders about the incidents in a timely manner.
- Drones are equipped with proper sensors and software to covert the data into useful information.
- Aeronautics division serves as the central point of UAS operations, coordinate the drone purchases and utilization across different entities, help to make the best use of the drones (e.g., the drones can serve multiple missions across different agencies),

and provide the service to the agencies needed (such as the Security and Emergency Management Team, and local communities).

- The drone inventories across the agencies are consolidated and managed by the Aeronautics Division in a centralized manner.
- The network can provide a complete and real-time list of the capabilities of the drones and the locations of the drones and pilots.
- Prequalified private drone operators (e.g., contractors, hobbyists) can be used in emergency scenarios as a layer of redundancy, if they have prior background/security clearance as well as insurance.
- Historical data of disasters can be used to assess drone usage benefits based on time, cost, and safety as the key performance indicators (KPI).

MSP (December 10, 2021)

- Lt. Michael A. George: MSP: the Incident Management Assistance Team and specifically the Unmanned Aerial Section, referred to as the MSP-UAS. Lt. George is in charge of the MSP-UAS.

Pilots and Drone Inventory at MSP-UAS

Overview

Mass Police has a total of 20 drones. CARS team has their own drones and four full-time pilots. MSP-UAS now has three full-time drone pilots and has hired five new pilots. New pilots were selected based on the location of residence to cover areas that are far away. MSP-UAS aims to have a drone network that can cover any location within an hour of travel time in the commonwealth.

Some of the drones utilized include the following:

- DJI-1 Inspire
- Eurocopter-31
- Airwing
- DJI Matrice 300
- DJI Mavic Enterprise Dual
- DJI Mavic Mini

Pilot certificate at MSP-UAS

Drone pilots need to have an FAA part 107 remote certificate and an additional three-day training by MSP after hiring. Drones are to be operated within visual line of sight and never BVLOS.

Locations of drones and pilots from the MSP-UAS

Each MSP-UAS pilot has his/her own drone(s) and is responsible for the drone operation. The locations of the pilots/drones include the following:

- Northeastern Boston
- Northcentral Massachusetts
- Northwestern Massachusetts
- Southwestern Massachusetts
- Southwestern Middle Massachusetts
- C troop area
- Foxborough area
- Cape Cod area

Drone Usage at MSP-UAS

- The major missions of the MSP-UAS include (a) responses to severe injury and fatal motor injuries/roadway incidents (evaluation and clearance), (b) SWAT team assistance, (c) assisting Special Emergency Response (SER) team in search and rescue operation. UAS are used for the aforementioned missions when appropriate and severe injury or fatal crashes are the top use for the drones. Additionally, MSP-UAS supported the fire department before they had their own drones and conducted a lot of training of people in the force (e.g., stopping a felony and general strategy training).
- As of now, MSP-UAS does not use drones in crowd control or traffic incident management. Lt. George cautioned that drones should *not* be used if there are chances of surveillance on private personnel/properties.
- The current inventory mostly satisfies the MSP needs. It is very rare that a drone is needed but not available to MSP, but the incident response time could be further improved.

Drone operation in injuries/fatal incidents

The CARS team is the primary agency for crash investigation, and the MSP-UAS team is the backup for the CARS team. When MSP-UAS is involved, the incidents are usually substantial and likely involve crimes. The MSP-UAS uses drones for their crime scene investigation, when needed, to collect evidence and assess the situation and clear the damage (evaluation of scene). MSP aims to protect personnel involved, clear the incident as soon as possible, and return traffic to the normal operation. *Traffic queueing is a point of interest for MassDOT and not the main focus for MSP-UAS.*

Currently, MSP uses drones for crash investigation about 15 times per week *(12)*.

Decision to use a drone

For injuries/fatal crashes, currently there is no strict protocol on when to use the drones. It is up to the judgment of the pilots. No prior approval is required. After using the drones, the operation will be documented. For other missions, permission is approved by the Lieutenant.

Conditions when drones will not be used

Drones will not be flown when the MSP-UAS decides that it is not effective or feasible to fly the drones. Some examples include nighttime, in a tunnel, over private property (need authorization/warrant), at very congested crash scenes (the drones would inevitably surveil the public in this case), or in extreme weather conditions (snow and heavy rain).

Timeline when using the drones

For planned events, the drone can be in the air within 10 minutes. For unplanned events, the time varies. Specifically, upon a request to use a drone, the pilot will need to travel to the incident location. The arrival time may be impacted by the traffic congestion. After arriving at the incident scene, the pilot will need to check airspace (it takes 1–2 min), get flight clearance if required (5 min), and do preflight checks (10–15 min). After launching, a mission can take 10–17 min on average. The mission duration depends on whether there are multiple locations to check, the altitude, and weather conditions.

Video footage

The footage is not streamed live but is stored and processed later. It can be streamed live when needed.

Flight time and charging

The flight time of drones are up to 5 hours, and the pilots can charge the drones in their car. The battery is self-discharged within 5 days if not used.

MSP-UAS and MassDOT

MSP-UAS focuses on the technologies that can be used immediately. MSP will *not* use drones for regular surveillance. The majority of flights are manual flights and within visual line of sight. For injuries/fatal crash scenes, MSP would fly a drone via their pilots, if needed. If a drone is not available, MSP would use the conventional methods to do the investigation.