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16. ABSTRACT

The California Department of Transportation (Caltrans) owns many medium to large equipment yards and maintenance stations. Vehicles are often stored in these fenced and secure yards. However, Caltrans still experiences vehicle component theft from these yards. In recent years, there has been a significant increase in theft at Caltrans facilities. The aim of this research project is to evaluate whether mobile robot security guards are effective in mitigating the theft problems seen at Caltrans' facilities. This research provided a technical assessment of two mobile guard systems. One system was tested for 6 months at a Caltrans Maintenance yard. Surveillance data was collected and analyzed and a system evaluation was performed, including initial cost-benefit analysis and patrol data statistics. Furthermore, an event response procedure to address incidents and supported pilot testing was developed.

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Evaluation of Mobile Robot Teams for Security of Caltrans Equipment Yards and Maintenance Stations

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Barbara Linke: Principal Investigator

AHMCT Research Report: UCD-ARR-25-04-30-04
Final Report of Contract: 65A0749 Task 4288
Date: May 20, 2025

California Department of Transportation

Division of Research, Innovation and System Information

Executive Summary

The California Department of Transportation (Caltrans) owns many medium to large equipment yards and maintenance stations. Vehicles are often stored in these fenced and secure yards. However, Caltrans still experiences vehicle component theft from these yards. In recent years, there has been a significant increase in theft at Caltrans facilities. The estimated cost for Caltrans to replace only catalytic converters is over $4 million cumulatively.

Problem, Need, and Purpose of Research

The aim of this research project is to evaluate whether mobile robot security guards are effective in mitigating the theft problems seen at Caltrans' facilities. Should the research show that a mobile robot security team can greatly reduce Caltrans' theft issues, Caltrans could immediately proceed to broader deployment. As these robot security teams are commercial off-the-shelf (COTS) units, procurement and deployment would be efficient. With such teams in Caltrans yards, corresponding savings from theft reduction would be added with each additional yard.

The Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center reviewed and compared candidate commercial solutions for mobile robot guards. The team tested the capabilities of an Asylon Robotics security system selected by the project panel.

Overview of the Work and Methodology

Early research by AHMCT indicated that there are few companies currently offering a system that meets all the project panel's requirements. The system must consist of customized outdoor security robot hardware (mobile systems) with intelligent software. Options for this type of system were manufactured by Team 1st Technologies, Asylon Robotics, Cobalt Robotics, Knightscope Robotics; these systems all offered a combination of integrated robots and smart detection and surveillance software.

This research provided a technical assessment of mobile systems made by two vendors: Team 1st Technologies (which customized SMP Robotics' Argus) and Asylon Robotics (which customizes Boston Dynamics' Spot). Both systems are equipped with a series of cameras/sensors integrated with the associated vendor's software for surveillance. The AHMCT team compared these two systems to better understand their features and limitations. The team's findings helped the panel decide on which system to implement for pilot testing.

This report uses material from the report for Task 4153, Caltrans Yard Security project, as a reference for some of the information regarding Team 1st as the robot they offered was still the same SMP Robotics Argus S5.2 PTZ IR IS.

Major Results and Recommendations

During this project, AHMCT researchers partnered with Caltrans and achieved the following:

- Reviewed the candidate mobile guard systems,
- Supported Caltrans' decision-making on a test system and a test site,
- Worked with the vendor for system design and procurement of the Asylon's proposed system,
- Supported deployment of the two pairs of DroneDogs and DogHouses at San Bernardino Shop 8,
- Developed an event response procedure to address incidents and supported pilot testing,
- Collected surveillance data and distributed a survey,
- Developed system evaluation, including initial cost-benefit analysis and patrol data statistics, and
- Summarized the results and recommended future improvements.

See Chapter 5 for major findings and recommendations for future procurement and deployment of mobile robot guard systems.

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Acronyms and Abbreviations

Acronym	Definition
AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
AI/ML	Artificial Intelligence/Machine Learning
ASO	Autonomous Security Officer
BVLOS	Beyond Visual Line of Sight
Caltrans	California Department of Transportation
CHP	California Highway Patrol
COT	Commercial Off-the-shelf
DOE	Division of Equipment
DOT	Department of Transportation
DRISI	Division of Research, Innovation and System Information
FHD	Full High-Definition
EO/IR	Electro-Optical and Infrared Sensors
GPS	Global Positioning System
HD	High-Definition
IoT	Internet of Things
IP	Ingress Protection
IR	Infrared
ISP	Internet service provider
IT	Information Technology
LTE	Long-Term Evolution

Acronym	Definition
PO	Purchase Order
PTZ	Pan/Tilt/Zoom
RDAC	Research and Development Advisory Committee
ROSC	Robotic Security Operations Center
SIM	Subscriber Identity Module
SOP(s)	Standard Operating Procedure(s)
UCD	University of California, Davis
Wi-Fi	Wireless Fidelity

Acknowledgments

The authors thank the California Department of Transportation (Caltrans) for their support, particularly Bob Myers, the Chief of the Division of Equipment; Alexander Pham with the Division of Research, Innovation and System Information; Michael Lemke from District 8 Maintenance Dispatch; David Schmiderer and Seannon Perkins attending Shop 8 at San Bernardino; and Dave Roth with the Division of Equipment. The authors acknowledge the dedicated efforts of the AHMCT team who have made this work possible.

Chapter 1: Introduction

Problem

The California Department of Transportation (DOT) (Caltrans) has many medium to large equipment yards and maintenance stations. Vehicles are often stored in these fenced and secured yards. However, Caltrans still experiences vehicle component theft from their yards. In recent years, there has been a significant increase in theft at Caltrans facilities. The estimated damages caused to the Division of Equipment (DOE) is over $4M cumulatively in stolen catalytic converters alone.

The aim of this research project is to evaluate whether mobile robot security dogs are effective in mitigating the theft problems seen at Caltrans' facilities. Should the research show that a mobile robot security team can greatly reduce Caltrans' theft issues, Caltrans could immediately proceed to broader deployment. As these robot security teams are commercial off-the-shelf (COTS) units, procurement and deployment would be efficient. With such teams in Caltrans yards, corresponding savings from theft reduction would be added with each additional yard.

Objectives

The Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center reviewed and compared candidate commercial solutions for mobile robot guards, e.g., Team 1st technologies and Asylon Robotics. The team tested the Asylon Robotics security system, selected by the project panel and evaluated the results to shed light on the pros and cons of mobile guard systems and provide recommendations for future deployment of security systems at Caltrans yards.

Scope

Key features investigated for any mobile guard security system include the following:

- Ease and cost of installation
- Initial system design and optimization of patrol routes
- Battery life
- Charging and operating times

- Coordination between other robots for movement and surveillance
- Image quality of surveillance cameras in various conditions (bright sun, night, fog, rain)
- Video transmission and real-time communication
- Ability to navigate in typical Caltrans yard terrain
- Performance in relevant weather (e.g., wind, rain, and snow)
- Obstacle detection and avoidance
- Advanced artificial intelligence (AI) capabilities, such as face detection and optimized movement and yard coverage
- Remote system monitoring of system status
- Integration of security solutions (stationary and mobile)
- Feasible customizations in terms of camera and on-board memory
- Sound detection (e.g., cutting through fence, gunshot, glass break)
- Sound alarm and capability of warning the intruders through robots
- Customer support and maintenance
- Third-party monitoring agent to clear out false alarms and respond to threats in real-time
- Response time and cooperation with law enforcement
- Mass and size of robots and the risk of robot theft or vandalism
- Charging station requirements
- Wireless/LTE internet communication

The AHMCT team prioritized core features of route planning, system monitoring, alarming, and alerting. Upon panel authorization, AHMCT procured a system consisting of two Asylon DroneDogs (as the surveillance robot) and two DogHouses (as the charging stations).

The AHMCT team supported the vendor and Caltrans in the deployment process. Before procurement, the researchers worked with the selected vendor to develop a pilot test plan closely assessing the aforementioned features. The research team was involved during the pilot study and performed specific tests to assess these key features.

The researchers distributed a survey among Caltrans personnel at San Bernardino Shop 8 (the selected pilot site) to determine their interaction and impression of Asylon's mobile robot security team. AHMCT researchers summarized the acquired data from the vendor's user dashboard called

DroneIQ, developed a final evaluation and an initial cost-benefit analysis, and made recommendations for any further deployment.

Background and Literature

Chapter 2 and Appendix A provide a technical assessment of mobile systems made by two vendors, namely Team 1st Technologies (that customizes SMP Robotics' Argus) and Asylon Robotics (that customizes Boston Dynamics' Spot). Both systems are equipped with a series of cameras/sensors integrated with the associated vendor's software for surveillance. The AHMCT team compared these two systems to better understand their features and limitations. The team's findings helped the panel decide on which system to implement for pilot testing.

This report uses material from the report for Task 4153, Caltrans Yard Security project, as a reference for some of the information regarding Team 1st as the robot they offered was still the same SMP Robotics Argus S5.2 PTZ IR IS.

Overview of Research Results and Benefits

This project concluded with reviewing two mobile guard systems, deploying the Asylon's proposed system with two DroneDogs at Shop 8 in San Bernardino, and completing six months of pilot testing. The collected patrol data were evaluated and major findings and recommendations for future procurement and operation of mobile guard systems are compiled in Chapters 3, 4, and 5.

Chapter 2:
Review Candidate Systems and Support Caltrans Decision

After an initial study and survey of available systems at the beginning of the project, AHMCT researchers and the panel narrowed their focus to two outdoor mobile guard security systems: Team 1st Technologies (who modified and programmed the Argus robot made by SMP Robotics for autonomous outdoor security) and Asylon Robotics (who integrated the Spot robot made by Boston Dynamics with their surveillance technology called PupPack). See Appendix A for the updated version of the interim report originally prepared as the deliverable for this task. The Caltrans panel made two decisions by the conclusion of this task:

i. Chose Shop 8, located at 320 South Sierra Way, San Bernardino as the pilot site.

ii. Chose Asylon Robotics, who integrates the Boston Dynamics robodog Spot with their hardware and software for surveillance, as the pilot system.

Chapter 3: Procurement, Deployment, and Implementation

AHMCT started meeting with the vendor virtually in October 2023. Preparations for deployment included design iterations and the installation of outlets at selected DogHouse locations. In February 2024, University of California (UC) Davis submitted a purchase order for a six-month pilot testing subscription at San Bernardino Shop 8. Asylon surveyed the yard prior to deployment to ensure that a sufficient connection to a public LTE network could be made. Asylon also spent three days at the yard to fully install and activate the system. Additionally, their pilots (human remote robot operators) were trained. On March 8, 2024, the pilot testing officially began at Shop 8 and lasted until September 8,2024. Pilot testing normally has a ramp-up period up to a month long during which the patrols are optimized and key security spots discovered. These assessments included certain parts of the perimeter especially gates that are normally locked during the yard's off-hours.

Problems and Issues that Affected Product Deployment

Generally, compared to other solutions that require installation of poles, trenching, or other construction, mobile robot guard solutions for outdoor security are easier and cheaper to deploy and are considered to be "plug and play" systems. This is especially true for Asylon's system, which requires two major items for deployment:

i. A public 4G network is needed in the area covering the yard; alternatively, a local private LTE network can be installed by a contractor. Asylon Robotics typically establishes and maintains a Starlink connection when the public LTE network in the area is insufficient. In this project, Asylon surveyed the yard in December 2023 and confirmed that the signal from public cell phone towers sufficiently covered the patrol route around the yard. Therefore, there was no need to acquire equipment such as antennas for a private LTE or Wi-Fi network. High-bandwidth Wi-Fi connectivity is an option and can be facilitated in the future to improve the stream resolution and bitrate. However, long range outdoor Wi-Fi networks are relatively expensive, high-maintenance, and susceptible to hacking/jamming by basic instruments.

ii. A single 110V and 20A power outlet is required at each DogHouse location, which was the primary challenge during deployment as outdoor outlets were not readily available for DogHouses. In February 2024, the two required outlets were installed by a Caltrans electrician:
    - One by extending power from inside an adjacent building to the outside wall, and
    - The other by using the existing cabinet for the electric car charging station to provide an additional outlet.

The above process took about two months to plan and about a week to carry out, because the spaces assigned to DogHouses were selected prior to deployment to avoid any changes to the ground or nearby buildings. The benefit of longer planning was that system deployment did not require any authorization or regulatory procedure other than coordinating with the yard staff and front office. For future deployments, if power is not available near suitable charging spots or providing outlets requires significant construction, the project manager must coordinate with the associated Caltrans District Engineering and Maintenance office and potentially other entities, such as the California Office of the State Fire Marshal to ensure safe deployment.

Other Considerations for Future Deployment

The AHMCT team developed the test plan with the vendor in collaboration with the Caltrans panel. The number of DroneDogs required to adequately patrol the entirety of Shop 8 was decided. The vendor informed the AHMCT team that two robots can take turns and patrol the yard continuously without significant interruption. The panel accepted the vendor's recommendation and confirmed that during weekdays only nighttime patrols were needed at the test site. Thus, the AHMCT team subscribed to a 112 hour/week plan (within the original budget) which covered 11 to 12 hours during the weekdays (5 PM to 5 AM) and the entire duration of weekend (from Friday 5 PM to Monday 5 AM).

There were no significant equipment or operational issues with the deployment. Since pilot testing was carried out without using the Caltrans network, no policy issues were encountered. There was a total of four maintenance incidents during the six-month period, three of which led to downtime and interruption in patrols. Table 3.1 lists these incidents, their causes, and how they were addressed. The major considerations based on the reported incidents are as follows:

- Any prescheduled work task in the yard that requires power cutoff must be communicated with the vendor to ensure that robots do not get stranded outside. The DogHouse cannot open/close without power.

- Yard staff support is required to address some maintenance incidents quickly without Asylon agents coming to the yard, including moving the DroneDog to safety or manually resetting the DogHouse.
- To the extent possible, placement of any new obstructions or objects that can block the patrol routes should be avoided or removed before the end of shift by yard staff to avoid collisions and patrol interruptions.

Table 3.1: Maintenance incidents during the six-month pilot testing at Shop 8 (as reported by Asylon and confirmed by AHMCT researchers)

Date	Root Cause	Down Time	Resolution	Notes
3/29	Site Power Outage	80 Hours	Power restored and on-site personnel recovered the stranded robot and powered both robots back on.	Site lost power, resulting in one robot being left stranded outside the DogHouse and the other stuck inside the DogHouse. Outage lasted long enough that both robots' batteries died and needed on-site support to resume operations. Outage occurred on a Friday and Monday was a state holiday, so no on-site support until Tuesday (4/2) morning. Asylon did not yet have after-hours access to facility.
4/12	Site Power Outage	56 Hours	Power restored and on-site personnel recovered the stranded robot and powered both robots back on. Asylon found a SoCal Edison tool that allowed them to monitor for any planned outages moving forward.	Site lost power, resulting in one robot stranded outside the DogHouse and the other stuck inside the DogHouse. Outage lasted long enough that both robots' batteries died and needed on-site support to resume operations. Outage occurred on a Friday and on-site support arrived Monday morning (4/15). Asylon did not yet have after-hours access to facility.

Date	Root Cause	Down Time	Resolution	Notes
4/21	Operator's maneuver into a small bush that damaged payload camera	72 Hours	Asylon shipped a replacement camera overnight on Monday and had a technician replace the broken camera on Tuesday.	Attempted to run additional patrols with the other robot to help make up gaps in coverage.
9/2	RSOC operator error caused DogHouse fuse to blow	None	Asylon had a technician on-site within 18 hours to replace the fuse.	Issue occurred around 2330 on 9/2. Asylon utilized the second DogHouse to keep both robots charged (charged one while the other ran a patrol) to ensure no patrols were missed. Further, Asylon continued to swap robots on the charger in the working DogHouse throughout the day to ensure both robots remained powered on and available outside of scheduled patrol times.

Chapter 4:
Pilot Testing and Analysis

The chapter addresses the results of pilot testing and the findings from patrol data recorded in DroneIQ.

Support Pilot Testing and Assessment

AHMCT researchers, with support from Caltrans Shop 8 attendants and Maintenance Dispatch, developed the *Standard Operating Procedures (SOPs) for Caltrans Shop 8 – Security/Safety Event Response Procedure* included in Appendix B. After discussing the SOPs during a meeting, Asylon RSOC was instructed to address the incidents at Shop 8 following this procedure. Based on these instructions, RSOC was to contact yard personnel to share information and pictures following security events.

RSOC also shared weekly reports, and more comprehensive 90-day and 6-month reviews with AHMCT researchers with scheduled meetings to discuss the results and future improvements. The 90-day review showed that Asylon had refrained from contacting the yard staff for repeated incidents, such as gates that were repeatedly left unlocked. AHMCT researchers clarified that, based on the SOPs, they are supposed to contact the yard for every incident without exception.

Simulated Break-in

During the 90-day review meeting between the Asylon Ops team and AHMCT researchers, it was confirmed that RSOC is authorized to contact Caltrans maintenance dispatch and California Highway Patrol (CHP) for any urgent/emergency incidents. To test their response, a simulated break-in was planned by the AHMCT team and executed by yard attendant personnel. CHP was previously informed about the details of this exercise and was on alert to be dispatched upon receiving the call from Asylon RSOC. However, RSOC never called CHP because they had reason to believe that the observed person walking inside and the person standing near the fence were Caltrans employees. An AHMCT researcher remotely monitored the simulated break-in via DroneIQ.

At 9:00 PM on August 22, 2024, it was planned to have a yard attendant act as though they were trying to enter Shop 8 to appear as an unauthorized entry and suspicious presence inside the yard. However, things did not go as planned because Asylon RSOC skipped an entire patrol scheduled for 9:00 to 9:30 PM.

RSOC did not initiate any patrols from 8:50 PM to 9:35 PM that night. This gap led to AHMCT investigating idle times (i.e., missing patrols) more closely and discussing them with the vendor in the following days.

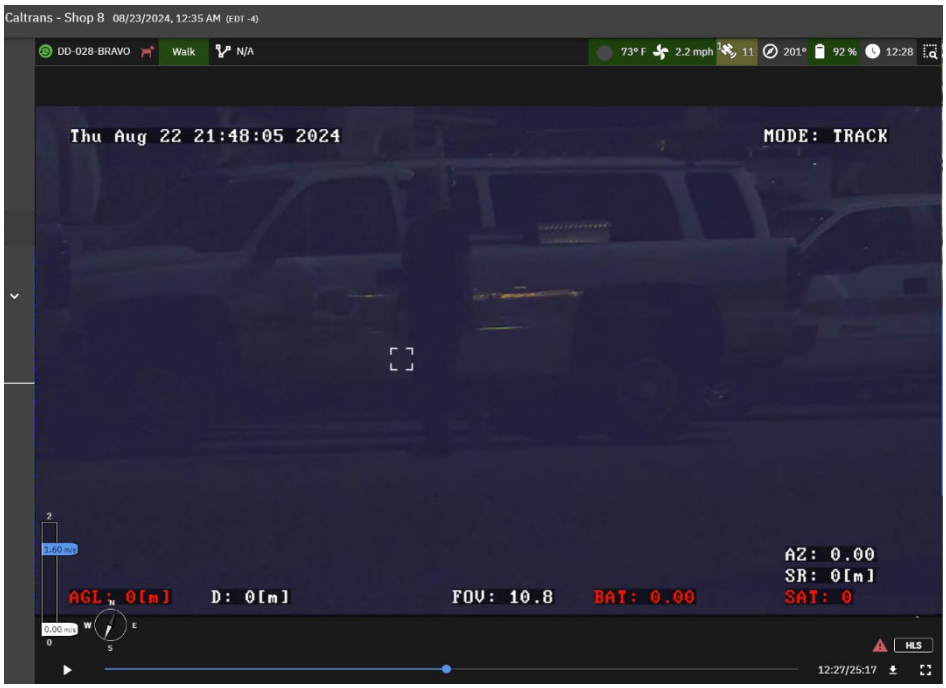
The recording of the next patrol shows that the DroneDog operator saw a nearby firework short after initiating the patrol at 9:35 PM, which caused a minute of distraction. Around 9:37 PM, our planned intruder (waiting inside the yard for over 45 minutes) stepped in between the DroneDog and the firework to be intentionally seen by the operator. He then attempted to capture the DroneDog's attention by opening and closing toolboxes in the back of a truck. The operator followed the suspicious person for ten minutes, but CHP was not contacted as RSOC thought that they were looking at Caltrans employees.

To understand how RSOC judged this situation, we need to refer to the abovementioned event response procedure which broke down the safety and security incidents to four tiers. Tiers 1 and 2 are considered urgent SOPs, and Tiers 3 and 4 fall under non-urgent SOPs. Following this simulation, it was learned that there must be explicit criteria to determine whether a situation falls under Tier 2 or Tier 3. Asylon was told to observe the behavior of any suspicious person and personally judge if they are an intruder; this criterion proved to be too subjective for operators piloting the DroneDog and the RSOC team.

As such, the Tier 2 incident description had to be modified following the simulated break-in, stating that any suspicious person seen inside the yard after 8 PM must be considered an intruder and treated as an urgent incident for which CHP and Caltrans Maintenance Dispatch must be called immediately.

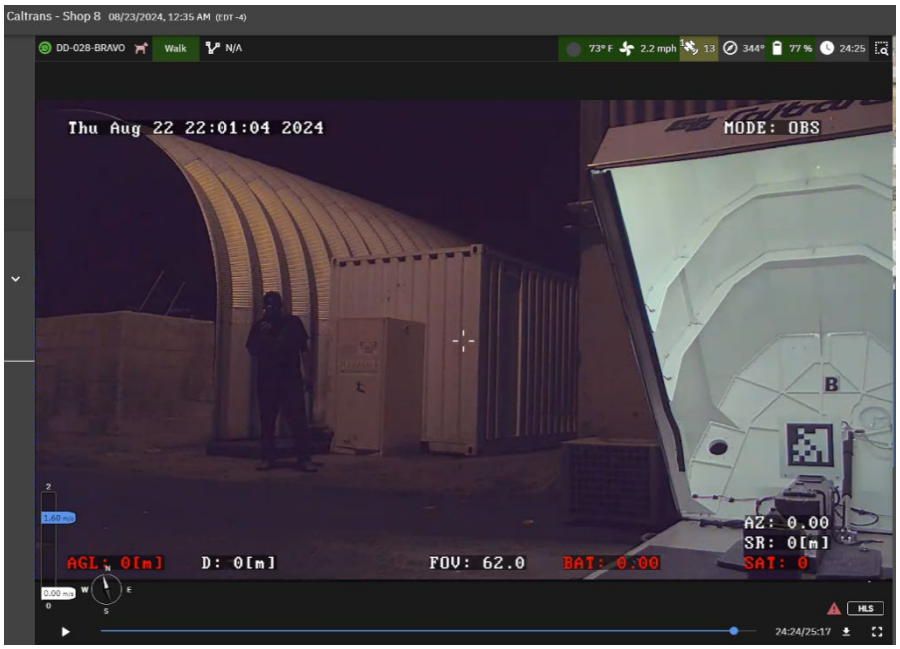
Since Asylon RSOC considered the simulated break-in as a non-urgent incident (Tier 3 SOP in the security event procedure), they sent an email to the contact list within an hour reporting the lack of malicious/nefarious action by the suspicious person and no sign of break-in:

> "At approximately 2142 local time this evening, our team was conducting a routine patrol when they observed a male individual roaming the yard. We continued to observe the individual as he approached and entered multiple trucks and toolboxes; however, he did not appear to break anything nor take anything from the trucks or toolboxes. Furthermore, he made no effort to hide from the robot as we followed him around the yard, and we also observed him going back and shutting previously opened toolboxes. We could also see a badge hanging off his waist.



At approximately 2150, we observed him approach the fence to speak to another individual standing on the sidewalk along Sierra Way for several minutes.

As the first robot's patrol came to an end, the individual followed the robot and recording it docking on his phone.



While the first robot was docking, we dispatched the second robot who continued its observation of the individual. At approximately 2209, the individual left through the pedestrian gate near the eastern entrance and appeared to replace the lock on the gate as he was joined by a second male individual. They spoke briefly before heading to separate vehicles parked along Sierra Way and departing the area.

Given the nature of our observations and the lack of any obvious criminal or otherwise unsafe activity, we elected to simply continue our monitoring and observation of what we have deemed to be an employee on site after hours versus alerting law enforcement."

It must be noted that Asylon judged the situation based on the original event response procedure that did not indicate any specific timeframe for Tier 2 incidents. After this incomplete exercise, the AHMCT team met with Asylon Ops team to discuss modifying the SOPs for late evening activity, especially regarding the suspicious presence after 8 PM. There was not enough time in the pilot testing period to carry out another simulated break-in. Future testing will determine how this procedure can be further improved or elaborated for the monitoring agency to assure the appropriate response.

Asylon's 6-month Review

Asylon's 6-month review was carried out late September 2024 upon completion of pilot testing. A summary of this review was prepared by Asylon

Ops team and is depicted in Figure 4.1. The security events were broken into five categories by Asylon based on what was observed during the pilot testing:

1. Damaged fence was detected ten times, mainly the fence between the two Caltrans facilities that was seen damaged in multiple occasions.
2. Suspicious persons, inside the yard or outside near the perimeter, were detected three times in total during pilot testing, one being the simulated break-in, the second being a yard staff seen early in the morning, and the last one being a person wondering outside staring at DroneDog late at night (who eventually turned and walked away).
3. Unsecured asset, detected five times, mainly triggered by placement of new objects, crates, or shipments in the open, near the fence, or too close to the main gate causing a safety/security concern.
4. Unsecured gate, detected 13 times especially on the northeast side of the yard, was the main security concern for different reasons, e.g., damaged locks, human error, or being left open as a shortcut between Caltrans facilities. RSOC helped Caltrans keep track of the situation and this led to fewer incidents by the end of pilot testing.
5. An unsecured vehicle was detected three times, most notably was a damaged Caltrans truck scheduled for repair after a crash, and another vehicle left open early in the morning by an employee when they showed up to work without being seen.

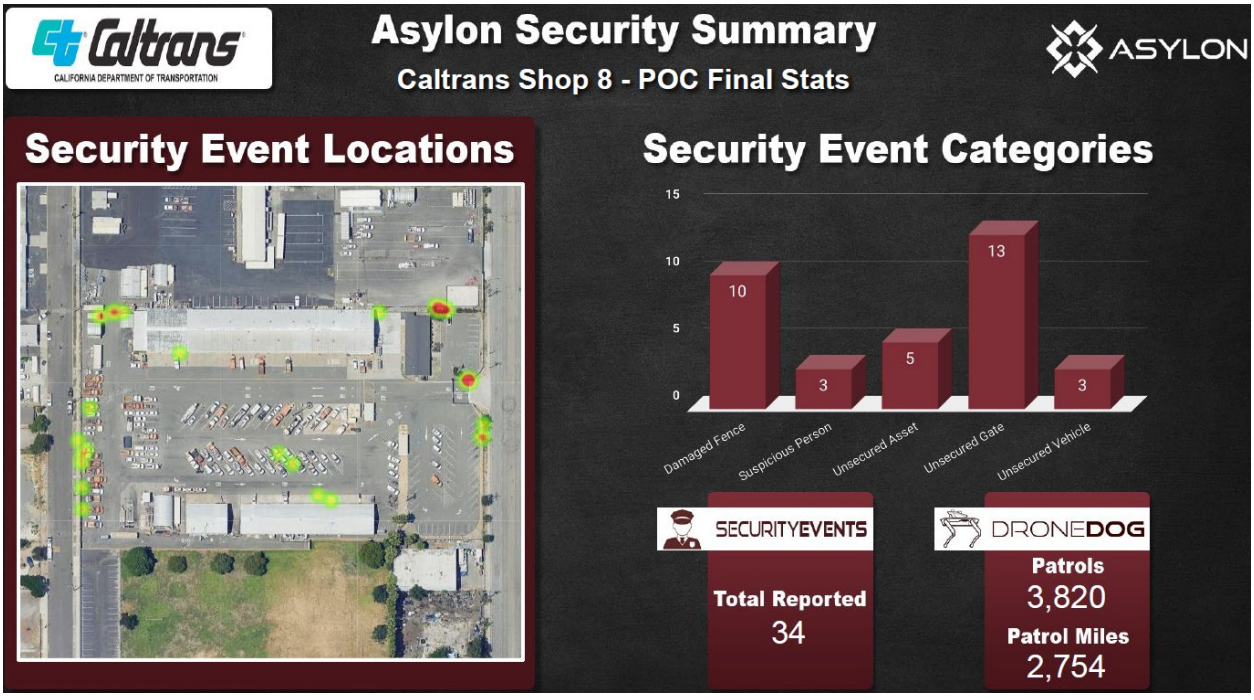


Figure 4.1: Type and frequency of incidents at Shop 8 during the entire 6-month pilot testing with highlighted security hotspots on the map (courtesy of Caltrans Shop 8 and Asylon Robotics)

Analyzed Pilot Test Data

Pilot testing was carried out with two DroneDogs: DroneDog A and DroneDog B. This section lists statistics regarding the pilot testing as well as the performance of the DroneDogs and their operator pilots. This analysis is accompanied with boxplots presenting the data and recommendations for improvement.

During 30 minutes of use, the units' battery percentage was decreased by 31% on average. Figure 4.2 shows that the battery percentage decreased by 0.7% to 1.4% per minute during use. This decrease is relatively small considering that most patrols were shorter than 30 minutes (see Table 4.1 and Figure 4.4).

The red cross **X** sign in all boxplots indicates the mean value. The black line inside the colored box is the median of the sample. The width of the colored box showcases the range of middle half of the sample data. The range in between the outside lines includes 75% of all data instances.

Patrols longer than 30 minutes sometimes led to simultaneous patrols when the next patrol started before the previous one ended. Normally, RSOC initiated the second DroneDog in case they observed something suspicious (e.g., damaged fence, broken car window, unsecured gate, etc.) or needed to track and find an intruder seen inside or outside the perimeter.

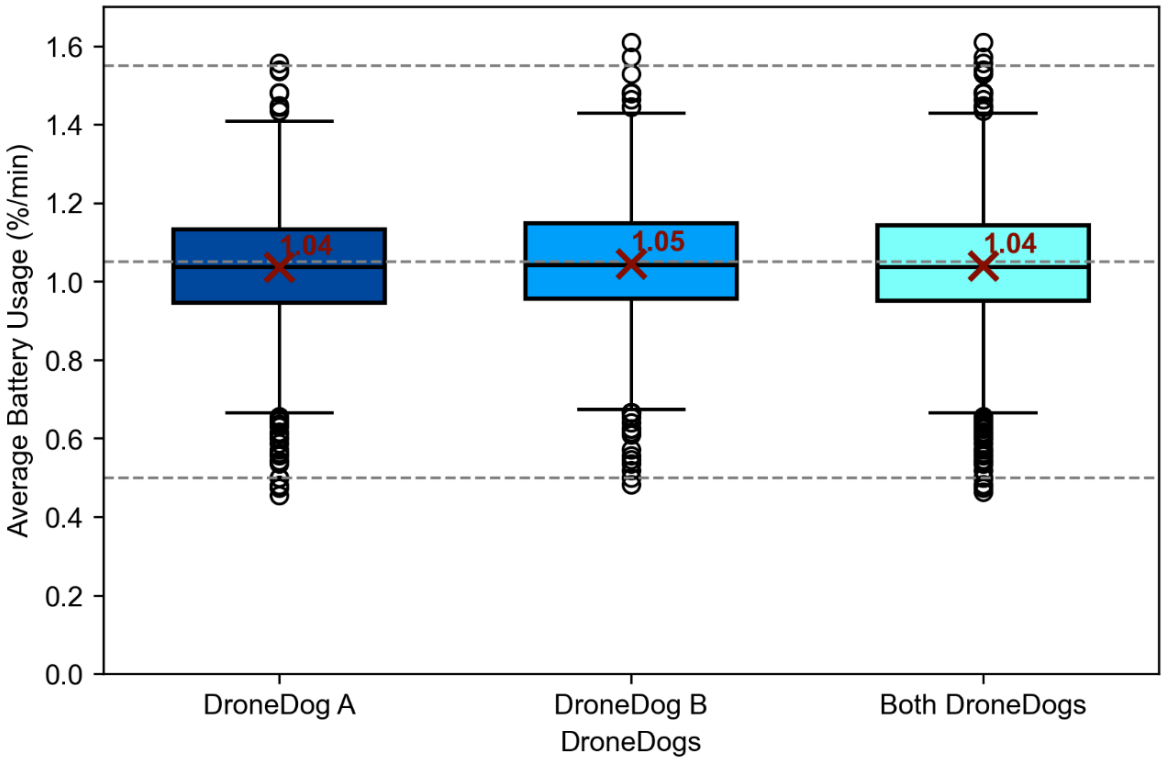


Figure 4.2: Average battery percentage discharge per minute of patrol time (Number of data instances = 1,787 and 1,548 for DroneDogs A and B, respectively)

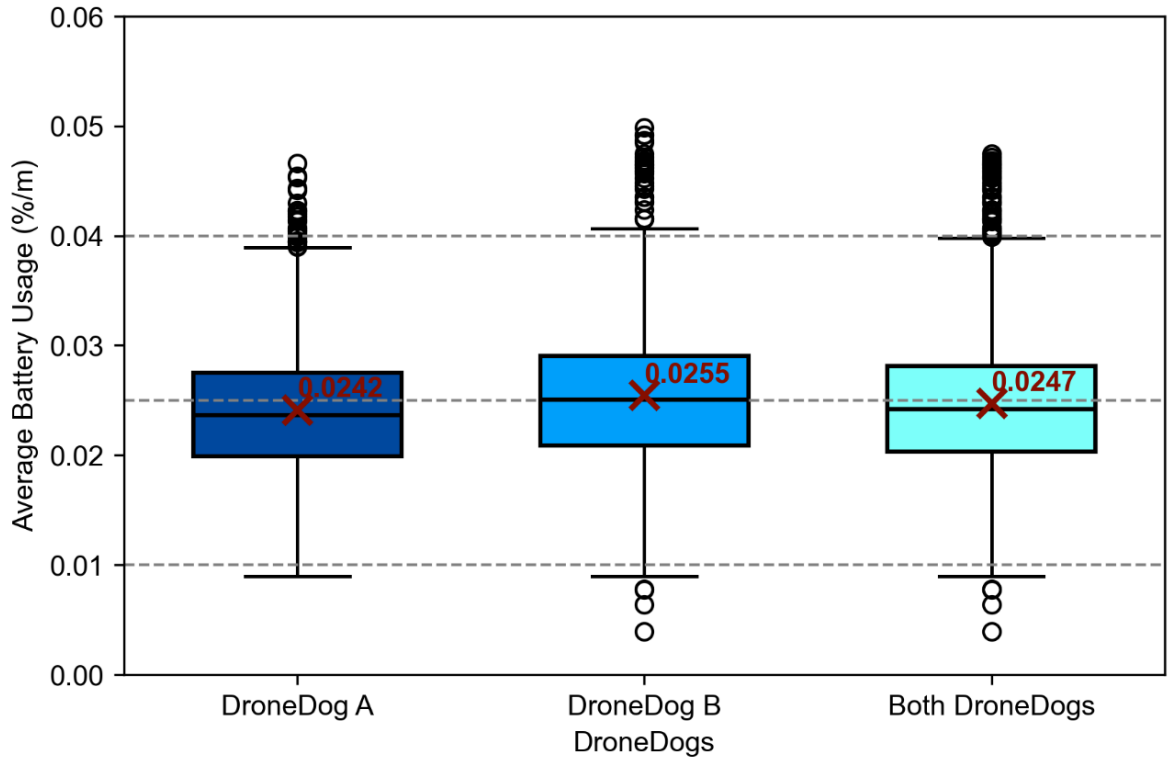


Figure 4.3: Battery percentage discharge divided by the length of patrol in meters[1] (Number of data instances = 1,792 and 1,550 for DroneDogs A and B, respectively)

[1] This graph does not consider the battery discharge when the DroneDog is patrolling without taking any steps or traversing the yard. In practice, a small portion of DroneDog battery is discharged while stationary.

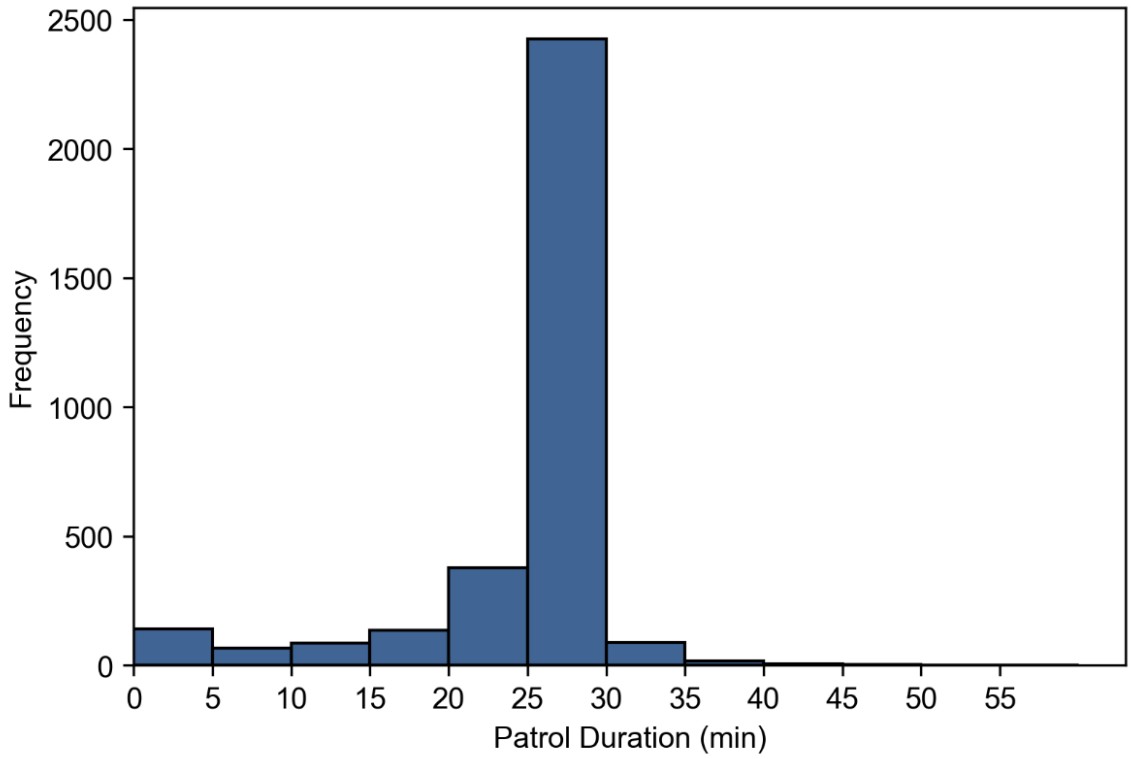


Figure 4.4: Patrol duration across both DroneDogs (Number of data instances = 3,349)

Figure 4.3 shows that the battery percentage decreased by 0.01% to 0.04% per meter on average. The average patrol distance for DroneDogs A and B in a single patrol was 1,186 and 1,130 meters, respectively. Figure 4.5 presents the patrol distances for each DroneDog in more detail. Given this information, the on-board battery supports patrols more than double the distance traversed in Marysville yard (typically utilized in larger areas with one-hour on and one-hour off schedule). However, by targeting 30-minute patrols, DroneDogs rarely surpass 2,000 meters of patrol distance; furthermore, shorter patrols covering only 500 meters or less are not ideal, indicating there is room for improvement and consistency.

Table 4.1 presents patrol time statistics for weekday and weekend patrols. Monday-Thursday from 5:45 PM to 4:15 AM were considered weekdays. Single patrols on Friday 5:45 PM to Monday 4:15 AM were considered weekends. The first and last 45 minutes of patrols and the entire month of April were excluded from these statistics in fairness to the vendor accounting for the ramp-up period. Also, the downtimes due to maintenance incidents (Table 3.1) were excluded from the presented statistics.

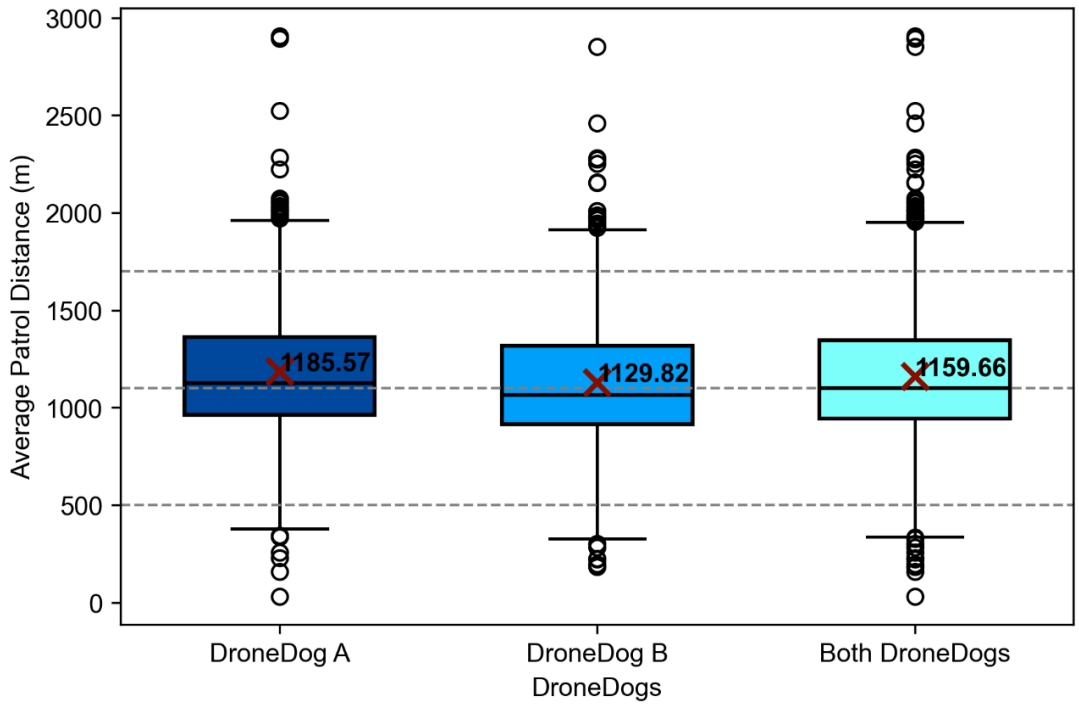


Figure 4.5: Average patrol distance for each DroneDog (Number of data instances = 1,805 and 1,568 for DroneDogs A and B, respectively)

Table 4.1: Patrol data statistics from May 1 to September 8, 2024[2]

Patrol Type	Number of DroneDogs Patrolling	Frequency per Weekday/Weekend	Duration per instance (mins)
Weekday	**One (normal patrol)**	14.8	24.6
	Zero (idle time)	10.8	17.6
	Two (simultaneous patrol)	3.4	4.7
Weekend	**One (normal patrol)**	64.5	24.9
	Zero (idle time)	44.6	21.0
	Two (simultaneous patrol)	13.0	4.8

[2] In Table 4.1, the average value is reported for each metric across all records in DroneIQ. The month of April was excluded from the stats to account for system ramp-up period.

While the value of normal patrols (with one of the DroneDogs) plus simultaneous patrols (with both DroneDogs) is relatively large to the amount of idle time when scheduled patrols were missed, the distribution of idle times (presented in Figures 4.6 and 4.7) shows several concerningly long idle times (up to several hours). The vendor reported that some of these long idle times were weather-related as RSOC operators used to pause the patrols during rainfall.

Short idle times up to ten minutes are expected while making the transition from one DroneDog patrol to the other; although this downtime can improve by automating the patrols with software. The idle times longer than 30 minutes represented in Figures 4.6 and 4.7 indicate entire patrols being missed. The frequency of such idle times cannot be justified only by poor weather or technical issues, and the role of the human factor is undeniable in the outcome.

Finally, Figures 4.8 and 4.9 show the frequency of simultaneous patrols (by both DroneDogs) during weekday and weekend patrols, respectively. Long simultaneous patrols are rare as they are often in response to safety/security events; for instance, to look for intruders trying to avoid the surveillance or keeping track of an ongoing situation.

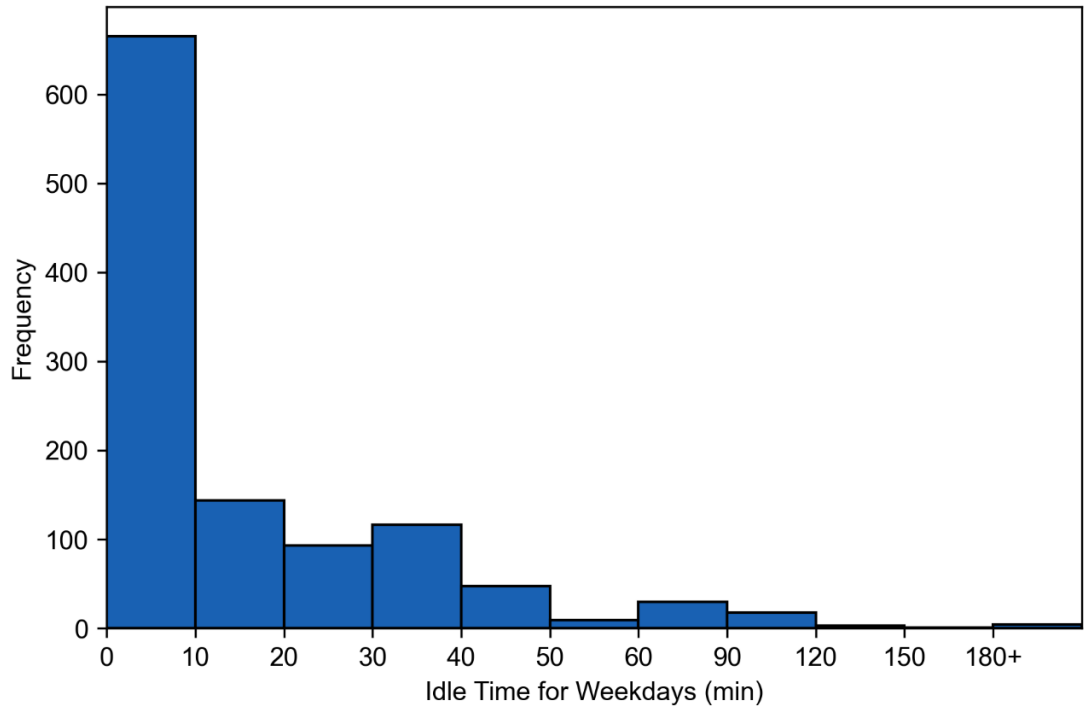


Figure 4.6: Distribution of idle times during the weekdays (Number of data instances = 1,130)

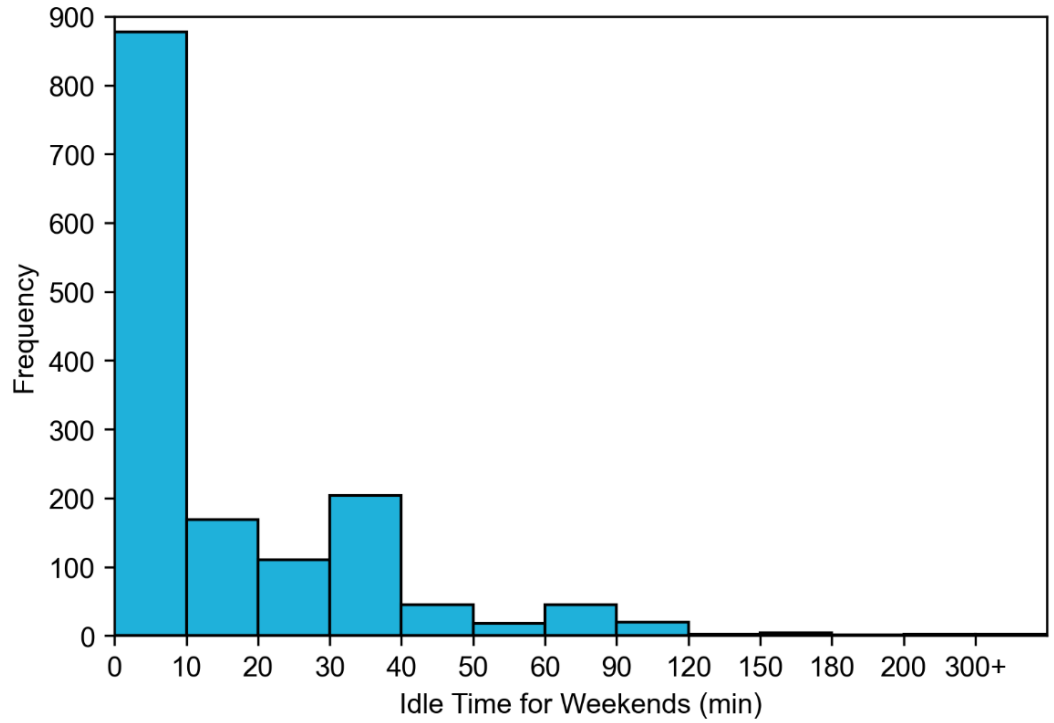


Figure 4.7: Distribution of idle times during the weekends (Number of data instances = 1500)

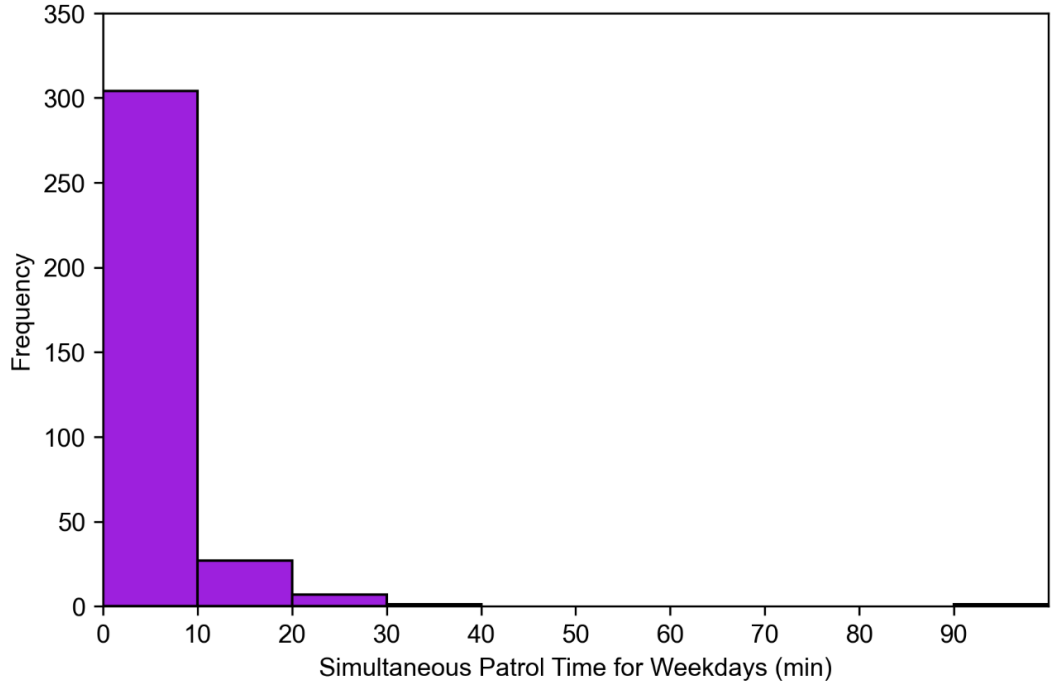


Figure 4.8: Distribution of simultaneous patrols during the weekdays (Number of data instances = 340)

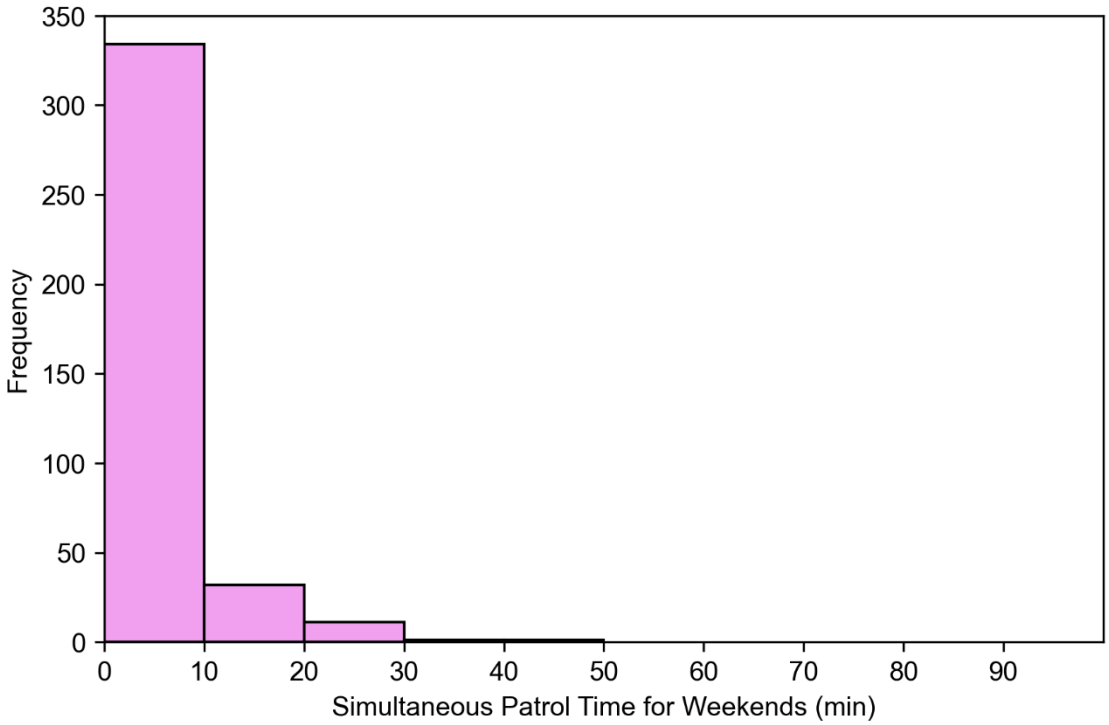


Figure 4.9: Distribution of simultaneous patrols during the weekends (Number of data instances = 379)

Develop Cost-Benefit Analysis

To better understand the difference between deploying mobile robot guards and human guards, a cost-benefit analysis was completed to quantify each with the available information from pilot testing and the data gathered from Shop 8 prior to deploying the Asylon system.

The Asylon system cost roughly $142,000 to deploy two DroneDogs at Shop 8 112 hours a week for six months. The annual subscription rates are lower for longer terms, and Asylon has made their service more affordable since the start of this project. Based on recent information, one human guard cost $110,000 annually to hire for Shop 8.

The workhours of human guards vary, and it is hard to compare the patrol time of human guards to robots. Considering that the Asylon system was piloted by human operators at the time of pilot testing, we may assume that their patrol and idle times were comparable to human guards. However, it must be noted that future updates can automate the robot patrols, which may significantly increase the proportion of patrol time to idle times.

During the six-month pilot testing, there were no incidents involving theft or damages at Shop 8. There were no confirmed break-ins reported by the yard staff. The AHMCT team infers that because the robot guards were visible from

outside the perimeter, some intruders were potentially discouraged from entering, reducing security costs. However, a longer deployment period may be required to make an accurate cost comparison.

Attempting to steal catalytic converters is common, but intruders target a variety of things. In the five months prior to deployment of Asylon system (October 2023 to March 8, 2024), Shop 8 had four confirmed theft/vandalism incidents (in addition to one likely vehicle break-in) that all required repairs for Caltrans vehicles which cost $2,776.84 to fix:

- Stolen rear license plate,
- Stolen tailgate, and
- Punched-in door lock, for which CHP came to Shop 8 and met with the yard staff to complete a report, realizing that the same vehicle was apparently broken into a few months prior to the incident.

Table 4.2 lists the frequency of incidents at Shop 8 and the associated costs for work orders since 2020. The frequency and the associated repair costs of theft/vandalism incidents had a significant drop in the first 9 months of 2024 compared to prior years. The data tabulated below accounts for vehicles damaged at Shop 8 as well as some that were damaged outside of Shop 8.

Table 4.2: Shop 8 work orders following break-ins and attempted theft/vandalism for 2020 to September 2024

Year	Number of repairs	Total cost of repairs
2020	12	$37,152.95
2021	9	$31,727.01
2022	23	$84,767.40
2023	20	$72,251.48
2024 until September	6	$9,188.52

If future testing shows promise in reducing the repair costs to a third or even half of prior four years at Shop 8 (2020-2023), then it will be justifiable to spend those funds on security contracts rather than allocating the budget and human resources to fixing damages to property while also maintaining a human guard.

Additional notes to consider is that Table 4.2 shows the repair costs only for damaged vehicles due to theft/vandalism at Shop 8. Historically, intruders have

caused damages to other Caltrans properties, and some yards are targeted more than others. The next step for Caltrans would be to implement a wider cost-benefit analysis for different security systems over the span of three years, which is a common term for mobile guard subscriptions.

Yard Staff Survey

To reflect on the impact of the mobile guard system deployed as pilot testing, a questionnaire was prepared and distributed anonymously among the Caltrans personnel who interacted with the system either to support, maintain, or supervise the operation of Asylon system at Shop 8. This section summarizes the opinions of three survey respondents regarding different aspects of pilot testing.

This survey evaluated the pilot testing in totality from early April to September 2024. In fairness to the vendor, Asylon was instructed not to communicate with Caltrans or the yard staff until the establishment of the event response procedure which took lasted over a month into deployment. Asylon typically trains on-site clients on the DroneIQ software, troubleshooting, and safe handling of hardware, but they were not given the opportunity to do so at the beginning of this project as their main contact was the AHMCT team who facilitated the deployment.

Based on the answers given, the personnel who interacted with the system generally did not feel they had enough training for using the system hardware, understanding how it operates, or understanding how to provide support specifically in situations, such as

- Robot being stranded or out of power,
- Charging station being shut or out of power, and
- Robot or charging station require other attention.

While the DogHouses are visible in the yard, few personnel stay during the off-hours to observe the patrols carried out by the DroneDogs, and even fewer were involved with addressing maintenance incidents. Those who took the survey did not feel that they understood the steps to restart or shut down the DroneDog or the DogHouse when needed for maintenance or emergency situations. Considering the need for quick response in some maintenance incidents, some basic training for at least a few yard attendants is recommended prior to future deployments. Training should focus on the following:

- Capabilities and susceptibilities of the system
- Manual controls on the DroneDog and the DogHouse
- Safety procedures

- Contact list to reach out to RSOC in emergency situations that relate to the security system

As for potential improvements, it was stated that visibility in both daylight and nighttime can be enhanced by better lighting on the DroneDog. It was also noted that a backup battery should be installed on the DroneDog, primarily for situations in which the DroneDog is out of power and stranded outside of the DogHouse. Without a backup battery, the only solution is to physically carry the DroneDog to its DogHouse and place it inside to charge.

Shop 8 staff shared mixed opinions about whether the robots' patrol interfered with yard staff duties. Depending on the work hours, some employees had to work off-hours before 5 AM or past 5 PM when the yard driveways were occupied by the DroneDog patrolling around gates and the parked vehicles. To the extent possible, these interactions should be predicted and communicated with the yard staff to avoid any disturbance to their work.

One point of focus for Asylon RSOC was to make sure the gates and entrances were secure during off-hours. The survey indicated that initially this helped the yard staff with better securing the gates, but eventually this was not deemed very impactful by the yard intendents.

Those who took the survey mostly agreed that Asylon's robot surveillance system excels at patrolling blind spots in the yard, which can be challenging to completely surveil with fixed security cameras. The DroneDogs' mobility allows them to cover blind spots, which is advantageous especially compared to a group of fixed cameras. Tens of cameras and motion sensors/radars may be needed in sites where large buildings, vehicles, and crates inside the perimeter create blind spots. This response is important for Caltrans yards that do not have power and connectivity available in the outside perimeter at every corner making the deployment of fixed cameras more challenging.

An important task in support of pilot testing was to develop and use the security/safety event response procedure. This procedure was created by AHMCT researchers and Shop 8 attendants. The AHMCT team received mixed feedback about the quality of this procedure. A key concern was whether the procedure properly addressed urgent and non-urgent situations at the yard. The data collected were not sufficient to evaluate this procedure; future testing is required to improve and implement this procedure.

There was a statement in the questionnaire that reads: "Asylon's Ops team successfully communicated with yard intendants after the security/safety event response process was in place (from May to September 2024). The communication included mainly email reports of the findings of patrols with images/details attached, sometimes followed by phone calls". Two of survey respondents agreed with this statement while one strongly disagreed.

Only one of the respondents agreed that they would like to see this security/patrol system further implemented at Shop 8 or other Caltrans yards, while one person disagreed, and the last one was neutral. To that end, there are multiple aspects to consider and on which to collect more data in future deployments, including:

- Situations where the mobile guard security system is more suitable than other means of surveillance
- Capabilities and susceptibilities of mobile guard security systems, especially related to the quality of security footage, possibility of theft and vandalism, and weather-related disruptions
- The response time and system effectiveness to detect and notify the incidents
- The security/safety event response procedure to address different incidents
- Future hardware and software updates that support automated GPS-based patrols and more advanced AI capabilities

All the above can change the impression Caltrans staff who benefit from more secure working environments with fewer break-ins.

Chapter 5:
Conclusions and Future Research

In this project, the AHMCT researchers partnered with Caltrans and successfully investigated a mobile guard system selected for the pilot testing; deployed the Asylon's proposed system with two DroneDogs each with their own DogHouse at Shop 8 in San Bernardino; completed six months of pilot testing; collected patrol data; and evaluated the results with some initial cost-benefit analysis. Overall, this project completed all the tasks originally proposed within the suggested timeline and achieved the intended goals given the data acquired.

When considering the results and conclusion, we first summarize the potential challenges or causes of delay with any future procurement and deployment of Asylon system, including:

- Availability of 110V, 20 Amps outlet (for each charging station) in locations that are strategically appropriate to initiate and end patrols.
- Modifying the event response procedure for the yard in coordination with yard staff, Caltrans Maintenance Dispatch, CHP, and others.
- Bandwidth and signal quality of public LTE in the area or alternatively the feasibility and cost of installing a Starlink system, private LTE, or Wi-Fi network.
- Wind and precipitation that can disrupt the robot's movement or cause damage due to low Ingress Protection (IP) rating (against dust and water).
- Maintenance requirements, including basic training for yard staff who handle the robots and long term costs of replacing or repairing damaged or stolen robots. This issue is mitigated by establishing direct line of communication (ideally phone call) between yard staff in charge and the vendor customer support team and vendor and/or Caltrans property insurance that covers the costs.
- Involvement of Caltrans IT department for any long-term deployment, especially if the security footage is accessible through the Caltrans network.

A future study may include deployment and pilot testing of mobile guard systems from other vendors, such Team 1st technologies which vary in terms of movement equipment, surveillance technology, and supporting software. For Caltrans and the use case studied in this research, robots with wheels may be as useful as robots with legs as the yard terrain often has low slope and no stairs.

Major findings and recommendations for future procurement and deployment of Asylon's mobile robot guard system include:

- This project tested a piloted system with human operators from RSOC remotely piloting the DroneDog during each patrol while also overseeing security monitoring and response to incidents. This is unlike autonomous systems in which surveillance/patrol is run by software and notified incidents are addressed by human agents.
- The main advantage of piloted system is human intelligence that leads to:
    - More target-oriented patrols focused on security hotspots across the yard,
    - Less predictability in patrols for the intruders who try to avoid the robots,
    - Quick reaction to incidents by simultaneous patrol of both DroneDogs to look for intruders,
    - Security monitoring and false alarm filtering carried out by the same pilot with support from the security operations team.
- The most significant disadvantage of the piloted system is that it relies on the presence and awareness of human agents who operate the system throughout the night and weekends. Patrol times are not ideal work hours for anyone, resulting in unpredictable idle times when scheduled patrols are delayed or missed due to human error.
- For the sake of comparison and acquiring data, future deployments should focus on evaluating autonomous patrolling systems (run by software with preprogrammed patrol routes and obstacle avoidance) supported by monitoring services that do not continuously rely on humans for initiating and ending patrols and/or detecting incidents and generating alarms.
- Future deployments should focus on reducing susceptibility to different weather conditions and improving the quality of surveillance footage transmitted wirelessly. Asylon admitted that, on multiple occasions, they had to pause patrols and secure the DroneDog in its DogHouse to protect it from rain and other weather conditions, resulting in loss of patrol time. This idle time gives intruders a window of opportunity to break in during bad weather and should be dealt with by improving the DroneDog hardware.
- The quality of surveillance footage transmitted wirelessly from the robots through LTE service is not on par with modern camera surveillance systems. The live video footage and recorded archive had 720p resolution and low bitrate not showing good-quality images of intruders

from far away. Future deployments can have an improved recording of incidents by using higher resolution cameras accompanied with an on-board memory to store temporary archive with higher video quality.

- The robot's movement causes significant sound disturbance to any equipped microphone. For this reason, Asylon chose not to record audio on security footage for our pilot testing. Future mobile guard surveillance can improve from software updates that allow audio recording when the robot is not using any actuators to position or tilt itself. This can later be expanded by equipping appropriate microphones and speakers on the robot to enable two-way communication between the drone pilot and intruders.
- Boston Dynamics Spot is equipped with additional cameras/sensors that support its movement. The integrated DroneDog system made by Asylon can improve from software updates that allow use of all on-board cameras either for obstruction warning, license plate reading, or to detect movement around the DroneDog making it harder for intruders to avoid surveillance by hiding on the side or behind the robot.
- One major focus for the Asylon system is to investigate the outcome of future updates as the vendor is continuously rolling out software, autonomous patrolling hardware, and notifying incidents. Asylon informed AHMCT upon conclusion of pilot testing that they expect the following enhancements and capabilities to roll out in the short term:
    - Fully automated GPS missions by rolling out updated hardware compatible with DroneIQ software.
    - Increased automation via battery threshold checks for launching pre-programmed automated missions and automated opening/closing of the DogHouse.
    - Deployment of artificial intelligence/machine learning (AI/ML) analytics for people and vehicles, including the ability to geo-reference detections and only alarm if detected inside an alarm zone.
    - Additional audible and visual alerts for falls, people/vehicle detection via AI/ML analytics, and low battery.
    - Ability to play pre-recorded messages and sounds from the PupPack.

Appendix A:
Overview of Candidate Robot Security Systems

Team 1st Technologies – SMP Robotics[3]

Team 1st offers, installs, and maintains outdoor security robots for surveillance. Specifically, they customize Argus S5.2 PTZ IR IS, a robot designed and built by SMP Robotics. Team 1st designs a specific plan for each yard, preprogramming a team of robots to routes, and maintains the robots as needed throughout the subscription period. These intelligent robots coordinate their movements and charging/operating times with each other to provide 24/7 autonomous surveillance of the area.

Team 1st delivers 24/7 "Autonomous Security Officers" (ASOs) with system integrated autonomous interdiction capabilities. Team 1st ASOs are a force multiplier[4], integrating fully autonomous all-weather, all-terrain robots for outdoor perimeter security protection. The system has the following features:

- 24/7 autonomous command/control and maintenance
- GPS accuracy to 2 inches
- Obstacle avoidance
- AI analytics
- Machine learning
- Services:
    - Autonomous robots are fully maintained by Team 1ST
    - 24/7 health and status monitoring with engineering support
    - Quarterly on-site maintenance of all robot systems
    - Automatic technology refresh with subscription renewals

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[3] By the end of the project (mid-2025) it appears that Team 1st Technologies (who modified the system made by SMP Robotics for surveillance) is no longer active online and SMP Robotics is seeking a new partner.

[4] Team 1st ASOs support learning for each other further optimizing routes and response time as more of them work together. Also, they constantly communicate with each other and respond to events with nearby robots together, converging to the location of potential intrusion and providing footage from different angles.

These robots can accompany security guards or work autonomously. Operator attention will be required when an intruder is detected, but robots can handle routine premise patrolling on their own. Team 1st also offers an Autonomous Command Center from which one or more operators can:

- Turn individual robots or entire system on and off.
- Receive potential intrusion notifications, then filter out false alarms or dispatch officers if needed.
- Receive notifications about robots getting stuck or not moving.
- Receive maintenance notifications.

This command center can be located anywhere (connected via internet or any secure connection to the yard) and can be operated by Caltrans employees. It also involves the following features:

- 75" interactive display on mobile stand and with built in Core i7 PC
- Direct integration with surveillance, access control and other systems
- 24/7 security monitoring that verifies and coordinates appropriate response from AI analytics notifications (provided by a 3rd party company that is a Team 1st partner)
- Integrated event data routed directly to 911 dispatchers and first responders
- Facilitation of system wide situational awareness for efficient first response in emergency event
- Reduction of false alarms by 99%
- Machine learning for proactive responses and reducing lockdown times
- AI automated cross-platform
- System wide emergency notification
- Availability of in-video wall options for security operations center up to 220"

A Team 1st subscription includes security robot subscription with thermal PTZ camera and AI surveillance system featuring:

- Autonomous travel within mapped routes
- Avoidance of obstacles and automatic return to route
- 360-degree thermal and video surveillance
- Six (6) 720p panoramic cameras
- Face detection
- Two (2) embedded T9-type computers
- Edge recording using H.264 video compression codec
- ONVIF support
- WebRTC support
- Sound notifications
- IP intercom
- Multi-color beacon
- Wi-Fi antenna 6 dBi

- Interactive display board with Integrated PC to run the Autonomous Command Center
- 24/7 system health monitoring, service, and support
- Video monitoring and event verification
- Dispatch to police, first responders, and emergency services

The robot made by SMP robotics is equipped with a dual-spectral pan/tilt/zoom (PTZ) camera. The arrangement of the PTZ camera allows for circular scanning of the surrounding area in the thermal and visible spectrums. Thermal video surveillance provides reliable detection of people and cars at night with little to no artificial lighting. The thermal camera can detect people within a 200 m (650 ft) and cars within an 800 m (2600 ft) radius. The visible spectrum camera forms a high-resolution image. The video image from both the thermal camera and the visible range camera is processed by the on-board computer. It provides PTZ camera control, human detection, and tracking.

Team 1st takes care of installation, mapping, and activation as follows:

1. Team 1st trains and creates digital twin mapping of area of routes with robot system navigator to enable robot to autonomously navigate in desired routes.
2. Team 1st installs autonomous charging stations for robots within mapped routes area.
3. Team 1st installs GPS refining beacon for system.
4. Team 1st sets up of the Autonomous Command Center and integrates the robots into system architecture.
5. Installation, commissioning, activation, and robot training require approximately a week on-site.

All electrical, Wi-Fi and LTE services are the responsibility of the owner unless stated otherwise, including LTE SIM cards with data for robots and the GPS station.

Apart from the rotating PTZ camera, to ensure the safe operation of the robot, each robot is also equipped with six high sensitivity and resolution cameras for continuous 360° circular surveillance. The image from these cameras is analyzed by a separate on-board computer of a panoramic video surveillance system including analytics for detecting people. This solution allows for detection of an approaching person at a time when the scanning PTZ camera is not facing in that direction.

The outdoor security robots are robust to harsh weather conditions and rough terrain. Each robot is suited for covering a 200-meter route with operating/charging time of 20/4 hours. With the right planning, a team of robots can provide 24/7 patrolling of preprogrammed routes.

As noted, Team 1st takes care of installation, route planning, maintenance, and command center setup. Additionally, they provide Autonomous Officer Monitoring to manage false alarms, but this feature requires sharing security footage with a third party. To work efficiently, teams of robots need to be connected to each other and the control center to coordinate charging, movement, maintenance, etc. Team 1st can set up a private LTE network (to be used in case no Wi-Fi or public LTE networks are available in the yard), taking care of local networking between the robots. Besides the local network, a high-speed internet service or a secure Caltrans network is required for connecting the system to the command center.

Asylon Robotics – Boston Dynamics

Asylon offers the DroneCore system (which covers air components by Asylon and ground security robotics by Boston Dynamics) based on a yearly service subscription model. Customers do not buy or maintain anything, and Asylon provides end-to-end solutions via flexible fully-managed services agreements. Asylon provides everything that is needed to take advantage of security robotics:

- Pre-sales engineering
- On-site assessments
- Deployment and programming
- Regulatory compliance
- Comprehensive insurance with anti-theft protection and liability coverage
- Training and system certification
- Third party alarm integrations
- Robotic Security Operations Center (RSOC) coverage
- DroneIQ software license with updates
- Computer vision analytics for people and vehicles in both EO and thermal
- Live talk-down capabilities between robot and operator
- Live and recorded video archive
- 24/7 customer support year-round
- Assist with building standard operating procedures (SOPs) for robotic security operations at scale.
    - SOPs are made of Tier 1, Tier 2, and Tier 3 Security Events
    - A trained robotic operator in the Asylon RSOC provides immediate human verification to SOPs.

- Customer is immediately notified per pre-defined SOPs, and the robotic asset gathers more real-time intelligence or continues the patrol.

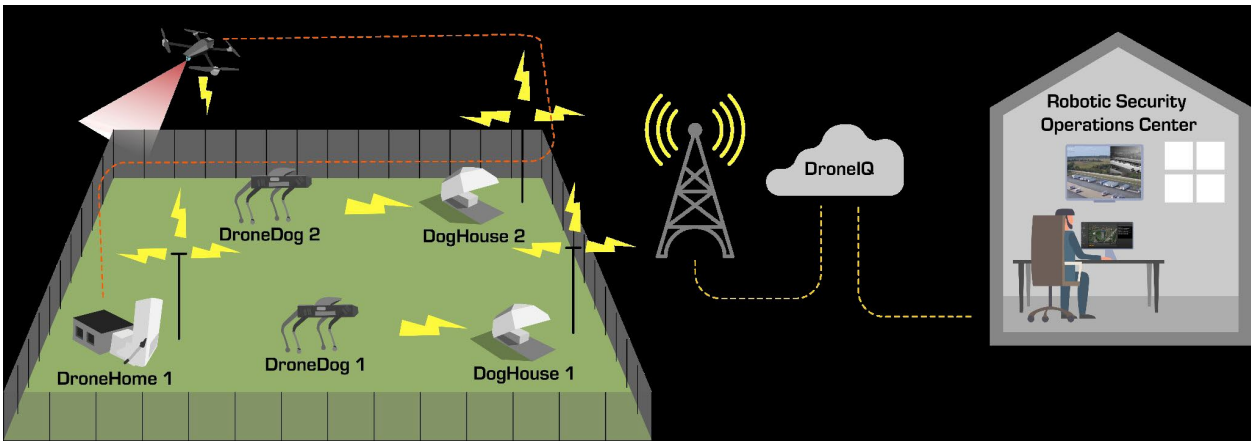

Figure A.1: Asylon DroneCore architecture made of robotic hardware including Asylon DroneDog + DogHouse and Aerial Drone + DroneHome connected through LTE and monitored remotely from RSOC (Copyright permission given by Asylon Robotics)

The RSOC consists of:

- Real-time situational awareness
- A 24/7 response, monitoring, and support mechanism year-round
- Around the clock data collection
- Trained RSOC analysts to manage security robotics and IoT sensor alarms
- Flexibility for ingesting new types of alarms and triggers
- Customer-specific SOPs, e.g., gunshot detection, door checks, gauge inspection, time and location based unauthorized people/vehicle detection, fence line inspections (for cuts/damage), lock checks, parking lot patrols for vandalism and theft protection, etc.

DroneCore Hardware

DroneCore includes five pieces of hardware:

1. **DroneDog** is a high-endurance, agile, and durable quadruped unmanned ground vehicle (Q-UGV) built to automate ground-based security patrols. The system leverages Boston Dynamics' Spot robot along with Asylon's custom-built PupPack, DogHouse, and DroneIQ Software. With live video monitoring, remote teleoperation, daytime/nighttime cameras, automated charging, and more, DroneDog makes perimeter security

easier by bringing the power of advanced robotics to the security operations center.

2. **DogHouse** is the automation infrastructure for the DroneDog. It enables power, weatherization, storage, and is optimized to maximize uptime. The system is all-weather and can safely, securely, and discreetly store the DroneDog during periods of non-use. This infrastructure is designed, engineered, and manufactured specifically to enable the Boston Dynamics Spot platform for repeat operations for patrols, alarm response, and routine inspections.
3. **PupPack** is a security payload that is fixed on top of DroneDog and connects to the cloud for remote operation and live streaming. This security payload is where much of the technology lives that makes DroneDog a highly effective security tool with the features below:
    - 20X optical zoom
    - Daytime/nighttime vision (EO/Thermal)
    - Flashing strobe for awareness
    - Cloud connectivity
    - People and vehicle classifiers
    - Object tracking via independent camera payload
4. **Guardian (previously called DroneSentry)** is a rugged, military-grade unmanned aerial vehicle that acts as a first responder and is wirelessly connected to the DroneHome station. The drone can autonomously fly pre-programmed missions, respond to exterior IoT device triggers or alarms, and provides real-time aerial EO/IR (visual/thermal) video streaming to security personnel. With a 20X optical zoom, the Guardian can rapidly to alarms and collect intelligence.
5. **DroneHome** is a state-of-the-art tactical base station that serves as a land and launch pad for Guardian while managing all aspects of the hardware autonomously. It has a military-grade design that protects Guardian from harsh elements, is connected to the cloud or client network, can send commands to the drone, receives and processes telemetry data, and includes a patented automatic drone battery swapping and charging system that optimizes response time.

Figure A.2: Automated charging bay and weatherization DogHouse and the DroneDog equipped with Asylon's PupPack integrated with Boston Dynamics Spot (Asylon Robotics system deployed at Shop 8 - courtesy of DRISI)

DroneIQ Software

DroneIQ is a cloud-based, open architecture, and advanced software platform that provides real-time security intelligence. It allows users to remotely manage and operate Guardian, DroneDog, DroneHome, DogHouse, and other sensors while processing all payload and telemetry data. For users/subscribers, DroneIQ is often set up to only allow live footage observation and viewing data. The RSOC pilots can access controls and send commands to each device using DroneIQ. As data are stored and managed securely in the cloud, the platform can be accessed anywhere and enables advanced historical reporting and data analysis for any number of deployment sites, enabling the Security Operations and center of the future. Below are some of the features of this intelligent software:

- American-made and secure
    - Designed, developed, and hosted in the United States
    - Data encrypted in transit and at rest
- Remote command and control

    - Remotely launch pre-programmed patrols or divert the security robotics for ad hoc inspections
    - Easy point-and-click mission planning and flight controls
- Robotic First Responder
    - Open API enables easy integration with existing IoT sensor systems, such as perimeter sensors and alarm panels
    - Deploy security robotics to investigate alarms quickly
- Live Video Streamed in Real Time
    - Live video is accessible by multiple remote users simultaneously
    - Cloud-based DVR capability enables easy recall and playback of previous flights

Asylon reports that they released and upgraded several features by mid-2025, including AI/ML classifiers for humans and vehicles as integration into Asylon's existing alarm implementation, geofence and time-based alerts, automated GPS missions with pre-program waypoint-based patrols, and two-way audio communication between DroneDog and RSOC.

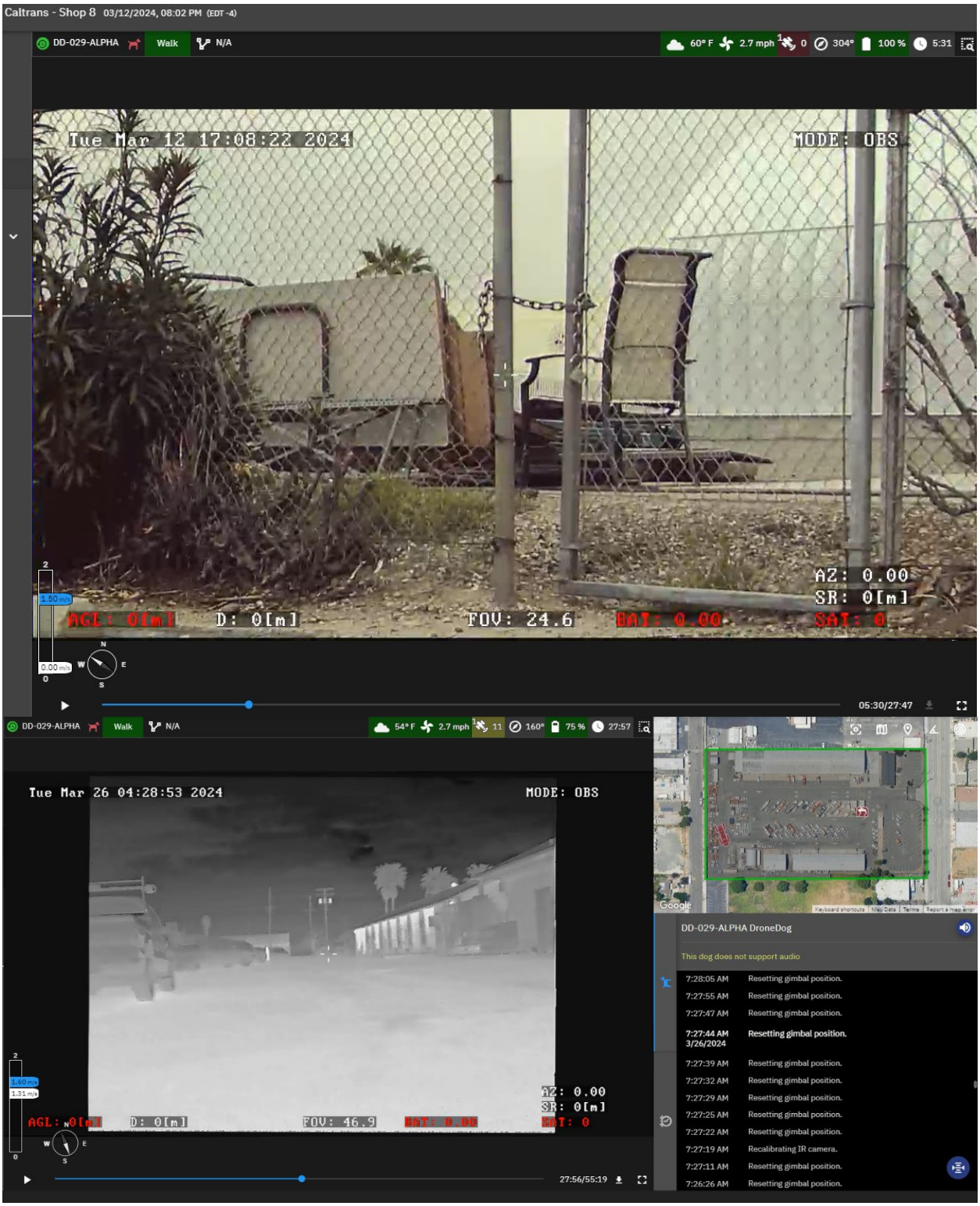

Figure A.3: Sample screenshot from DroneIQ during daylight and nighttime patrols (Source: Asylon Robotics DroneIQ)

One concern raised by the panel was that "From their experience, intrusion detection mostly relies on motion detection either from cameras, lidar, or thermal imaging. This requires that the motion detecting device being static. How would the robot, or robot dog, detect and report motion if the sensors mounted on the robots are moving and the image is not stable? (Uneven ground, gravel etc.)".

Asylon representative responded by stating, "Their tech works well with those existing legacy systems mentioned. So, if there is a trigger from a camera analytic, intrusion detection system, or alarm panel, they can ingest that alarm data in the software and have a robot respond to it. It just requires working with the manufacturer for the software integration to get the two systems talking (communicating). And for motion detection, on the robot itself, there is human/vehicle detection via computer vision and onboard analytics (such as automated license plate recognition). So, it is not motion-based since the robot is already in motion, but it is (continuously) looking for specific objects (people/vehicles in this instance). What that looks like is a pink bounding box with data like object type & confidence level surrounding the object in question". Asylon agent also mentioned that Asylon's RSOC can further clarify the image detection process if needed.

One concern that AHMCT has is regarding the smaller battery size of Asylon DroneDog compared to Team 1st ASO. Standard schedule for Asylon's DroneDog is 30 minutes on - 30 minutes off, because 30-minute patrols typically consume ~30-45% of battery and 30-minute charge time replenishes ~50% of battery. Hence, each DroneDog can maintain 30:30 schedule indefinitely. This means that with the same number of robots, Asylon's system would often be covering the yard with one less robot (charging in its DogHouse) compared to Team 1st ASOs, which are claimed to run for 16-20 hours on one charging session.

Asylon confirms that the 30:30 schedule can maintain the following coverage plans which come at different prices as they include third party monitoring services for filtering out false alarms and dispatching law enforcement.

- 40 hours per week
- 70 hours per week
- 112 hours per week as the standard option
- 168 hours per week as the 24/7/365 option

If the panel selects Asylon's system for the pilot test, a follow-up decision from the panel would be the choice of either 112 hour/week or 168 hour/week plan based on cost information in Chapter 3 of this report and the project budget available to AHMCT for procurement.

The other concern with DroneDog, and generally Boston Dynamics Spot, is the small size and low mass of this robodog. While Asylon offers an insurance for

possible theft or vandalism, the term of such insurance is pending information. Caltrans may rely on their own insurance for yard's equipment as well. This concern wis not as high with the Team 1st robots as they are heavier and bulkier (see Table A.1).

Systems Similarities

- **Smart analytics:**
  - Both systems apply 24/7 visual threat detection facilitated by PTZ cameras and other low-light sensitive sensors.
  - Both systems are supported by intelligent machine learning software that detect humans, vehicles, certain sounds, and other security breaches.
- **Autonomy:** Both autonomously generate alarms, and their monitoring agents filter out false alarms and communicate with law enforcement when abnormal activities are detected.
- **Surveillance patterns:** Both systems have autonomous perimeter or area surveillance capability, depending on preprogrammed routes.
- **Communication:** For communicating with other robots and the outside world, Wi-Fi internet service or high-speed connection via 4G network is required. It is the responsibility of the customer to provide other internet service provider (ISP) options in case the local 4G network in the pilot test yard is insufficient in terms of latency or bandwidth.

Systems Differences

- **Mobility:** Team 1st robots have wheels while Asylon robodogs have legs. The only difference for Caltrans yards is the ability of robodogs to step up/down the stairs and curbs, or navigate over/around objects that the on-site day staff may accidentally place in the middle of a patrol route like a pallet, trash can, or equipment.
- **Camera, Point of View, and Perspective:**
  - Team 1st robots view objects at human height level, while Asylon robots are half as tall.
  - Team 1st robots cover predefined paths with 360° panoramic high definition (HD) footage (using 6 HD sensors) accompanied with a rotating PTZ camera, while Asylon robots are only equipped with one rotating PTZ camera. Sample video footages are shared with the panel via email.
  - Team 1st PTZ camera has a higher optical zoom (30X vs. 20X).
  - Asylon can potentially provide aerial + ground coverage (using their Guardian) by tackling the regulatory obstacle, which mandates that aerial drones must have a registered pilot present at the yard or alternatively Beyond Visual Line of Sight (BVLOS) waiver in the State of California.

- **Power Management**:
  - Team 1st robots need to be taken offline to recharge roughly after 20 hours, and it takes them around 4 hours to fully charge.
  - Asylon robodogs have smaller batteries and can maintain 30-30 minute schedule indefinitely but require a significantly higher number of charging rounds during a 24 hour surveillance. A 30-minute patrol with the DroneDog typically consumes ~30-45% of battery, and a 30-minute charge time replenishes ~50% of battery.
- **Communication:** Team 1st and Asylon robots both require a Wi-Fi or local 4G network (two sims each robot) to exchange real-time data. However, Team 1st has a partner which offers private LTE (for additional cost) in case local mobile providers in the area turn out to have insufficient bandwidth.
- **Operating temperature:** Team 1st robots are more heat and cold resistant than Asylon robodogs (refer to Table A.1).

Table A.1 summarizes several physical and technical features for these systems, some of which are pending information and require further research or pilot testing to confirm.

Table 5.1: Physical and technical features of candidate systems in early 2024[5]

Feature	Team 1st Technologies	Asylon Robotics
Robot model	SMP Robotics Argus S5.2 PTZ IR IS	Boston Dynamics Spot
Robot mass	275 lbs. without batteries, 350 lbs. with batteries	70 lbs. without the battery ~100 lbs. with the camera (PupPack) and battery
Robot dimensions	2.5*4.5 ft^2 & 6 ft high	1.65*3.6 ft^2 & 2 ft high
Camera point of view height	5.5 ft	2.5 ft
Ground clearance	0.45 ft with wheels	Roughly 1 ft with legs
Operating temperature	-25°C to 60°C -13°F to 140°F	-20°C to 45°C -4°F to 113°F
Surveillance Camera/s	6 cameras for 360° panoramic HD + 1 camera with EO/IR 1080P PTZ, 30x optical zoom	1 camera with 1080P EO/IR PTZ, 20x optical zoom

[5] System features were updated for Asylon after completion of pilot testing. However, the Team 1st system was not deployed by Caltrans, and feature details are not confirmed. Additionally, the information in Table A.1 does not account for any future updates to each system during 2024 and beyond. Mobile guard surveillance systems is a fast changing industry both in software and hardware, which is why subscription terms often last one to three years.

Feature	Team 1st Technologies	Asylon Robotics
Operating/ Charging time	20 hours operating, 4 hours charging [details pending pilot testing].	30-minute patrols typically consume ~30-45% of battery, 30-minute charge time replenishes ~50% of battery, Maintains 0.5 h : 0.5 h schedule.
Charging station	Included in the plan, 3*4 ft^2 – 30 ft clearance.	Included in the plan, 3*7 ft^2 – 10 ft clearance.
Traveling speed	2.5 - 4 mph	3.5 mph
Connectivity	4G, LTE, Wi-Fi, Separate Private LTE available for purchase.	4G, LTE, Starlink
Robot mobility	Has wheels, Can traverse rough terrain with moderate slope.	Has legs, Can traverse rough terrain with moderate slope and walk up/down stairs.
Aerial surveillance	N/A	Aerial coverage available via drones which can support ground robodogs, BVLOS waiver is required which Asylon provides.
Ease and cost of installation	Cost included in the subscription fee. Shipping, tax, LTE, and ISP costs not included in cost estimation.	Deployment costs include • Subscriptions per robot for 40, 70, 112 or 168 hours/week • LTE setup and monthly rate • One-time shipping and install Branding and licensing
Initial system design and optimization	Design, installation, & activation by Team 1st.	Design, installation, & activation all carried out by Asylon.
Robots' coordination	Robots coordinate their movement and patrol with each other autonomously.	Robots do not communicate with each other as patrols are piloted by humans.
Image quality (bright sunlight, nighttime, fog, rain)	IR thermal imaging. On-board SSD storage available. [info pending pilot test]	IR thermal imaging available. Footage in 720p resolution with no sound. No local storage (no memory on board).

Feature	Team 1st Technologies	Asylon Robotics
Video transmission and real-time communication	Live video monitoring available. [Info pending pilot test]	Live video monitored by human pilots. User can access system status, live footage, and video archive via DroneIQ.
Performance in relevant climates	Rain proof, heat resistant [detailed info pending]	Patrols are usually paused during heavy rain or snowfall to protect the actuators.
Obstacle detection and avoidance	Uses 360° view and machine learning to optimize patrol	Camera sensors equipped around the robot which detect obstacles and allow climbing and stepping
Artificial Intelligence	Face, vehicle, and sound detection available in software; machine learning for routing [More info pending pilot test]	Image pattern recognition, sound detection, and machine learning not yet available. Software to be updated and microphone to be added in the future.
Remote system monitoring	Remote status monitoring for maintenance. Automatic security notifications.	Safety/security notifications addressed by Asylon RSOC based on event response procedure delivered by Caltrans and AHMCT.
Integration of other security solutions	Info pending pilot test.	Aerial support available. Footage from other cameras can be added to DroneIQ for surveillance. Alarm panels, intrusion detection systems, and sensors can be integrated into DroneIQ.
Feasible customizations	Camera upgradable to 4K. Onboard SSD drive available for local archive.	No local storage and no camera upgrade for the PupPack yet. Microphone and speaker recently added.
Sound detection (e.g., cutting through fence, gunshot, glass break)	Available [More info pending pilot test]	Not available with current software and hardware. Future upgrades planned.
Sound alarm and capability of warning the	Mic and speaker equipped. Two way	Mic and speaker to be equipped in the future to

Feature	Team 1st Technologies	Asylon Robotics
intruders through robots	communication and sound alarm available.	enable two-way communication.
Customer support and maintenance	Included in the subscription. Robots upgraded periodically.	Included in the subscription. Robots are upgraded periodically.
Monitoring agent to clear false alarms and respond to threats	Available [More info pending pilot test]	Asylon operate their own 24/7 Robotic Security Operations Center (RSOC)
Incident Response and cooperation with law enforcement	Monitoring agent clears out false alarms and contact law enforcement if needed. [Response time pending pilot test]	Monitoring agent performs individual site inspections for points-of-interest (e.g., gates, locks, doors, etc.) and clears out false alarms and contacts law enforcement if needed based on delivered event response procedure.
Chance of robot theft or vandalism	Low risk due to big size and mass, insurance info not confirmed.	Moderate risk due to small size and mass, GPS on board to track the robots, vendor has insurance coverage.
Charging station requirements	Regular AC power and 30 ft clearance space	One 110V, 20A outlet for each DogHouse, 20 ft clearance space.
wireless/LTE internet communication	2 sims required for each robot if LTE used. Private LTE is offered as an alternative to public LTE services.	One LTE sim required for each robot. Wi-Fi modem is equipped to be used indoors or where outdoor wireless network is available. Starlink connection can be used in areas with no LTE or Wi-Fi network.

Appendix B:
Standard Operating Procedures (SOPs) for Caltrans Shop 8 – Security/Safety Event Response Procedure

Shop 8 contact list of who will support the operation of robots and respond to non-urgent events and are also notified about urgent incidents are as follows:

- Person A, Person B, Person C.

Only AHMCT researchers currently have access to the DroneIQ secure portal where the video archive is accessible. Asylon may need to create accounts for others upon request. AHMCT researchers are still gathering more feedback from events and may adjust this response process as the panel sees fit upon requesting Asylon to update their procedures.

The following is proposed by AHMCT and Shop 8 attendants and approved by the Caltrans panel as a response procedure to urgent and non-urgent events:

Urgent Security/Safety Events (Confirmed/obvious cases of human/vehicle intrusion, gunshot, fire, human injury, robot theft/vandalism, etc.)

1. Asylon will immediately call CHP at **XXXX**.
2. While CHP is on the line, Asylon will contact the 24/7 Caltrans Maintenance Dispatch at **XXXX** immediately after CHP is contacted. This will allow dispatch to track the situation and provide CHP with additional information if requested (including gate access if CHP already doesn't have it).
3. As soon as the ongoing event is confirmed to be an intrusion inside the yard, Asylon will retreat and secure the robots either out of sight or in their Doghouse without further engagement or interaction with the potential threats to protect the robots until further notice from CHP officers present in the yard. Please note this may result in a time window (5-15 minutes as CHP is dispatching officers) when RSOC pilot has no eyes on the yard and will not provide any updates.

4. As soon as the yard opens (the next working day), Asylon will follow up with yard attendants via email and phone call as deemed necessary. Asylon's Ops or RSOC will contact yard staff directly (all four in the contact list above) while copying Persons as specified in all the emails. Asylon may provide images and link to DroneIQ footage for everyone.

Non-Urgent Events (Unsecured gates/vehicles, suspicious activity/presence outside the fence, early morning/late evening observation of human/vehicle suspected to be yard staff)

1. Asylon will immediately notify the yard superintendent(s) via email in the contact list. This notice will be a direct communication between RSOC and yard staff. Persons specified will be copied in the entire email conversation.
2. As soon as the yard opens for their regular daily shift, Asylon will further notify yard staff via phone call and provide images and link for footage.

SOPs Tier List (Proposed by AHMCT based on the above-mentioned procedures)

We may break down urgent events, when CHP is getting involved, as follows:

- **Tier 1:** Dangerous situations compromising safety, e.g., detection of fire, gunshot, injured/immobile humans, etc.
- **Tier 2:** Confirmed or highly suspected cases of theft/vandalism, e.g., weekend or late evening break-ins and any suspicious presence after 8 PM[6], detection of humans inside the yard or newly broken fence in the perimeter (that was not previously recorded especially late at night), damaged cars, hearing electric saw, any attempt to steal or disturb the robot's operation with laser or other tools, detection of dangerous animals inside the yard.

We may categorize non-urgent incidents that do not require involvement of CHP as follows:

- **Tier 3:** Suspicious presence outside the fence (without break-in), early morning/late evening observation of humans/vehicles suspected to be

[6] Added following the simulated break-in.

yard staff during working days (often involving trucks or uniforms with Caltrans logo on it), detecting unsecured vehicles, gates, or fences (especially if the problem is not resolved within 24 hours of yard being open). As a reminder yard's working hours are currently 5:30 AM – 2:30 PM during weekdays. Weekends and holidays are off-hours for Shop 8. Detection of animals that are not a serious threat to yard staff can be considered non-urgent (mainly during off hours).

- **Tier 4:** Power outage, heavy precipitation, or failure due falling or natural causes that require attention to DroneDog or Doghouse. This involves all incidents that disrupt the patrols but do not compromise yard security or safety of yard staff. These incidents may require cooperation from yard attendants or dispatching maintenance crew from Asylon.