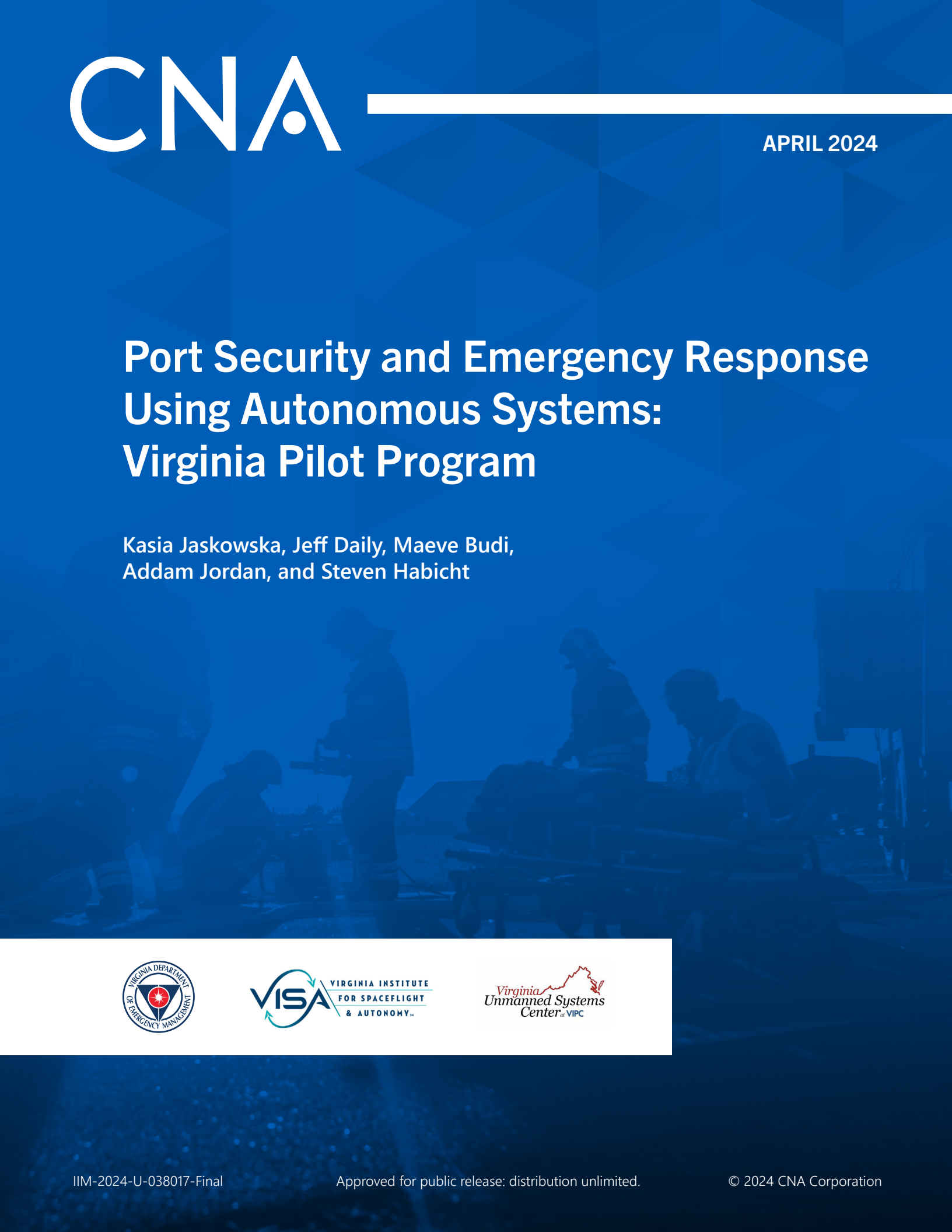
CNA

APRIL 2024

# Port Security and Emergency Response Using Autonomous Systems: Virginia Pilot Program

Kasia Jaskowska, Jeff Daily, Maeve Budi, Addam Jordan, and Steven Habicht



IIM-2024-U-038017-Final

**Abstract**

The Port Security and Emergency Response (PS&ER) Using Autonomous Systems (UxS) project focused on applying innovative UxS solutions to enhance the safety, security, and operational effectiveness of the Port of Virginia. This report documents a two-year collaborative effort to advance the use of autonomous vehicles from the conceptual stage to real-world demonstrations. The project began with a series of workshops to first identify and prioritize public safety and emergency response challenges and then generate requirements for UxS technologies to address these challenges. Next, the project funded five cross-domain solutions (air, ground, and maritime) that demonstrated UxS capabilities deployed to detect and observe public safety or emergency response events that affect the Port of Virginia. Based on the outcomes of the project, we explore a holistic integrated solution for PS&ER in the context of port operations and scenarios that enhances the safety, security, and overall effectiveness of the port.

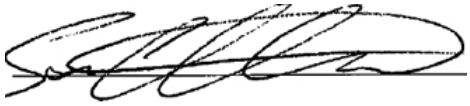


This report was funded by an internal CNA research grant.

**Cover image:** Shutterstock.



**Approved by:** **April 2024**



Steven Habicht, Director
Center for Enterprise Systems Modernization
Institute for Public Research

Request additional copies of this document through inquiries@cna.org.

# TABLE OF CONTENTS

PAGE INTENTIONALLY LEFT BLANK.

# PROJECT OVERVIEW

The Port Security and Emergency Response (PS&ER) Using Autonomous Unmanned Systems (UxS)[1] project (hereafter referred to as the PS&ER UxS Project) showcased innovative unmanned technologies in an effort to enhance the safety, security, and operational effectiveness of the Port of Virginia. The project was a two-year collaborative effort to advance the use of autonomous vehicles from the conceptual stage to real-world demonstrations. The effort was led by the Virginia Unmanned Systems Center and Public Safety Innovation Center at the Virginia Innovation Partnership Corporation (VIPC), Virginia's Homeland Security Division, the Virginia Department of Emergency Management (VDEM), the Virginia Institute for Spaceflight and Autonomy (VISA), the Virginia Port Authority, and CNA's Institute for Public Research. The PS&ER UxS Project was launched to assess the potential benefits of using UxS to address the security and emergency response challenges that come with protecting the safety and operational readiness of the Port of Virginia.

Also known as the "most modern gateway in America,"[2] the Port of Virginia stands as a pivotal economic and strategic asset within the Hampton Roads region, contributing billions of dollars to Virginia's economy and playing an essential role in global trade. The port is of paramount importance: nearly 30 international shipping lines offer direct service to and from Virginia, connecting the port and the state to more than 200 countries, and the port handles more than 40 vessels weekly.[3] It significantly affects Virginia's economy because it exports locally manufactured goods and processes and distributes imports for Virginia businesses.[4] The port's strategic location along the East Coast enables swift delivery to 75 percent of the US population within two days, allowing companies to access key inland markets and distribution hubs across the Midwest and the Eastern seaboard.[5] On completion of dredging operations in 2024, the Port of Virginia will reclaim its status as the deepest port on the East Coast,[6] resulting in increased vessel traffic. The PS&ER UxS Project tested UxS technologies in an effort to enhance security measures in the Port of Virginia while recognizing the unique public safety challenges maritime facilities face and the potential benefits of UxS solutions in safeguarding vital assets.

During the summer 2021 UxS PS&ER Workshop, project sponsors sought to identify and prioritize public safety and emergency response challenges, referred to as "pain points," as well as generate requirements for UxS technologies to address these pain points (see Figure 1). At the subsequent Unmanned Systems Industry Engagement Summit:

[1] UxS refers collectively to air, surface, and underwater unmanned systems.

[2] Virginia Port Authority, "Experience the Most Modern Gateway in America," Port of Virginia Official Site, accessed Apr. 14, 2024, https://www.portofvirginia.com/gateway/.

[3] Virginia Port Authority, "About the Agency," Commonwealth of Virginia Official Site, accessed Apr. 11, 2024, https://www.virginia.gov/agencies/virginia-port-authority-/#:~:text=The%20Port%20of%20Virginia%20is,200%2B%20countries%20around%20the%20world.

[4] Virginia Port Authority, "Report: Port Helps Drive Economic Investment and Job Creation Throughout the Commonwealth," Port of Virginia Official Site, May 23, 2023, https://www.portofvirginia.com/who-we-are/newsroom/report-port-helps-drive-economic-investment-and-job-creation-throughout-the-commonwealth-2/.

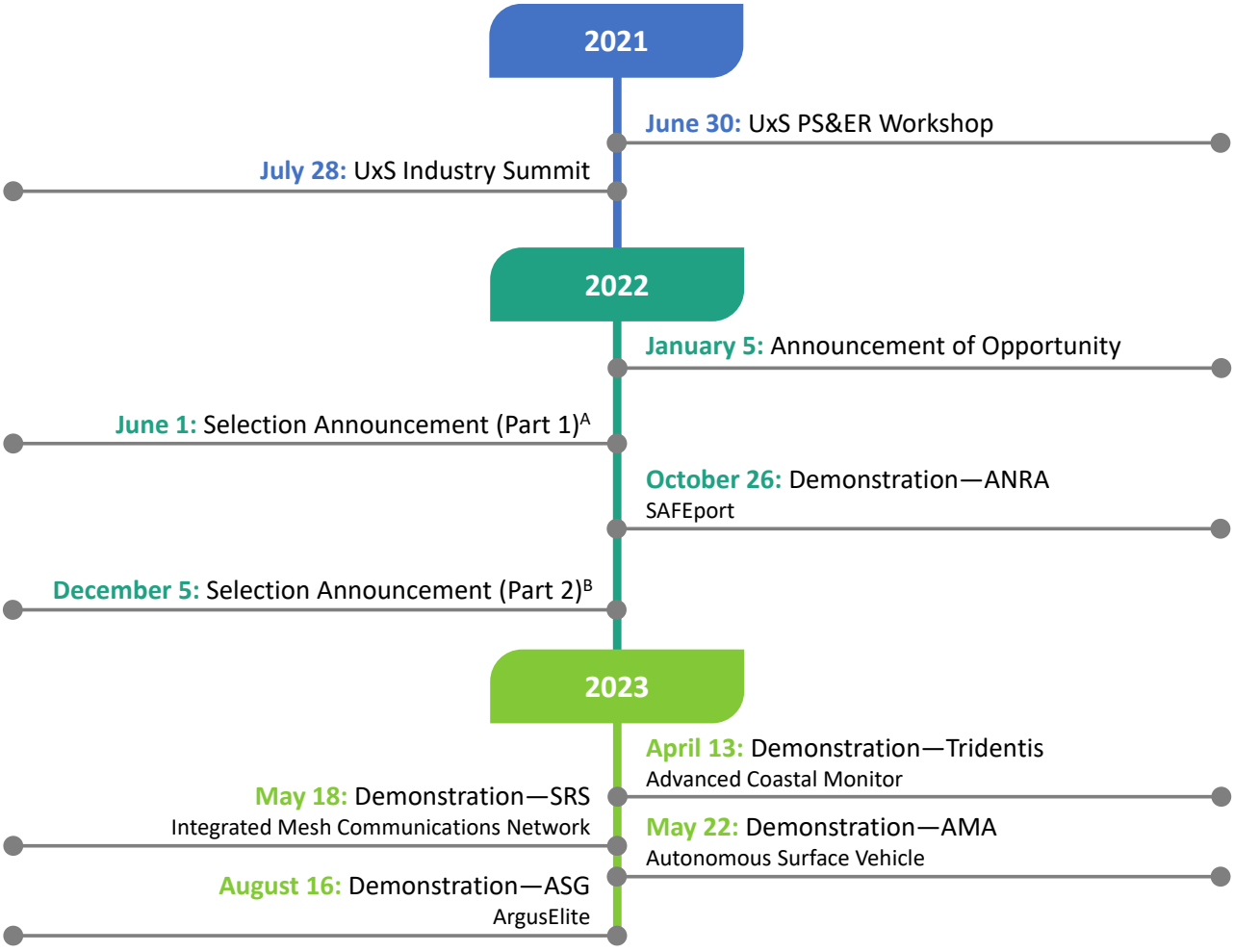
[5] "Experience the Most Modern Gateway in America."

[6] Joe Garvey, "ODU's Virginia Institute for Spaceflight & Autonomy Helps Lead Unmanned Systems Port Security Demonstration," Old Dominion University, Nov. 14, 2022, https://www.odu.edu/article/odus-virginia-institute-for-spaceflight-autonomy-helps-lead-unmanned-systems-port-security.

Seeking Innovative Solutions for Port Security and Emergency Response (hereafter referred to as the UxS Industry Summit), sponsors communicated the pain points to attending members of public organizations, industry, and academia. Attendees provided feedback about the technical and operational readiness of UxS platforms, sensors, and information management systems to solve these challenges.

The PS&ER UxS Project used the aforementioned pain points and UxS solution capability requirements as the basis for the PS&ER Announcement of Opportunity (AO). The selection committee received numerous submissions for proposed solutions in response to the AO. Ultimately, the PS&ER UxS Project funded five cross-domain solutions (air, ground, and maritime) that could demonstrate UxS capabilities to observe and detect public safety or emergency response events that affect the Port of Virginia, forming the foundational basis for the PS&ER use cases. The proposed UxS solutions were provided an opportunity to demonstrate the application of UxS platform(s), sensor(s), and data

Figure 1. High-level timeline of the PS&ER UxS Project




*A Selection announcement included ANRA Technologies (ANRA) and Alliance Solutions Group (ASG).*
*B Selection announcement included Analytical Mechanics Associates (AMA), Sentinel Robotics Services (SRS), Tridentis.*

Source: CNA.

and information management capabilities to address PS&ER pain points in the context of five use cases, including marine environment, hazardous material (HAZMAT), search and rescue (SAR), security, and port operations and reconstitution efforts.

The purpose of this report is to demonstrate how various innovative cross-domain UxS solutions can be leveraged to develop holistic solutions for PS&ER operations that can be applied across all port environments. The report includes an overview and comparative analysis of the five cross-domain UxS solutions demonstrated during the PS&ER UxS Project. Because the solutions were funded and developed independently of each other, the comparative analysis helps identify synergies across the solutions' capabilities as well as opportunities to combine these solutions into a comprehensive PS&ER solution that can be used to improve port security and operations. At the conclusion of this report, we assess the resulting proposed integrated cross-domain UxS solution in the context of two scenarios. The scenarios provide an opportunity to demonstrate how the UxS solution, inspired by the innovative cross-domain capabilities originally derived from the PS&ER UxS Project, can holistically improve the safety, efficiency, and reliability of port operations during both routine (i.e., day-to-day) and incident response operations. They showcase the integrated use of various UxS technologies to enhance the safety, security, and operational effectiveness of port environments.

## Requirements elicitation

On June 30, 2021, Virginia's Homeland Security Division, VIPC, VISA, and CNA hosted the UxS PS&ER Workshop. The purpose of the workshop was to identify public safety activities that lend themselves to using unmanned technologies to enhance safety and security in the Hampton Roads maritime environment. The workshop focused on five PS&ER use cases: marine environment, HAZMAT, SAR, security, and port operations and reconstitution efforts. The Workshop Planning Team, led by members of CNA, developed the following objectives:

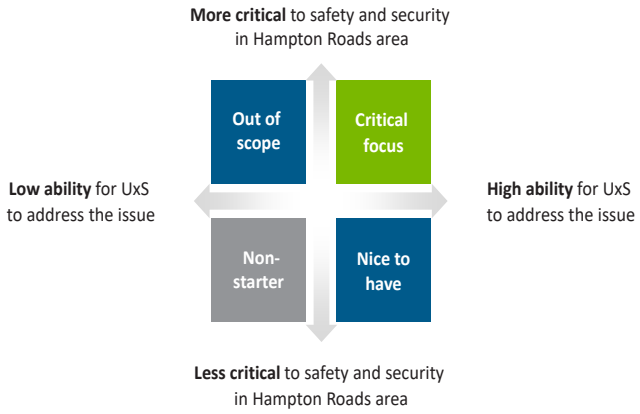
1. Identify opportunities to improve the operational effectiveness and efficiency of maritime safety and security activities in the Hampton Roads area.

2. Identify specific requirements and capabilities required to optimize these activities.

The workshop consisted of two parts: (1) identifying and prioritizing pain points and (2) identifying requirements for any solution that might address those pain points.

Participants from 20 federal, state, and local agencies, representing a diverse spectrum of stakeholders from law enforcement, emergency response, and maritime industry communities, as well as technology innovation hubs, identified several major pain points that are critical to the safety and security of those in the Hampton Roads area and that UxS solutions could address. These pain points were prioritized by workshop participants according to how critical the pain points are to safety and security in Hampton Roads and the possibility that they could be addressed by a UxS solution. We plotted results on a matrix (see Figure 2) and assessed the matrix to identify the pain points that should be considered a critical focus (see green quadrant). Participants further assessed the identified pain points and developed a list of common needs and capabilities that UxS solutions would require to meet the various needs of different port safety and security operations.

Figure 2. PS&ER pain point assessment matrix




Source: CNA.

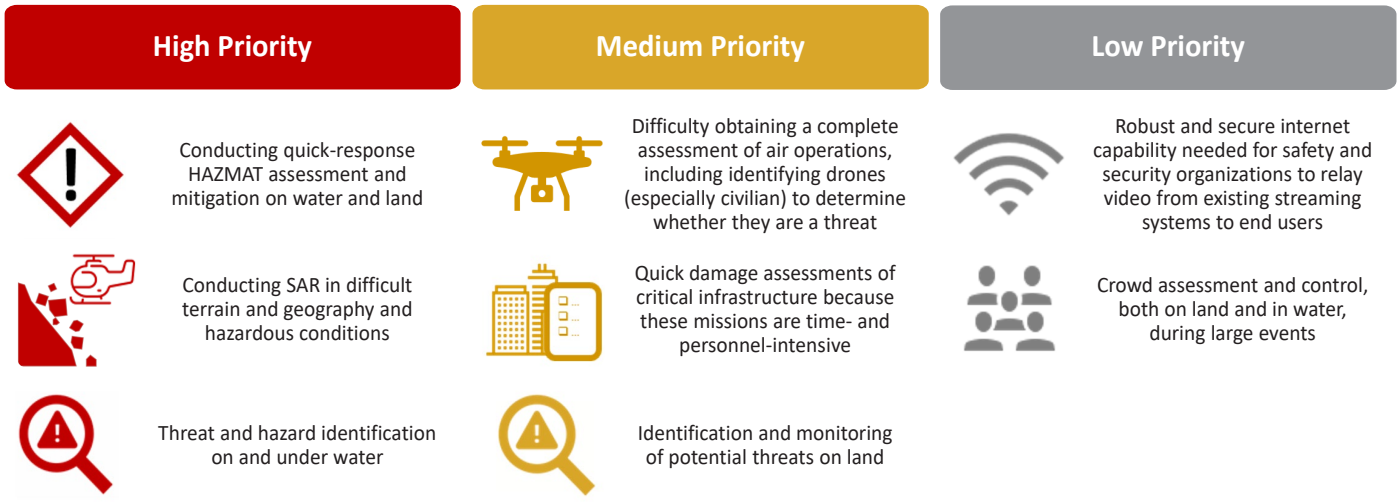
## PS&ER pain points and UxS solution requirements

The UxS PS&ER Workshop identified eight pain points that present security and emergency response challenges in the Port of Virginia and also could be addressed by UxS solutions. The pain points are identified as high, medium, or low priority based on information gathered during requirement elicitation events (see Figure 3).

The UxS PS&ER workshop also identified a corresponding set of 12 common requirements that most UxS solutions would need to appropriately address the challenges of operating at the Port:

1. A solution must have adverse weather and environment operations.
2. It must have 24-hour (day and night) operations.
3. It must be ruggedized for water, dust, and so forth.
4. It must have mobility and navigation on uneven terrain, in currents, and in cluttered and confined spaces.
5. It must have portability and maintainability.
6. It must have real-time capability for mapping terrain, sea floor, and coast.
7. It must be easy to use (training, interfaces, operations, etc.).
8. It must have interchangeable and interoperable sensors.

Figure 3. PS&ER pain points




Source: CNA.

9. It must be upgradable and extendable (modularity).
10. It must have secure and persistent comms.
11. It must have automation—autopilot with Detect and Avoid.
12. It must have a sweet spot range of 1 to 3 miles and 1 to 12 hours of endurance.[7]

Overall, the information collected from the workshop participants yielded important insights into safety and security challenges in the Port of Virginia and the surrounding Hampton Roads area, and it highlighted the capabilities and requirements that UxS solutions need to provide in order to address those challenges.

## UxS vendor selection

After the workshop, the UxS Industry Summit took place in Norfolk, Virginia, on July 28, 2021. The summit provided an opportunity to present the workshop findings to UxS vendors and hold a dialogue between the Hampton Roads safety and security stakeholder community and vendors who might be able to meet the UxS solution requirements outlined during the workshop. The summit confirmed the validity of the previously identified pain points and challenges emergency responders face in the port environment.

On January 5, 2022, VISA and VIPC released the AO for the PS&ER UxS Project. The AO asked respondents to demonstrate how to apply UxS capabilities (e.g., UxS platforms, sensors, data, and information management) to address the eight pain points identified in the UxS PS&ER Workshop and outlined in the subsequent UxS PS&ER Summit. The AO specified that any solutions proposed should demonstrate UxS capabilities that can be deployed to observe and detect PS&ER use cases related to HAZMAT, security (i.e., bomb squad), SAR, marine environment, and port operations and reconstitution efforts within and around the Port of Virginia.

Companies and teams submitted 19 UxS solution proposals in response to the PS&ER AO. Following review, the PS&ER selection committee selected five cross-domain solutions to receive PS&ER funding. We released the selections over the course of two separate announcements because of changes in funding. The first announcement, released on June 1, 2022, identified ANRA Technologies and Alliance Solutions Group (ASG) as the initial VIPC funding recipients.[8] Following the initial selections, VDEM provided additional funds that enabled the selection of three additional proposals. The second announcement, released on December 5, 2022, identified Analytical Mechanics Associates, Inc. (AMA), Sentinel Robotic Solutions, LLC (SRS), and Tridentis as recipients of the additional VDEM funds.[9] The PS&ER UxS Project culminated in a set of real-world demonstrations of each solution to an audience of PS&ER stakeholders in and around the Hampton Roads area of the Port of Virginia. The demonstrations were scheduled over the course of 10 months, with the first demonstration, presented by ANRA, taking place on October 26, 2022, and the final demonstration, presented by ASG, taking place on August 16, 2023.

---

[7] The endurance requirement varies by pain point.

[8] Angela Costello, "VIPC and VISA Announce Proposals Selected for UxS Port Security and Emergency Response Opportunity," GlobeNewswire, June 1, 2022, https://www.globenewswire.com/en/news-release/2022/06/01/2454350/0/en/VIPC-and-VISA-Announce-Proposals-Selected-for-UxS-Port-Security-and-Emergency-Response-Opportunity.html.

[9] Angela Costello, "Unmanned Systems for Port Security and Emergency Response Project in Hampton Roads Expands with Three More Companies," EIN Presswire, Dec. 5, 2022, https://wreg.com/business/press-releases/ein-presswire/604868684/unmanned-systems-for-port-security-and-emergency-response-project-in-hampton-roads-expands-with-three-more-companies/.

# PS&ER CROSS-DOMAIN SOLUTIONS OVERVIEW

The PS&ER UxS Project selection committee chose five UxS vendors that represent Virginia's leadership in the UxS industry. The innovative UxS solutions developed and demonstrated by the vendors exemplify the cutting-edge technology resources and expert and experienced workforce available in Virginia.

The first part of this section provides an overview of the selected vendors alongside a high-level description of their proposed UxS solutions.

The second part of this section provides a comparative analysis of the vendor UxS solutions in relation to the objectives and requirements of the PS&ER AO. The objective of the analysis is to determine the solutions' collective success in meeting the PS&ER criteria and to identify opportunities to form an integrated UxS solution that leverages the strengths of each independent UxS solution.

## Autonomous Modular Sensor Platform (Analytical Mechanics Associates)

AMA, based in Hampton, Virginia, submitted its proposal, "Low-Cost Autonomous Modular Sensor Platform for Port Security and Emergency Response," for a low-cost autonomous surface vessel (ASV) that is easy to deploy, enables autonomous navigation for operations, and is modular to enable customization for end user needs. Figure 4 provides a high-level overview of AMA's UxS solution, including its alignment to PS&ER pain points and AO requirements.

Figure 4. High-level overview of AMA solution

| Analytical Mechanics Associates, Inc. (AMA)<br>Proposal: *Low-Cost Autonomous Modular Sensor Platform for Port Security and Emergency Response* | | | |
|---|---|---|---|
| **Proposal Solution** | Develop a low-cost modular Autonomous Surface Vehicle (ASV) with an on-board, solar-powered electric propulsion system, an array of sensors, processors and controllers, and communication links. The system will also include an autonomous navigation system with positional awareness using sensors and cameras for above- and below-water coverage, environmental monitoring sensors, and a sonar system to identify underwater hazards that enables both autonomous navigation as well as operator-controlled navigation in the event of an emergency response. | | |
| **Demonstration Objectives** | Use the proposed solution across three diverse use cases to support (1) identification and real-time mapping of spot contaminants and radiation sources in the water, (2) underwater and surface mapping, and (3) emergency response and inspection. | | |
| **PS&ER Pain Points** | High<br>☑ Quick-response HAZMAT assessment and mitigation<br>☑ SAR in difficult terrain and geography, as well as in hazardous conditions<br>☑ Threat and hazard identification on and under water | Medium<br>❑ Air operations assessment; UAS detection technologies<br>☑ Quick critical infrastructure damage assessments<br>☑ Identification and monitoring of potential threats on land | Low<br>☑ Robust and secure internet capability to support data exchanges<br>❑ Crowd assessment and control on land and water |
| **Requirements and Features** | ❑ Support adverse weather and environment operations<br>☑ Support 24-hour (day and night) operations<br>❑ Be ruggedized for water, dust, etc.<br>☑ Have mobility and navigation on uneven terrain, in currents, and in cluttered and confined spaces | ☑ Have portability and maintainability<br>☑ Have real-time capability for mapping terrain, sea floor, and coast<br>☑ Easy to use (training, interfaces, ops, etc.)<br>☑ Swappable and interoperable sensors | ☑ Upgradable and extendable (modularity)<br>☑ Secure and persistent comms<br>☑ Support automation—autopilot with Detect and Avoid<br>☑ Provide a sweet-spot range of 1 to 3 miles and 1 to 12 hours of endurance |

Source: CNA.

The technical capabilities and features of AMA's ASV include the following:

- **360-degree coverage:** uses red, green, and blue wavelength (RGB) cameras to offer full coverage above and below the water surface.
- **Autonomous navigation:** employs Light Detection and Ranging (LIDAR) and Global Positioning System (GPS) for autonomous navigation with positional awareness.
- **Communication and data management:** uses off-the-shelf 4G Internet to communicate with the data management server, enabling the upload of geotagged sensor data and photographs.
- **Emergency response:** enables immediate operator control via a secure very high frequency frequency-hopping link for real-time access to navigational and sensory telemetry in emergency situations.
- **Hazard identification:** features a side-scan sonar system for detecting underwater hazards.
- **Power and propulsion:** uses an onboard solar power system and electric propulsion for sustainable energy usage.
- **Control mode selection:** allows operator to switch between autonomous navigation and manual remote control with first-person view for operator intervention.
- **Sensor suite:** includes a comprehensive array of sensors for environmental monitoring and navigation purposes.

For the demonstration of its UxS solution, AMA focused on addressing PS&ER use cases related to environmental monitoring, research in support of marine and port operations, and emergency response. AMA demonstrated how its UxS solution will autonomously patrol prespecified areas in the port while avoiding watercraft and other obstructions. During its patrol, the ASV can conduct comprehensive environmental monitoring of air and water quality, as well as pollution levels, using its onboard sensor package, while simultaneously recording GPS coordinates and uploading sensed data to the AMA-provided Data Management Server. During the autonomous patrol, the ASV's onboard sonar devices can be used to perform underwater and surface mapping to develop and compare depth maps and alert the port if any unusual or new underwater objects are encountered. AMA's UxS solution supports emergency response by enabling the port to inspect a specific portion of the waterway through its manual or first-person view mode.

## UxS Port Mission Management (ANRA Technologies)

ANRA Technologies, Inc., based in Reston, Virginia, submitted its proposal, "UxS Port Mission Management with Integrated and Distributed Common Operating Picture," for a UxS Port Mission Manager with an integrated and distributed common operating picture (COP). ANRA's solution is powered by a single software platform called SAFEport that connects air, surface, and ground UxS for PS&ER missions. The software develops a 4D (time/space) COP that can be distributed to authorized users by integrating the locations of every connected UxS and crewed aircraft operating within the mission airspace. Figure 5 provides a high-level overview of ANRA's UxS solution, including its alignment to PS&ER pain points and AO requirements.

Figure 5. High-level overview of ANRA solution

| ANRA Technologies, Inc. (ANRA)<br>Proposal: *UxS Port Mission Management with Integrated and Distributed Common Operating Picture* | | | |
|---|---|---|---|
| **Proposal Solution** | Utilize SAFEport, a single software platform, to connect to UxS for manual or autonomous operations and transmit live video or data throughout its network in support of PS&ER missions | | |
| **Demonstration Objectives** | Deploy a standards-based platform using a modular software design that adapts to a variety of UxS and sensors that address all AO pain points and common requirements and features while also providing interoperability, ease of use, and increased safety and coordination capabilities. | | |
| **PS&ER Pain Points** | High<br>☑ Quick-response HAZMAT assessment and mitigation<br>☑ SAR in difficult terrain and geography, as well as in hazardous conditions<br>☑ Threat and hazard identification on and under water | Medium<br>☑ Air operations assessment; UAS detection technologies<br>☑ Quick critical infrastructure damage assessments<br>☑ Identification and monitoring of potential threats on land | Low<br>☑ Robust and secure internet capability to support data exchanges<br>☑ Crowd assessment and control on land and water |
| **Requirements and Features** | ☑ Support adverse weather and environment operations<br>☑ Support 24-hour (day and night) operations<br>☑ Be ruggedized for water, dust, etc.<br>☑ Have mobility and navigation on uneven terrain, in currents, and in cluttered and confined spaces | ☑ Have portability and maintainability<br>☑ Have real-time capability for mapping terrain, sea floor, and coast<br>☑ Easy to use (training, interfaces, ops, etc.)<br>☑ Swappable and interoperable sensors | ☑ Upgradable and extendable (modularity)<br>☑ Secure and persistent comms<br>☑ Support automation—autopilot with Detect and Avoid<br>☑ Provide a sweet-spot range of 1 to 3 miles and 1 to 12 hours of endurance |

Source: CNA.

The technical capabilities and features of ANRA's SAFEport include the following:

- **Comprehensive situational awareness:** provides access to information through purpose-built map layers (e.g., ArcGIS, Federal Aviation Administration (FAA) charts), aircraft and maritime surveillance data (e.g., radar, Automatic Dependent Surveillance–Broadcast (ADS-B), automatic identification system), and weather information.
- **Data integration:** integrates multiple UxS platforms and associated sensor data into a 4D environment.
- **Distributed information architecture:** uses internet-based sharing, accessible through web or mobile apps, to enable real-time collaboration and decision-making among authorized stakeholders.
- **Hazard identification:** uses HAZMAT sensors and sonar (e.g., side scan, multibeam underwater) to identify various hazards.
- **Research-vetted platform:** leverages ANRA's UAS Traffic Management platform that was developed using years of FAA and National Aeronautics and Space Administration (NASA) research, testing, and credentialing, ensuring reliable and safe support for unmanned aircraft system (UAS) operations.
- **Route planning and conflict resolution:** uses intelligent algorithms to deconflict UxS with known digital routes, comply with regulations, and avoid restricted zones and hazards through dynamic rerouting.
- **Scalability of operations:** supports an unlimited number of participating UxS without geographic limits.

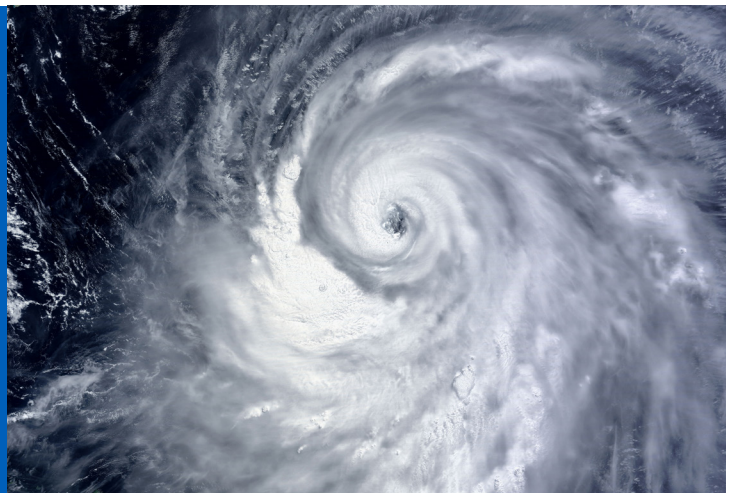
- **Secure video streaming:** supports streaming of live video feeds from multiple UxS equipped with secure high-definition (HD) camera and videos and infrared (IR) cameras.

ANRA demonstrated its UxS capabilities through two use cases. The first use case focused on the location and identification of HAZMAT in the port environment. ANRA simultaneously deployed a UAS to conduct airborne monitoring and an unmanned ground system (UGS) to conduct a ground-based search of the container area where the HAZMAT was "reported." SAFEport established a comprehensive COP by creating map layers that displayed information received from the UxS solutions, which included live video streams, ADS-B location data, and HAZMAT indicator sensor data. The data were used to identify the location of simulated HAZMAT.[10] ANRA's second use case focused on conducting an underwater debris field survey to assess hurricane damage to a major shipping channel. Specifically, the UxS solution would verify the integrity of an aid to navigation (ATON) (e.g., channel buoy). As with the previous use case, SAFEport established a COP based on sonar data received from the unmanned maritime system (UMS) that was deployed to conduct a manually operated, sea-based underwater hazard assessment survey. The sonar video provided bathymetric images of the sea floor that were used to verify that the channel buoy and ATON chain were intact.

## Hazmat UAS Solution (Alliance Solutions Group)

ASG, based in Newport News, Virginia, submitted its proposal, "Hazmat UAS Mission Demo and Validation," for the ArgusElite, which is a fully integrated UAS with nine chemical, radiological, and spectral (i.e., electro-optical/IR (EO/IR)) sensors that are designed to accurately detect, identify, quantify, and map hazards in real time for enhanced situational awareness. In addition, based on a collaborative effort with the Port of Virginia to identify HAZMAT detection and response capabilities, limiting factors, and constraints, ASG developed the Maritime Security and Emergency Response UAS concept of operations (CONOPS) for the integration of UAS across response phases for a HAZMAT incident. Figure 6 provides a high-level overview of ASG's UxS solution, including its alignment to PS&ER pain points and AO requirements.

ANRA's second use case focused on conducting an underwater debris field survey to assess hurricane damage to a major shipping channel.



[10] To simulate this use case, ANRA placed simulated HAZMAT targets in and around containers. The UAS and UGS were deployed in response to a report of a harsh smell and fluid on the ground near containers.

Figure 6. High-level overview of ASG solution

| Alliance Solutions Group (ASG)<br>Proposal: *Hazmat UAS Mission Demo and Validation* | | | |
|---|---|---|---|
| **Proposal Solution** | Develop the ArgusElite®, a fully integrated UAS with infrared sensors that detect, identify, quantify, and map hazards in real time for enhanced situational awareness. | | |
| **Demonstration Objectives** | Demonstrate the use of the ArgusElite Hazmat UAS solution to enhance safety and security and improve the operational effectiveness of use cases related to HAZMAT response and recovery, SAR, and general response operations. | | |
| **PS&ER Pain Points** | High<br>☑ Quick-response HAZMAT assessment and mitigation<br>☑ SAR in difficult terrain and geography, as well as in hazardous conditions<br>☑ Threat and hazard identification on and under water | Medium<br>❑ Air operations assessment; UAS detection technologies<br>☑ Quick critical infrastructure damage assessments<br>☑ Identification and monitoring of potential threats on land | Low<br>☑ Robust and secure internet capability to support data exchanges<br>❑ Crowd assessment and control on land and water |
| **Requirements and Features** | ☑ Support adverse weather and environment operations<br>☑ Support 24-hour (day and night) operations<br>☑ Be ruggedized for water, dust, etc.<br>☑ Have mobility and navigation on uneven terrain, in currents, and in cluttered and confined spaces | ☑ Have portability and maintainability<br>❑ Have real-time capability for mapping terrain, sea floor, and coast<br>☑ Easy to use (training, interfaces, ops, etc.)<br>☑ Swappable and interoperable sensors | ❑ Upgradable and extendable (modularity)<br>☑ Secure and persistent comms<br>❑ Support automation—autopilot with Detect and Avoid<br>☑ Provide a sweet-spot range of 1 to 3 miles and 1 to 12 hours of endurance |

Source: CNA.

The technical capabilities and features of ASG's ArgusElite include the following:

- **Extended range operations:** is capable of operating in day or night conditions, up to three miles with line of sight, and with secure and constant radio communication.
- **Hazard assessment:** performs both quick damage assessments of critical infrastructure and HAZMAT assessments, displaying results quantitatively and qualitatively through hazard area visualization.
- **Hazmat response support:** provides essential scene size-up, reconnaissance, and hazard area definition at breathing height to aid critical decision-making.
- **Portability and maintenance:** is contained in two Pelican cases for easy portability and maintainability.
- **Propulsion technology:** is powered by AVID's[11] 8" ducted fan, which enables both accurate quantification of airborne hazards via its sensor placement and navigation in confined areas that are typically inaccessible to larger multicopters.
- **Rapid deployment:** is launchable within 10 minutes for flight over land or water.
- **Spectral imagery and sensors:** uses differential IR absorbance to differentiate hazards from surrounding water and provide real-time video of hazard containers, leaks, and spill areas, while onboard sensors provide confirmation of volatile hazards.
- **Weather-resistant and rugged design:** mitigates the effect of dust and precipitation, enabling operations in light precipitation, wind conditions up to 15 miles per hour, and temperatures between 0 and 110 degrees Fahrenheit.

[11] ASG partnered with AVID LLC in 2015 to collaborate on the development of a HAZMAT UAS.

ASG's demonstration of the ArgusElite aligned with the scenario and required flight patterns established in its CONOPS. In this scenario, a Maritime Incident Response Team was called to a HAZMAT incident at the Port of Virginia terminal that involved a leaking container and an irritating odor. The incident prompted the deployment of a UAS to detect and map HAZMAT across three flight missions: elevated perspective, hazard mapping in the isolation zone, and hazard mapping in the protective action zone. For the first flight mission, the ArgusElite flew to an elevated altitude and provided multiple EO/IR perspectives to HAZMAT responders that enabled the ArgusElite to locate HAZMAT leaks, identify placards used to identify HAZMAT and any associated safety protocols (e.g., respiratory protections), and determine ingress and egress routes. Using HAZMAT software and the placard number, ASG determined and displayed the isolation zone and protective action zone distance under current conditions; it also plotted potential flight pathways for follow-up hazard-mapping flights while accounting for various obstacles in the area. During the hazard-mapping flights into the isolation and protective zones, the ArgusElite used simulated EO/IR and UAS flight path data to create visuals of the hazard area, specifically focusing on identifying the presence, or lack thereof, of hazards in the upwind and downwind hazard areas. This information informs the development of entry and egress routes, hazard zones, and public action decisions (e.g., evacuation, shelter-in-place).

## Networked Command and Control System (Sentinel Robotic Solutions)

SRS, based in Wallops Island, Virginia, submitted its proposal, "Networked PS&ER Command and Control System," for an integrated, multidomain autonomous solution that addresses several of the key PS&ER pain points listed in the AO. The backbone of the solution is an Internet Protocol–based mesh network,[12] developed by Silvus Technologies, which serves as a mobile, agile, and reliable secure command-and-control communication system and provides high-speed communications and video transmission in complex urban and maritime environments. Figure 7 provides a high-level overview of SRS's UxS solution, including its alignment to PS&ER pain points and AO requirements.

During the hazard-mapping flights into the isolation and protective zones, the ArgusElite used simulated EO/IR and UAS flight path data to create visuals of the hazard area.

[12] A mesh network is composed of a group of nodes (i.e., connectivity devices), each capable of transmitting and receiving data, that function as information relays in order to form a single network.

Figure 7. High-level overview of SRS solution

| GROUP AIR \| LAND \| SEA | Sentinel Robotics Solutions, LLC (SRS)<br>Proposal: *Networked PS&ER Command and Control System* | | |
|---|---|---|---|
| **Proposal Solution** | Use a fully integrated mesh communications network and counter-drone/threat detection technology system to support security and surveillance operations for multiple use cases at the Port of Virginia. | | |
| **Demonstration Objectives** | Demonstrate in an operationally relevant scenario a fully integrated mesh network for security and surveillance response missions using Silvus Radio and SpotterRF Counter-UAS technologies; integrated through a network that includes rapidly deployable long-endurance UAS, mobile unmanned ground surveillance station, tethered Aerostat, and manned Operations Control Center. | | |
| **PS&ER Pain Points** | High<br>☑ Quick-response HAZMAT assessment and mitigation<br>☑ SAR in difficult terrain and geography, as well as in hazardous conditions<br>☑ Threat and hazard identification on and under water | Medium<br>☑ Air operations assessment; UAS detection technologies<br>☑ Quick critical infrastructure damage assessments<br>❑ Identification and monitoring of potential threats on land | Low<br>☑ Robust and secure internet capability to support data exchanges<br>☑ Crowd assessment and control on land and water |
| **Requirements and Features** | ❑ Support adverse weather and environment operations<br>☑ Support 24-hour (day and night) operations<br>☑ Be ruggedized for water, dust, etc.<br>☑ Have mobility and navigation on uneven terrain, in currents, and in cluttered and confined spaces | ☑ Have portability and maintainability<br>☑ Have real-time capability for mapping terrain, sea floor, and coast<br>☑ Easy to use (training, interfaces, ops, etc.)<br>☑ Swappable and interoperable sensors | ☑ Upgradable and extendable (modularity)<br>☑ Secure and persistent comms<br>❑ Support automation—autopilot with Detect and Avoid<br>☑ Provide a sweet-spot range of 1 to 3 miles and 1 to 12 hours of endurance |

Source: CNA.

The technical capabilities and features of SRS's integrated mesh network UxS solution include the following:

- **Ad-hoc mesh networking:** is capable of establishing a self-sufficient local area network independent of existing cellular or network infrastructure presence or accessibility.
- **Counter-UAS detection:** utilizes an integrated UxS solution that uses radar to track, identify, and pinpoint locations of rogue operators and their UAS.
- **Industry-leading UAS technology:** uses long-endurance UAS, capable of flying for more than 85 minutes while carrying up to a pound, to provide persistent video monitoring for situational awareness.
- **Integrated command-and-control system:** seamlessly integrates multiple platforms with the mesh network, providing a diverse set of capabilities to monitor and inform decision-making for multiple simultaneous PS&ER response operations.
- **Rapid deployment and scalability:** is capable of rapidly standing up a mesh network comprising 20 or more mobile ad hoc networking (MANET) radios to quickly establish a secure and dedicated communications network.
- **Real-time situational awareness:** enables transmission of high-quality voice and HD video streaming, as well as high-bandwidth data, to enhance real-time situational awareness while also improving communications and coordination of operational response.
- **Robust and reliable communications:** leverages high-performance systems to deliver an uninterrupted communications network (e.g., Sentinel Aerostat).[13]

[13] SRS used a tethered Sentinel Aerostat to act as a reliable pop-up tower, capable of withstanding challenging weather conditions and increasing network coverage through a communication relay node. The aerostat can provide reliable performance even in challenging weather conditions and can stay aloft for up to 96 hours without replenishment.

- **Versatile mission-specific configuration:** can be easily tailored and configured to meet the unique requirements of different emergency response scenarios, including surveillance, access control, and security measures.

For its demonstration, SRS showcased the application of its integrated UxS solution across a variety of use cases that aligned with seven of the eight total pain points identified by the PS&ER UxS Project. Leveraging the Silvus mesh network as the backbone of the UxS solution, SRS focused on displaying capabilities that demonstrated "quick deployment of aerial surveillance, SAR efforts in difficult maritime and shallow water terrain, real-time visual identification and reporting of UAS and Counter-UAS technologies, infrastructure damage assessment surveys, live streaming crowd surveillance and autonomous control with the ability to integrate the latest in crowd control measures." SRS demonstrated these capabilities across four stations that all connected back to the mesh network. One station demonstrated the designated operational control center, which received all the information being tracked and gathered across the various platforms, and its command-and-control platform, which provided control over the connected autonomous systems that were continuously providing monitoring and situational awareness alerts. This station included a tethered aerostat used to create a communication link at a higher elevation to help expand the boundary of the communication relay. Another station used a ground security and surveillance system as well as a long-endurance UAS to gather situational awareness of the ongoing events occurring within the surrounding area. The third station deployed the UxS solution to show how autonomous systems can maintain communication in an adversarial environment and transmit video and data feeds from field missions back to the command center. Specifically, SRS demonstrated the use of a UAS to support a HAZMAT-related mission inside a shipping container. The final station demonstrated the solution's counter-UAS capabilities by focusing surveillance of surrounding port areas on detecting potential threats or anomalies in the environment (e.g., an "unfriendly" UAS entering the port airspace) that require tracking or that need to be escalated to the command center and port security.

## Autonomous Coastal Monitor (Tridentis)

Tridentis, LLC, based in Alexandria with offices in Norfolk, Virginia, submitted its proposal, "Port Security and Emergency Response Using the Autonomous Coastal Monitor," which demonstrates the utility, modularity, and effectiveness of its already-developed autonomous surface vehicle, Advanced Coastal Monitor (ACM). The ACM is a stable coastal-focused autonomous vessel that has modular sensor bays and can operate for weeks using green-powered fuel. The integrated solution was developed for use by the National Oceanic and Atmospheric Administration (NOAA) for data collection in marine environments. Figure 8 provides a high-level overview of the Tridentis ACM solution, including its alignment to PS&ER pain points and AO requirements.

Figure 8. High-level overview of Tridentis solution

| TRIDENTIS | Tridentis, LLC (Tridentis)<br>Proposal: *Port Security and Emergency Response using the Autonomous Coastal Monitor* | | |
|---|---|---|---|
| **Proposal Solution** | Use the Advanced Coastal Monitor (ACM), a completely integrated unmanned maritime system that can be equipped with sub-surface, surface, and atmospherics sensors, to support PS&ER operations by providing fully autonomous operations for weeks using an on-board, solar-powered rechargeable battery system. | | |
| **Demonstration Objectives** | Demonstrate the utility, modularity, and effectiveness of the Tridentis integrated Advanced Coastal Monitor (ACM) as it relates to the maritime aspects of all five PS&ER use cases. Demonstrate how ACM can support a wide range of sensors in a persistent manner, how the vehicle can be quickly reconfigured based on need, and how the vehicle supports the maritime parts of each use case. | | |
| **PS&ER Pain Points** | High<br>☑ Quick-response hazmat assessment and mitigation<br>☑ SAR in difficult terrain and geography, as well as in hazardous conditions<br>☑ Threat and hazard identification on and under water | Medium<br>❑ Air operations assessment; UAS detection technologies<br>☑ Quick critical infrastructure damage assessments<br>❑ Identification and monitoring of potential threats on land | Low<br>❑ Robust and secure internet capability to support data exchanges<br>❑ Crowd assessment and control on land and water |
| **Requirements and Features** | ☑ Support adverse weather and environment operations<br>☑ Support 24-hour (day and night) operations<br>☑ Be ruggedized for water, dust, etc.<br>☑ Have mobility and navigation on uneven terrain, in currents, and in cluttered and confined spaces | ☑ Have portability and maintainability<br>☑ Have real-time capability for mapping terrain, sea floor, and coast<br>☑ Easy to use (training, interfaces, ops, etc.)<br>☑ Swappable and interoperable sensors | ☑ Upgradable and extendable (modularity)<br>☑ Secure and persistent comms<br>☑ Support automation—autopilot with Detect and Avoid<br>☑ Provide a sweet-spot range of 1 to 3 miles and 1 to 12 hours of endurance |

Source: CNA.

The technical capabilities and features of the Tridentis ACM solution include the following:

- **Autonomous technology:** leverages collision avoidance capabilities to support autonomous operations compliant with International Regulations for Preventing Collisions at Sea.
- **Modular sensor bay:** open architecture modular sensor capability allows rapid configuration changes to support various mission operations.
- **Real-time mapping:** is capable of transmitting real-time sea floor–mapping imagery using multibeam or side-scan sonar.
- **Rugged and resilient system:** is built to support all-weather, 24/7 persistent operations with a minimum duration of 72 hours without recharging; can withstand most HAZMAT contaminants, and is designed to the highest standards for waterproof and weatherproof containment.
- **Seaworthiness:** is capable of operating effectively in waves as high as 2 to 2.5 feet and during unfavorable maritime conditions such as adverse winds and currents.
- **Stable design:** is designed as a Small Waterplane Area Twin Hull to provide exceptional stability when operating in smaller coastal bodies of water (e.g., bays, harbors, rivers).
- **Sustainably powered:** is equipped with solar-powered battery banks for extended operations and a low-emission generator for backup and high-speed operations.
- **Versatile sensor integration:** is equipped with several sensor adaptors that can support more than 100 different sensors, allowing multiple marine, sea-air interface, and atmospheric installations.

For the demonstration of its ACM solution, Tridentis focused on addressing PS&ER use cases related to disaster recovery, pollution control, and security of port operations. For the disaster recovery use case,

Tridentis used ACM's side-scan sonar to quickly survey key navigation channels around the port and validate the positions of ATON following a hypothetical hurricane. During an ATON validation, ACM can conduct a simultaneous survey to identify potential navigation hazards that could affect commercial shipping operations. For the pollution use case, Tridentis demonstrated how ACM can map the extent of a hypothetical oil or other chemical spill in the waterway. This capability can be used to support effective containment and cleanup efforts. Tridentis also used ACM's radar to identify potential targets (i.e., vessels) operating in the surrounding area. This capability could be used to provide effective 24/7 monitoring and improve port security.

## Comparative analysis: UxS solutions versus PS&ER requirements

Following the conclusion of the PS&ER UxS Project, CNA assessed all five project-funded UxS solutions against the initial need and capability requirements outlined by the PS&ER AO. The assessment sought to determine each solution's alignment with the PS&ER UxS Project's 8 pain points, 12 common UxS solution requirements and features, and 5 use cases. All documentation submitted[14] by the vendors as well as the real-world demonstrations were considered for the assessment.

All solutions covered at least four of the eight key challenges identified in the pain points. Figure 9 provides an overview of each UxS solution's alignment with the eight pain points. As shown in the figure, ANRA's SAFEport UxS solution was the only solution that addressed all eight pain points. The five UxS solutions consistently focused on addressing the highest priority pain points, with all UxS solutions addressing all three high-priority pain points. Alignment with the medium- and low-priority pain points varied among the five UxS solutions, with both priority categories containing one commonly addressed pain point.

Figure 9. Comparison of vendor UxS solutions to PS&ER pain points

| | | PS&ER Vendors | | | | |
|---|---|---|---|---|---|---|
| PS&ER Pain Points | | AMA | ANRA | ASG | SRS | Tridentis |
| HIGH | Quick-response HAZMAT assessment and mitigation | ✓ | ✓ | ✓ | ✓ | ✓ |
| | SAR in difficult terrain and geography, as well as hazardous conditions | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Threat and hazard identification on and under water | ✓ | ✓ | ✓ | ✓ | ✓ |
| MEDIUM | Air operations assessment; UAS detection technologies | | ✓ | | ✓ | |
| | Quick critical infrastructure damage assessments | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Identification and monitoring of potential threats on land | ✓ | ✓ | ✓ | | |
| LOW | Robust and secure internet capability to support data exchanges | ✓ | ✓ | ✓ | ✓ | |
| | Crowd assessment and control on land and water | | ✓ | | ✓ | |

Source: CNA.

[14] Vendor-submitted documentation includes initial UxS solution proposals, proposal executive summary charts, and final reports.

All the proposed UxS solutions met at least 9 of the 12 common requirements and features identified in the PS&ER AO. Figure 10 provides an overview of each UxS solution's alignment with the 12 common requirements and features. Based on the data, all of the proposed solutions addressed 7 of the 12 requirements: support 24-hour day and night operations; have mobility and navigation on uneven terrain; have portability and maintainability; easy to use; swappable and interoperable sensors; secure and persistent communications; and provide a sweet-spot range of 1 to 3 miles and 1 to 12 hours of endurance.

The assessment also reviewed the proposed application of each UxS solution relative to the five use cases identified by the PS&ER UxS Project as events that affect the Port of Virginia. Based on details outlined in each solution's submitted documentation, the funded UxS solutions collectively addressed all five use cases. However, if the assessment were based solely on the application of each UxS solution during the PS&ER UxS Project demonstrations, only four use cases would have been addressed, with the SAR use case as the outlier.

Overall, the five UxS solutions funded by the PS&ER UxS Project collectively met the needs and requirements outlined by the PS&ER AO.

Figure 10. Comparison of vendor UxS solutions to PS&ER requirements and features

| | PS&ER Vendors | | | | |
|---|---|---|---|---|---|
| **PS&ER Common UxS Solution Requirements and Features** | **AMA** | **ANRA** | **ASG** | **SRS** | **Tridentis** |
| Support adverse weather and environment operations | | ✓ | ✓ | | ✓ |
| Support 24-hour (day and night) operations | ✓ | ✓ | ✓ | ✓ | ✓ |
| Be ruggedized for water, dust, etc. | | ✓ | ✓ | ✓ | ✓ |
| Have mobility and navigation on uneven terrain, in currents, and in cluttered and confined spaces | ✓ | ✓ | ✓ | ✓ | ✓ |
| Have portability and maintainability | ✓ | ✓ | ✓ | ✓ | ✓ |
| Have real-time capability for mapping terrain, sea floor, and coast | ✓ | ✓ | | ✓ | ✓ |
| Easy to use (training, interfaces, ops, etc.) | ✓ | ✓ | ✓ | ✓ | ✓ |
| Swappable and interoperable sensors | ✓ | ✓ | ✓ | ✓ | ✓ |
| Upgradable and extendable (modularity) | ✓ | ✓ | | ✓ | ✓ |
| Secure and persistent communications | ✓ | ✓ | ✓ | ✓ | ✓ |
| Support automation—autopilot with Detect and Avoid | ✓ | ✓ | | | ✓ |
| Provide sweet-spot range of 1–3 miles and 1 to 12 hours of endurance | ✓ | ✓ | ✓ | ✓ | ✓ |

Source: CNA.

# INTEGRATED CROSS-DOMAIN UXS SOLUTION

The PS&ER UxS Project's five chosen technologies offer the potential to develop an integrated solution that holistically addresses common operational challenges inherent to port environments. These solutions also address challenges specific to public safety and emergency response operations. Integrating UxS technologies can lead to heightened situational awareness, empowering port operators, first responders, and the wider public safety community in the Hampton Roads area to make more informed assessments across both routine and incident response operations.

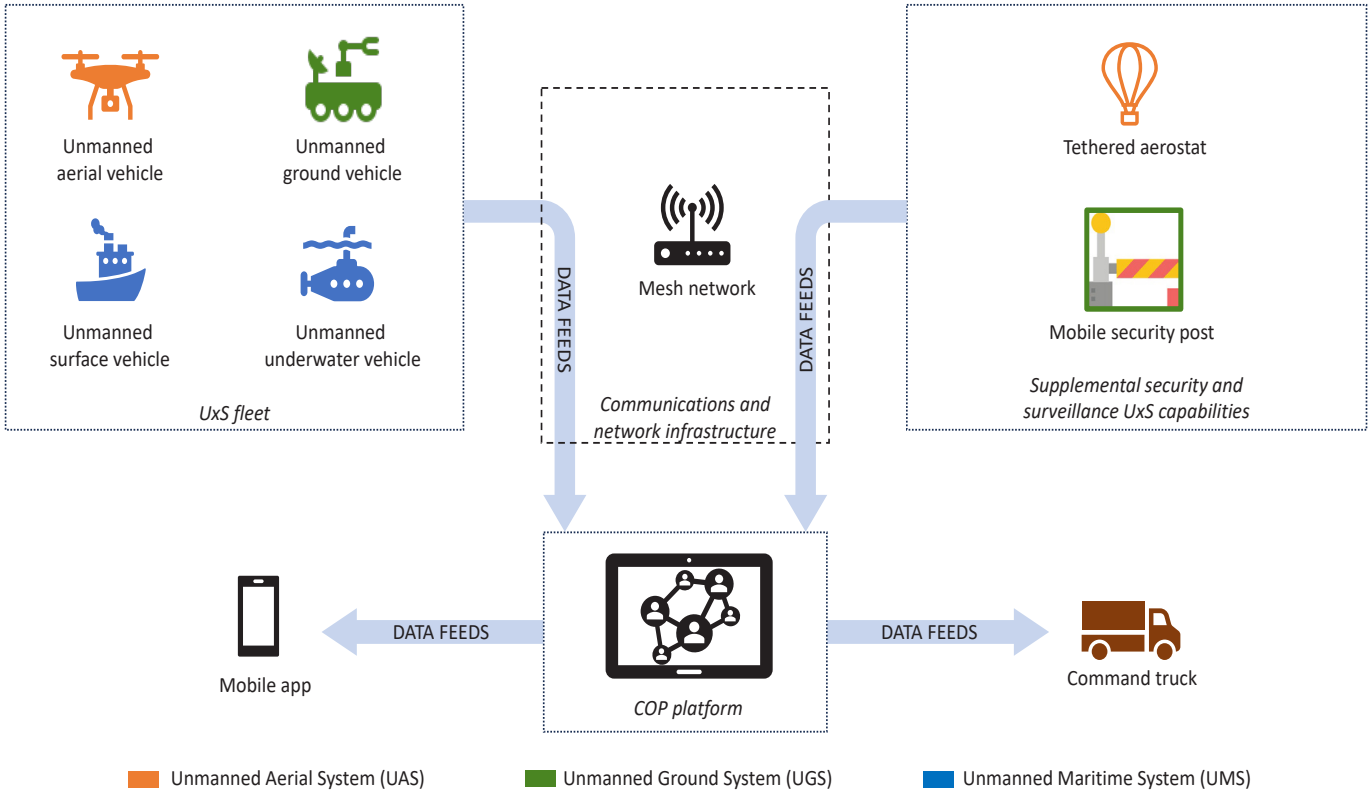
The first part of this section provides an overview of one integrated approach to addressing the port security and emergency response PS&ER UxS Project pain points at the Port of Virginia. Specifically, the approach proposes leveraging the innovative PS&ER UxS Project solutions to implement a cross-domain UxS technology in port environments to improve the safety, efficiency, and reliability of routine and incident response port operations.

The latter part of this section describes the implementation of the proposed integrated UxS solution within the context of routine and incident response port operations. The description provides a comprehensive overview of how various components of the proposed UxS solution can be deployed to support both types of operations. This section includes a review of diverse UxS missions capable of supporting routine and incident response operations and their related benefits, including heightened situational awareness, strengthened port security, and enhanced safety and operational efficiency. In addition, the description outlines the application of the proposed UxS solution within hypothetical scenarios tailored to the Port of Virginia, including a high-level overview of each scenario and associated port security and emergency response challenges. Finally, we offer a walkthrough of how the UxS solution's capabilities could be deployed to address the needs of each scenario.

## Solution overview

Although there are many approaches to creating an integrated UxS solution to address the challenges identified by the PS&ER pain points, this assessment focuses on one potential approach that utilizes UxS technologies based on those demonstrated by the PS&ER UxS vendors. This integrated approach would develop a cross-domain UxS solution composed of three main components: a communications or network infrastructure, an interoperable COP platform complete with user interface, and a diverse UxS fleet capable of performing airborne, maritime, and ground missions as part of routine or incident response operations (see Figure 11). In addition, the solution may include supplemental security and surveillance UxS capabilities as well as ancillary devices to support the COP platform (e.g., mobile command truck, mobile application interface).

Figure 11. Proposed integrated cross-domain UxS solution for PS&ER port operations




Source: CNA.

The backbone of the integrated cross-domain UxS solution would mirror the mesh network solution demonstrated by SRS, which provides a reliable, scalable, secure, and persistent network that allows data transmission and communications across a range of UxS systems and their users. The mesh network is especially vital during public safety or emergency response operations because it can rapidly scale up to extend coverage beyond normal operations, enable secure communications in the event of a cyber event, and provide network connectivity independent of the availability of other existing communication infrastructure. In addition, during the comparative assessment of the PS&ER solutions, communications availability was the area most often cited as needing improvement. The problems were most often due to signal disruptions and loss of connectivity with deployed UxS vehicles as a result of physical obstructions or signal range limitations. To extend the range of coverage, a relay node can be deployed on a tethered aerostat, transforming the aerostat into a pop-up communications tower.

Deploying a COP platform such as ANRA's SAFEport that leverages the mesh network would establish a command center for routine and event-driven incident response operations. The COP platform provides a holistic view of the operational environment that can be used to continuously monitor all port assets. The platform also provides a central location where data received from numerous sources across the port environment can be accessed and leveraged to make more informed decisions. Information available on the COP platform could also be accessed by users deployed in the field through mobile devices connected to the mesh network. In addition, the COP platform could also be integrated with a Port

Mission Manager that enables UxS operators to perform manual or autonomous operations of their unmanned vehicles by connecting their UxS to the COP platform.

The diverse UxS fleet should include systems capable of performing airborne (i.e., UAS), maritime (i.e., UMS[15]), and ground (i.e., UGS) operations. Ideally, the UxS fleet should align with requirements and features similar to those identified in the PS&ER AO. To provide the most value, the UxS should be modular to allow each system to be reconfigured to meet the diverse needs of both normal and response operations. The systems should offer a diverse set of technical capabilities, including a sensor suite capable of supporting simultaneous operations, surveillance technologies (i.e., radar, sonar, cameras), multi-mode controls (e.g., autonomous, manual remote control), and transmission of telemetry data. The UxS fleet may be used for both routine and incident response operations or may be designated to a specific operational mission set. For example, assuming that the fleet comprises the PS&ER UxS Project–funded UxS solutions, AMA's ASV could be designated for routine waterway and marine environmental monitoring, ASG's ArgusElite could be used for HAZMAT-related operations, and Tridentis's ACM could be used for emergency incident response operations as well as long-endurance routine operations. For its UAS and UGS solutions, the fleet could incorporate the unmanned aerial and ground vehicles used in both the ANRA and SRS UxS solution demonstrations.

The supplemental security and surveillance UxS provide additional capabilities to expand the range of different routine and incident response port operations the solution could be leveraged to support. In addition to its potential use as a pop-up communications tower, the tethered aerostat can be deployed in a central location within a port environment to provide reliable surveillance data. The mobile security post provides a scalable, easy-to-deploy access control solution that can be tailored to help address a port's specific surveillance, access control, and security challenges.

Ultimately, combining a mesh network infrastructure with a COP platform, a fleet of diverse UxS systems, and supplemental surveillance and security UxS capabilities enhances routine port operations as well as port security response by providing continuous surveillance, efficient communication, rapid deployment, and increased situational awareness.

To access the full range of capabilities offered by the proposed cross-domain UxS solution and based on the importance of the Port of Virginia as a pivotal economic and strategic gateway, CNA designed the following configuration of UxS solution components:

**Command and control elements**

- **Mesh network:** is composed of MANET radios and relay nodes and integrated into all UxS as well as supplemental UxS capabilities and devices. The number of relay nodes depends on the size of the port and the desired level of network coverage. Additional radios should be reserved for deployment during incident response operations to enable scalable coverage.
- **COP platform:** includes Port Mission Manager software and mobile user interface that enable remote or autonomous control of UxS missions by and data sharing among authorized mesh network users in support of enhanced situational awareness.

[15] The UMS portion of the fleet should include ASVs and unmanned underwater vehicles (UUVs).

- **Command truck:** includes multiple stations dedicated to the different UxS capabilities as well as COP interface, data feed monitor, and other miscellaneous command requirements.

**UxS fleet**

- **UAS technologies:** includes at least one of the following two vehicles: a small quad rotor capable of flying into tight spaces (e.g., inside structures) or a multicopter equipped with chemical, radiological, and spectral (EO/IR) sensors designed for HAZMAT-specific missions.
- **UMS technologies:** includes at least one of the following two vehicles: ASV for routine operations equipped with sonar and water/air testing sensors or UUV for underwater critical infrastructure inspections.
- **UGS technologies:** includes at least one ground rover to perform ground-based reconnaissance missions.

**Supplemental security and surveillance UxS capabilities**

- All-weather **tethered aerostat:** deploys in a central location or near the command truck, equipped with a radio network node.
- Transportable **mobile security post:** is tailored to specific surveillance, access control, and security needs and is equipped with gate arm, temporal scanners, and license plate reader.

It is important to note that this configuration represents just one of many possible approaches to composing the proposed integrated UxS solution. The exact size and diversity of the UxS fleet should be determined by each port based on a combination of multiple factors including the scale of the port's operations, the scope of its routine and common incident response operations, and its budget.

This proposed integrated cross-domain UxS solution can improve the safety, efficiency, and reliability of port operations during both normal routine and incident response operations. The following subsections detail how the solution can be leveraged in two scenarios, with one focused on use cases relevant to routine port operations and the other focused on use cases relevant to emergency response operations. Although both scenarios will be specific to the Port of Virginia and surrounding Hampton Roads area, the use cases can be applied to other port environments.

## Routine UxS port operations

Implementing the proposed UxS solution at the Port of Virginia to support routine port operations will result in more efficient monitoring of the marine environment and operational improvements that enhance the safety, security, and overall operational effectiveness of the port. The integrated cross-domain solution can support a variety of use cases that address normal operational challenges encountered in a port environment and improve the efficiency and safety of day-to-day operations performed at any port.

To support monitoring and research efforts related to the marine environment, the integrated UxS solution can deploy a UMS to conduct bathymetric surveys of the surrounding waterways. The UMS can be programmed to conduct regular prescheduled surveys along a set route, and the data it transmits can inform the port of any unusual or new underwater objects and provide historical data to track changes in the port waters over time. While conducting these surveys, the UMS can simultaneously perform routine water and air quality tests. When such tests are conducted routinely, the resulting data can form a baseline against which the port can more easily detect abnormal changes that require mitigation or trigger an alert when a contaminant in the water that requires immediate response is detected.

UMS with surface and underwater surveillance capabilities can support routine inspections of port assets and infrastructure, including ship hulls, bridge and building supports, and submerged infrastructure (e.g., pipelines), which can help identify irregularities (e.g., dents in ship hulls) and assess the overall structural integrity of port structures and supporting infrastructure. The information gathered from these inspections can inform decisions about maintenance schedules and allocation of funds for port infrastructure improvement projects. UMS can also be deployed to inspect ATON and identify any debris that may affect commercial vessels traveling through the port.

In addition, all UxS vehicles can be deployed to provide continuous monitoring of operations within the port and conduct patrols along the port's perimeter. Monitoring activities can alert port security about the presence of unknown vessels or rogue UAS that requires further action. If suspicious activity is detected, port security can tap into live video streams to gain real-time awareness of the situation and determine the appropriate course of action. The data gathered during all routine port operations are transmitted back to the COP platform, using the communications connectivity established by the mesh network, to provide a holistic view of the port and improve overall situational awareness.

## *Scenario: plausible threat to ports*

This scenario demonstrates how the Port of Virginia could leverage the proposed cross-domain UxS solution to address reports of potential threats to the port during routine operations. The reported threats, representing the key aspects of this scenario, include the following:

- Intelligence assessments indicate a plausible threat of attacks on the shipping industry and area ports.
- The threat includes potential hidden improvised explosive devices (IED) on a truck that entered the port an hour earlier.
- A tugboat reports that a small fishing boat has dropped metallic objects into the shipping channel.

Given the potential life and safety risk of the reported threats, the Port of Virginia decides to leverage all available resources for surveillance, detection, and inspection related operations. Because this threat is received during the course of routine operations, the port is able to use the interoperable COP platform to access surveillance data and gain real-time situational awareness to make an informed decision about the appropriate course of action. In addition, the existing mesh network provides secure communications among port personnel and across the components of the UxS solution deployed to assist in the threat response. If needed, the network can be scaled up depending on how the threat evolves. The port personnel inspecting the possible threat use the command truck, parked at a location that is central to all port operations,[16] to manage all UxS missions. After assessing the surveillance data from the tethered aerostat near the command truck, personnel decide to deploy UAS, UGS, and UMS for additional surveillance operations.

The UAS and UGS are deployed to the area where the threat reported a possible IED hidden in a truck. The two UxS solutions work in tandem to provide surveillance feeds back to the command truck and use their respective onboard sensor suites to detect possible explosive devices in the mission area. If detected, the systems can alert the port personnel through the COP platform of the threat's location by sharing their GPS coordinates. If needed, the UGS

[16] In this scenario, the command truck is located at the Virginia Port Authority's Norfolk International Terminal.

can be remotely controlled closer to the potential IED in order to allow port personnel to visually inspect the object and confirm whether or not the situation needs to escalate to an incident response operation involving the Hampton Roads public safety community.

In this scenario, port personnel may reroute the ASV vessel—already deployed on a routine bathymetric mapping mission—toward the fishing boat that was reported to have dropped metallic objects into the shipping channel. Using the COP platform's Port Mission Manager, the UMS is remotely controlled en route to the fishing boat. Data collected from the UMS is used to identify the vessel and inspect the metallic objects dropped into the water around the fishing boat. For this scenario, the metallic objects are deemed to pose no threat to human life, and port personnel are dispatched to the location to remove the debris. To ensure that no other debris is present in the area, the port deploys the UMS to conduct sonar scans of the waterway within a mile radius of the fishing boat's location.

Although it was not needed for this scenario, the Port of Virginia could deploy the mobile security post in the area where the suspicious truck was reported. This would provide a temporary method of access control until the threat was thoroughly evaluated. In addition, the port could use the mobile security post's license scanner capability to collect information on all traffic coming through the temporary access control point.

## Incident Response UxS Operations

Implementing the proposed cross-domain UxS solution at the Port of Virginia to support public safety and emergency response operations will enhance port resilience by bolstering response and recovery efforts for both natural and man-made disasters. During these events, integrated UxS solutions offer port and public safety communities a game-changing toolbox of diverse technical capabilities. The proposed integrated cross-domain UxS solution provides scalable technologies that can be reconfigured to adapt to the evolving needs of each unique response and recovery operation.

> "Unmanned maritime system[s] [are] a useful force-multiplier for first responders, especially during disaster recovery." —Chris Sadler, director of VIPC's Public Safety Innovation Center

At the beginning of a response operation, the existing mesh network supporting routine port operations must be assessed to determine whether its network boundary needs to change for incident response operations. By rapidly scaling up the mesh network, a secure local area network can be expanded to provide communications for the response team. Digital communication channels provided by the mesh network enable constant communications and real-time data sharing between a central command center, response units deployed in the field, and UxS vehicles.

The COP platform can then process the data gathered in the field and create a comprehensive real-time visualization of ongoing response activities throughout the port, environmental conditions, security threats, and the condition of critical infrastructure. Typically located in the command center, the COP platform provides a holistic view of the operational environment to enable informed decision-making and proactive

responses to emerging situations as they continue to evolve. Ports can use the COP platform to assess incoming data from UxS vehicles, help determine the appropriate next course of action, and prioritize allocation of valuable resources. During response and recovery efforts, the COP platform can also facilitate interagency coordination and collaboration because law enforcement and public safety entities that are approved for incident-specific access can share situational awareness data, leading to a more effective response effort and reduced downtime for port operations.

The fleet of UxS vehicles can be leveraged to support a multitude of response-related use cases. In support of developing a comprehensive COP, UxS can be deployed to conduct surveillance operations, support initial situation assessments, and provide aerial assessments by transmitting real-time imagery and video feeds to the command center. During aerial assessments, UAS equipped with advanced sensors, such as LIDAR and multispectral cameras, can provide detailed environmental monitoring and infrastructure inspection support. Because UMS are usually equipped with an assortment of high-resolution cameras, thermal/IR imaging, sonar, and radar systems, they can be deployed to assess the situation in the surrounding port waters. UMS may also simultaneously identify vessels encountered during the surveillance operation, conduct critical infrastructure inspections, and monitor for any irregular environmental conditions or potential security threats. Likewise, UGS may be deployed to conduct ground-level inspections of port infrastructure and security patrols.

The UxS vehicles can also assist in HAZMAT- or SAR-related operations. For HAZMAT operations, UxS vehicles may be deployed to perform reconnaissance missions to identify the precise location of a HAZMAT spill or leak and define the hazard area. The surveillance data transmitted from the HAZMAT location can be used to identify the type of hazardous material, assess the situation, and inform the containment and clean-up plan. Data gathered from UxS hazard mapping as well as air and water testing can inform first responder and public safety procedures (e.g., respiratory precautions, shelter-in-place orders), identify isolation and protective zones, and detect the presence of related contaminants in the surrounding water and air. For SAR operations, UxS solutions equipped with spectral sensors or imaging capabilities can be deployed to help locate missing individuals. UxS supporting SAR operations may also be equipped with RBG cameras for facial recognition and speakers to help broadcast alerts (e.g., missing person information, BOLOs).

As the response phase begins to transition into the recovery phase, the integrated cross-domain UxS solution can be leveraged to support the restoration of maritime operations and port reconstitution efforts. UxS can perform aerial, maritime, and ground surveillance to assess any new damage or potential hazards resulting from the emergency. In addition, UxS can conduct thorough inspections of critical port infrastructure. UMS vehicles can be deployed to conduct sonar scans focused on locating any debris that may pose a hazard to the vessels navigating through the port. UMS can also conduct bathymetric surveys to assess any long-term effects on the sea floor and detect any irregular changes. For HAZMAT-related recovery efforts, UxS can be used to conduct continuous monitoring of containment and clean-up efforts and perform routine water and air quality tests for contaminants identified in initial response operations.

## *Scenario: nor'easter*

This incident response scenario demonstrates how the Port of Virginia could leverage the proposed cross-domain UxS solution to address the multifaceted challenges posed by a powerful nor'easter. The storm begins to wreak havoc as it makes landfall

in the Hampton Roads area, triggering multiple incidents that pose threats to the safety and security in and around the port. The incidents caused by the nor'easter, representing the key aspects of this scenario, include the following:

- Building roofs have sustained extensive damage is visible, widespread flooding has occurred, trees and power lines have been downed, and debris is blocking roads and railroads.
- A container ship has run aground on Rip Raps Island, near the Hampton Roads Bridge Tunnel. The extent of any damage to the vessel is unknown.
- A tugboat and barge have crashed into the Craney Island Fuel Depot Pier, resulting in a fuel spill.
- The Thimble Shoal Channel buoy is reported missing.
- Two kayakers are reported missing in the Warwick River. They were last seen being swept down river, south of the Denbigh Boat Ramp.

Given the extensive damage to infrastructure, the widespread flooding, and the numerous maritime incidents, comprehensive situational awareness and swift response become imperative. The Port of Virginia could leverage various capabilities provided by the proposed cross-domain UxS solution to address challenges posed by each aspect of the nor'easter.

In this scenario, the mesh network is scaled up from routine port operations to expand the boundaries of network coverage to all incident sites. This includes deploying radios to all port and public safety personnel performing response operations that are equipped with relay nodes as well as push-to-talk handsets, GPS, cameras, and Wi-Fi.

Port personnel use the COP platform and Port Mission Manager the same way they do during routine operations. If needed, the COP platform can also facilitate interagency coordination and collaboration throughout the response and recovery efforts by enabling the Hampton Roads public safety community to connect to the platform and exchange data between their situational awareness or data sharing applications and the COP platform. For example, the COP platform can forward high-priority alerts gathered during the course of UxS missions to law enforcement and public safety agencies using the Android Team Awareness Kit (ATAK).[17] Overall, the COP platform allows the Port of Virginia to make informed decisions and efficiently allocate its resources; it also enables all stakeholders involved in the incident response operations to prioritize areas for assistance, navigate around debris-blocked roads and waterways, and coordinate rescue operations effectively.

It is important to note that the following proposed deployment of components of the UxS fleet represents one of many approaches the Port of Virginia could elect to pursue in this scenario. In this scenario, the initial data gathered from the routine operation surveillance feeds is used to determine the priority of response operations and allocation of fleet resources. Based on the information available, the port decides on the following course of action.

The quad rotor and ASV are deployed to assist in the aerial SAR operations for the missing kayakers. Utilizing spectral sensors and imaging capabilities, both UxS can provide invaluable support in searching for missing persons in the water. Once the missing kayakers are located, the GPS coordinates of the UxS can be sent to SAR incident teams to guide the rescue operations.

[17] ATAK allows users to share situational awareness, navigation, and incident response data.

The fleet's quad rotor is deployed to conduct a set of aerial inspection missions related to the container ship. First, the quad rotor performs an aerial inspection of the container ship to determine the possible extent of damage to the vessel. Video feeds indicate no major damage to the vessel and no debris or fuel in the surrounding water. To ensure that there is no damage to the submerged portions of the container ship, a UMS is deployed to conduct an underwater inspection. The underwater unmanned vehicle assesses the extent of any damage to the ship's hull in order to identify potential leaks or structural weaknesses. Meanwhile, the quad rotor conducts an inspection of the bridge tunnel to determine whether the vessel collided with the structure. Although no obvious damage is detected, because of the proximity of the vessel to the bridge tunnel and the structure's vital role to the Hampton Roads area infrastructure, the port utilizes the UUV to inspect the structural integrity of the bridge tunnel.

In response to the fuel spill caused by the tugboat and barge crash, the Port of Virginia deploys the multi-rotor tailored for HAZMAT response operations. The multi-rotor can quickly assess the extent and spread of the fuel spill, providing real-time data on the size and composition of the spill that can be used to determine effective containment and cleanup efforts. In addition, the ASV equipped with sonar can help monitor the spread of the fuel spill in the surrounding water and identifying areas of high concentration for targeted cleanup efforts.

The Port of Virginia can deploy the ASV to verify the integrity of the reportedly missing buoy. The vessel can use its sonar to conduct underwater surveys in the area of the missing ATON to determine whether it has sunk beneath the surface or has been dislodged from its original location.

UxS technologies can be used during the response and recovery operations focused on addressing the extensive damage caused by the nor'easter. Any of the UxS fleet's UAS can be deployed to conduct aerial assessments of the port's roofs and structures. The UMS can be deployed to detect the presence of submerged debris or hazards resulting from the storm and monitor water quality. In addition, the UGS can navigate through any debris-blocked roads or areas of the port rendered inaccessible by storm damage to help assess the extent of blockages and identify safe routes for emergency responders.

# CONCLUSION

The PS&ER UxS Project demonstrated innovative uses of UxS solutions to improve and support PS&ER operations. This project laid the groundwork for the needs that UxS solutions are expected to meet and the technical capabilities that UxS solutions are expected to have if they are developed to support PS&ER operations. The PS&ER UxS Project selected five cross-domain UxS solutions to receive funding, and of those five, none was able to address all the pain points and align with all the capability requirements outlined in the PS&ER AO. Collectively, however, the five UxS solutions were able to meet all the needs and requirements identified by the PS&ER UxS Project, highlighting a need for an integrated solution.

The proposed integrated cross-domain UxS solution is developed based on the solutions demonstrated during the PS&ER UxS Project. The UxS solution combines the unique capabilities offered by each PS&ER solution into a holistic system composed of a mesh network, a COP platform, and a fleet of aerial, maritime, and ground UxS systems. The proposed solution may also include supplemental surveillance and security UxS capabilities and ancillary devices to support the COP platform. Implementing the proposed integrated UxS solution at the Port of Virginia to support routine operations promises tangible benefits, including enhanced monitoring of the marine environment and operational efficiency improvements that bolster safety and security measures. Specifically, by implementing the integrated UxS solution to support bathymetric surveys, perform routine inspections, and continuously monitor efforts, the Port of Virginia stands to gain invaluable data that will facilitate informed decision-making and proactive measures focused on maintaining continuous operations and safeguarding port infrastructure. Likewise, the proposed cross-domain UxS solution at the Port of Virginia for public safety and emergency response operations represents a significant step toward enhancing port resilience in the face of natural and man-made disasters. By deploying the mesh network and using the COP platform early in an emergency, response teams can gain real-time insights, make more informed decisions, and respond proactively throughout its duration. Leveraging the UxS fleet can extend support further into the recovery phase, helping restore maritime operations and advancing port reconstitution efforts, ultimately leading to a more effective response and reduced downtime for port operations.

Overall, leveraging an integrated cross-domain UxS solution in a port environment is an innovative approach to port management that promises to improve the safety, efficiency, and reliability of routine and emergency port operations, ultimately enhancing port resilience. By integrating the diverse capabilities of UxS platforms and vehicles into a cohesive system, ports can ensure safety, security, and operational effectiveness in an ever-evolving maritime environment.

# ACRONYMS

| | |
|---|---|
| ACM | advanced coastal monitor |
| ADS-B | automatic dependent surveillance–broadcast |
| AMA | Analytical Mechanics Associates, Inc. |
| AO | announcement of opportunity |
| ASG | Alliance Solutions Group |
| ASV | autonomous surface vessel |
| ATAK | Android Team Awareness Kit |
| ATON | aid to navigation |
| CONOPS | concept of operations |
| COP | common operating picture |
| EO/IR | electro-optical/infrared |
| FAA | Federal Aviation Administration |
| GPS | global positioning system |
| HAZMAT | hazardous materials |
| HD | high-definition |
| IED | improvised explosive device |
| IR | infrared |
| LIDAR | light detection and ranging |
| MANET | mobile ad hoc networking |
| NASA | National Aeronautics and Space Administration |
| NOAA | National Oceanic and Atmospheric Administration |
| PS&ER | Port Security & Emergency Response |
| RBG | red, blue, and green wavelength |
| SAR | search and rescue |
| SRS | Sentinel Robotic Solutions, LLC |
| UAS | unmanned aircraft system |
| UGS | unmanned ground system |
| UMS | unmanned maritime system |
| UUV | unmanned underwater vehicle |
| UxS | unmanned system |
| VDEM | Virginia Department of Emergency Management |
| VIPC | Virginia Innovation Partnership Corporation |
| VISA | Virginia Institute for Spaceflight and Autonomy |

# REFERENCES

Costello, Angela. "Unmanned Systems for Port Security and Emergency Response Project in Hampton Roads Expands with Three More Companies." EIN Presswire. Dec. 5, 2022. https://wreg.com/business/press-releases/ein-presswire/604868684/unmanned-systems-for-port-security-and-emergency-response-project-in-hampton-roads-expands-with-three-more-companies/.

Costello, Angela. "VIPC and VISA Announce Proposals Selected for UxS Port Security and Emergency Response Opportunity." GlobeNewswire. June 1, 2022. https://www.globenewswire.com/en/news-release/2022/06/01/2454350/0/en/VIPC-and-VISA-Announce-Proposals-Selected-for-UxS-Port-Security-and-Emergency-Response-Opportunity.html.

Garvey, Joe. "ODU's Virginia Institute for Spaceflight & Autonomy Helps Lead Unmanned Systems Port Security Demonstration." Old Dominion University. Nov. 14, 2022. https://www.odu.edu/article/odus-virginia-institute-for-spaceflight-autonomy-helps-lead-unmanned-systems-port-security.

Virginia Port Authority. "About the Agency." Commonwealth of Virginia Official Site. Accessed Apr. 11, 2024. https://www.virginia.gov/agencies/virginia-port-authority-/#:~:text=The%20Port%20of%20Virginia%20is,200%2B%20countries%20around%20the%20world.

Virginia Port Authority. "Experience the Most Modern Gateway in America." Port of Virginia Official Site. Accessed Apr. 14, 2024. https://www.portofvirginia.com/gateway/.

Virginia Port Authority. "Report: Port Helps Drive Economic Investment and Job Creation Throughout the Commonwealth." Port of Virginia Official Site. May 23, 2023. https://www.portofvirginia.com/who-we-are/newsroom/report-port-helps-drive-economic-investment-and-job-creation-throughout-the-commonwealth-2/.

**This report was written by CNA's Enterprise Systems and Data Analysis Division (ESDA).**

CNA's Enterprise Systems and Data Analysis division (ESDA) creates advanced, integrated enterprise systems and data management solutions that empower clients to make decisions at pace with the speed and scale of their mission. ESDA analyzes the entirety of systems—the people, the process, the data, and the technology—to improve the efficacy of operations through optimized data-driven environments.



## ABOUT CNA

CNA is a nonprofit research and analysis organization dedicated to the safety and security of the nation. It operates the Center for Naval Analyses—the federally funded research and development center (FFRDC) of the Department of the Navy—as well as the Institute for Public Research. CNA develops actionable solutions to complex problems of national importance. With nearly 700 scientists, analysts, and professional staff, CNA takes a real-world approach to gathering data. Its unique Field Program places analysts on aircraft carriers and military bases, in squad rooms and crisis centers, working side by side with operators and decision-makers around the world. CNA supports naval operations, fleet readiness, and strategic competition. Its non-defense research portfolio includes criminal justice, homeland security, and data management.

Dedicated to the Safety and Security of the Nation

www.cna.org

IIM-2024-U-038017-Final