
# C-THRU

## Operational Field Assessment Report

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Science and Technology

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NATIONAL URBAN SECURITY TECHNOLOGY LABORATORY

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DHS S&T works closely with the nation's emergency response community to identify and prioritize mission capability gaps, and to facilitate the rapid development of critical solutions to address responders' everyday technology needs. DHS S&T gathers input from local, tribal, territorial, state, and federal first responders, and engages them in all stages of research and development—from building prototypes to operational testing to transitioning tools that enhance safety and performance in the field. The goal is to advance technologies that address mission capability gaps in a rapid time frame, and then promote quick transition of these technologies to the commercial marketplace for use by the nation's first responder community.

As projects near completion, NUSTL conducts an operational field assessment (OFA) or technical demonstration of the technology's capabilities and operational suitability to verify and document that project goals were achieved.

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Visit the DHS S&T website, www.dhs.gov/science-and-technology/first-responder-capability-rd-program-fact-sheets, for information on other projects relevant to first responders.

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# EXECUTIVE SUMMARY

On August 24, 2023, the U.S. Department of Homeland Security (DHS), Science and Technology Directorate (S&T), National Urban Security Technology Laboratory (NUSTL) conducted an operational field assessment (OFA) of the C-THRU system at the San Diego Fire-Rescue Training Facility in San Diego, California. The OFA consisted of eight firefighter evaluators using C-THRU while conducting job tasks typically encountered during fire response and incident command efforts.

C-THRU is a real-time visualization system developed by Qwake Technologies which intends to provide firefighters with technology that can minimize the disorientation associated with emergency response by offering a suite of imaging, navigation, and visual communication applications via the helmet-mounted C-THRU Navigator and corresponding Visual Command platform. Research and development of the prototypes was funded and managed by DHS S&T's Office of Mission and Capability Support.

During the OFA, evaluators donned C-THRU Navigator and conducted various activities representative of fire response operations in fire props (structures for controlled fire operation training). These activities conducted by firefighter evaluators included searching for a heat source using varying techniques (duck walks, leg forward, and crawling) while stretching hose line; conducting a search and rescue effort; and searching for a downed firefighter. Additionally, responders used Visual Command to simulate incident command operations. In simulated incident command operations, responders observed real-time feeds of evaluators wearing C-THRU Navigator and requested actions such as face-to-face meetings through the system.

Throughout the OFA, evaluators provided feedback on the strengths and weaknesses of C-THRU Navigator and the Visual Command platform. Evaluators appreciated the development of C-THRU as a method of advancing navigation and situational awareness capabilities in the fire service. They found C-THRU Navigator's display to have high-fidelity object colors, supporting differentiating elements of the scene. Evaluators indicated that the system's capability added value to the overall command presence, as it provides real-time updates on responders and displays their overall surroundings.

However, evaluators voiced concerns about the comfort, weight, and placement of C-THRU Navigator. There were also concerns about the cellular connectivity, transmission of data, and streaming capabilities, particularly in rural environments or areas with limited communication infrastructure.

Evaluators also suggested improvements

- Make C-THRU Navigator buttons more identifiable (e.g., increase ridge size between buttons, add a nipple to the center button) to increase usability
- Include an option for lower resolution video, or alternate method to increase the reliability of video feeds (e.g., video compression) to improve communication in low connectivity environments
- Explore swappable batteries and/or rapid charging methods for C-THRU Navigator
- Enhance Mayday alerts in Visual Command (e.g., improving current red outline by making it bolder, adding a flashing component, including audible alerts, changing the symbol to something other than a circle) to ensure it grabs the attention of incident command

# TABLE OF CONTENTS



# LIST OF FIGURES

## LIST OF TABLES

# 1.0 INTRODUCTION

To perform their duties, firefighters often navigate through low to zero visibility environments with dense smoke. Existing techniques to avoid becoming disoriented in these scenarios require slow methodical movement through a space, generally while touching a wall. To counteract this, firefighters might use handheld thermal imaging cameras. However, this requires a free hand, and screen visibility might still be challenging in dense smoke, potentially impacting the effectiveness of a thermal imaging camera as a visual aid for navigation in these environments.

The U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) has funded Qwake Technologies to conduct research and development of a Real-Time Indoor Visualization (RT-Viz) System. The goal of this effort has been to provide firefighters with technology that can minimize the disorientation associated with emergency response operations in low visibility environments (e.g., smoke filled) by offering a suite of imaging, navigation, and visual communication applications. The research effort has been managed by DHS S&T's Office of Mission and Capability Support.

Qwake Technologies developed C-THRU, which is comprised of C-THRU Navigator, a helmet mounted augmented reality heads-up display for firefighters. It's a cellular connected device equipped with a thermal imaging camera. The onboard connectivity allows Incident Commanders to view a real-time feed of the camera, as well as communicate with the users via simple personnel accountability report checks or order an evacuation of a building using tools such as Visual Command. A complete system description is included in Section 1.4.

On August 24, 2023, NUSTL conducted an OFA of C-THRU focusing on the usability, capability, and compatibility with the use of personal protective equipment (PPE). During this OFA, eight firefighters from agencies in California, Illinois, Maryland, New York, North Carolina, and Texas served as evaluators and performed various firefighting job tasks while wearing C-THRU Navigator and using Visual Command. They provided feedback on the usability, capability, and compatibility with the use of PPE when used in operational settings.

This report describes the activities performed, results from those activities, and evaluators feedback.

## 1.1 PURPOSE

The purpose of the OFA was to assess the C-THRU system for use in operational environments for fire and incident command response operations.

## 1.2 OBJECTIVES

The OFA was designed to test:

- Usability: C-THRU Navigator and Visual Command's ability to be comfortable and intuitive for use by fire personnel during response operations.
- Capability: C-THRU Navigator's ability to clearly distinguish outlines and edges in heated, low or no-visibility environments, and to stream live video. Visual Command's ability to receive video stream and allow users to send commands to C-THRU Navigator users.
- Compatibility with the use of PPE: C-THRU Navigator can be used with typical firefighting gear that does not impede response operations.

## 1.3 REQUIREMENTS

The guiding requirements for this project are described in the Statement of Work for Real-Time Indoor Visualization System for Low Visibility Fire Environments. [1] Table 1-1 below is from the C-THRU (Real-Time Visualization) Operational Field Assessment Plan [2] and describes the requirements against which C-THRU was assessed. During the OFA, only operationally testable requirements were assessed. The ability to withstand extreme environments was not assessed as it was deemed a performance testing requirement, which will be handled by the performer as part of later certification testing. Additionally, requirements related to integration with a self-contained breathing apparatus (SCBA) mask were no longer relevant due to a design change.

**Table 1-1 Requirements and Activities Matrix**

| NUSTL No. | Requirement | Assessment Method |
|---|---|---|
| 1 | The ability to clearly and quickly distinguish outlines and edges of walls, doors, and large pieces of furniture in a smoky super-heated environment such as a house fire | Evaluator dons PPE (turnout gear, gloves, SCBA) and helmet with C-THRU Navigator. Evaluator checks system fit/functionality. Evaluator approaches entry of burn building and sets entry point. In each of the three scenarios below evaluators work as either engine company or ladder company performing tasks and carrying equipment typical of that role.<br><br>Scenario 1:<br>Engine Company: 3-person team of nozzle person, backup, and third deploy hose. Move the line deeper into the building as appropriate, including while standing, crouching, and crawling.<br><br>Scenario 2:<br>Ladder Company: 3-person team of Officer and two firefighters deploy. Following standard firefighting procedures, search for the heat source, then look for signs of life. Use firefighting tools such as Halligans to open doors and windows. Upon completion of activities, use compass navigation to exit the building.<br><br>Scenario 3:<br>Incident Commanders (ICs) will observe operations being conducted by the engine and ladder companies using Visual Command and will request a personal accountability report (PAR) and an evacuation (EVAC).<br><br>Scenario 4:<br>IC will report a Mayday and a ladder company will respond as a Firefighter Assist Search Team (FAST)/ Rapid Intervention Crew (RIC). They enter the building searching for the firefighter and remove them from the structure once found.<br><br>Activities will be conducted using simulated (theatrical) smoke and heaters. |

| NUSTL No. | Requirement | Assessment Method |
|---|---|---|
| 2 | Ergonomic fit with typical firefighting gear that does not impede operations | Evaluated throughout #1 (using buttons while wearing gloves, interference with face mask, crawling, carrying equipment). |
| 3 | Ability to withstand the extreme environment in a burning building near high-pressure water and other firefighting tools (i.e., foam, etc.) | Not Operationally Assessed |
| 4 | If the solution is integrated with the current full self-contained breathing apparatus (SCBA) face piece with the expectation that it would always be worn (e.g., during active firefighting and during overhaul), then it must allow the firefighter to switch between the SCBA harness and cylinder assembly without exposing the operator to unfiltered atmosphere. In this configuration, the solution's objective is that the SCBA harness and cylinder assembly can be dismounted once the novel solution is operational with the existing face piece. If instead the solution will be stored in the emergency vehicle until it is needed and therefore donned and doffed in a safe zone, then the requirement becomes a change in concept of operations (CONOPS). | N/A due to change in configuration of prototype |
| 5 | Wireless connection to mobile or existing communication devices | While not in the building, evaluators will be observing live streaming connection to C-THRU via Visual Command to monitor responses to communications.<br><br>During simulated smoke, walking, they will issue a PAR check.<br><br>During simulated smoke, crawling, they will issue an evacuation order. |
| 6 | Hands-free operation | Evaluated throughout #1 |

## 1.4 SYSTEM DESCRIPTION

C-THRU Navigator is a helmet mounted augmented reality (AR) heads-up display for firefighters (Figure 1-1). Onboard image processing of a thermal imaging camera allows it to present the user with a simplified view of the scene that highlights information necessary for navigating in a low or zero visibility environment. This includes the outlines of walls, furniture, or other obstacles. Additionally, it performs simultaneous localization and mapping based on the camera feed. C-THRU Navigator is also equipped with a green laser on the front of the unit and two taillights on the back of the unit. The taillights remain solid green during operations, and flash red when the user is in "Mayday mode" as another alert method for those in the vicinity.


**Figure 1-1 C-THRU Navigator**
*Courtesy of Qwake Technologies*

The onboard cellular connectivity allows incident commanders to view a real-time feed of the camera, as well as communicate with the wearers by sending icons to their heads up displays. These communications (i.e., personnel accountability report checks, evacuation orders, and face to face (F2F) requests) are transmitted through an app called Visual Command. Key aspects shown in Figure 1-2 include a carousel of video feeds of users (left), notifications of events (upper center – evacuation in this image), status of users depicted with color and shape fill (upper right), and timeline of events (bottom).


**Figure 1-2 Visual Command**
*Courtesy of Qwake Technologies*


Figure 1-3 Evaluators wearing C-THRU Navigator

# 2.0 OPERATIONAL FIELD ASSESSMENT DESIGN

## 2.1 EVENT DESIGN

The OFA was designed as a one-day event bringing together eight firefighting subject matter experts to use the C-THRU system in simulated operational scenarios and to provide feedback on its design. Evaluators were encouraged to test the system usability and capability based on their experiences and their typical or expected concept of operations.

The test venue was the San Diego Fire-Rescue Training Center in San Diego, California. The test team used a classroom for briefings and product familiarization sessions. Operational scenarios were conducted in:

- the Interior Attack Fire Prop, which is a single-story structure outfitted with several rooms and furniture in varying conditions (Figure 2-1)
- the Truck Grinder House Fire Prop, which is a two-story structure with metal staircases furniture, appliances, and roof access (Figure 2-2)
- a tented incident command outdoors area

Tented areas at the test site also served as rest stations. In addition to hosting the OFA, San Diego Fire-Rescue provided test equipment including hand tools, hose line, PPE, manikins, and environmental controls required to conduct the assessment.

Figure 2-1 Outdoor (left) and interior (right) aspects of the Interior Attack Fire Prop

Figure 2-2 Outdoor (left) and interior (right) aspects of the Truck Grinder House Fire Prop

## 2.2 PARTICIPANTS

Table 2-1 lists the OFA participants. This included eight firefighters who served as evaluators to test and provide feedback on C-THRU.

**Table 2-1 Participant Roles and Organizations**

| Role | Organization |
|---|---|
| Evaluator | New York City Fire Department (NY) |
| Evaluator | Rockville Volunteer Fire Department (MD) |
| Evaluator | Youngsville Fire Department (NC) |
| Evaluator | San Diego Fire-Rescue Department (CA) |
| Evaluator | Consumnes Fire Department (CA) |
| Evaluator | Chicago Fire Department (IL) |
| Evaluator | Menlo Park Fire District (CA) |
| Evaluator | Dallas Fire-Rescue Department (TX) |
| Venue Host | San Diego Fire-Rescue Department (CA) |
| OFA Director and Data Collectors | DHS NUSTL |
| Technology Developer | Qwake Technologies |
| Observers | DHS S&T, IDEX Corporation |

## 2.3 SCOPE AND LIMITATIONS OF TEST ACTIVITIES

The assessment consisted of five activities that incorporated different tasks, summarized in Table 2-2. The test plan [2] contains complete details of the OFA design.

Throughout the OFA, each group of evaluators was paired up with a NUSTL data collector. Data collectors recorded observations and candid comments while evaluators conducted OFA activities. Data collectors also administered a questionnaire to elicit evaluator feedback on C-THRU after each activity station rotation.

**Table 2-2 Summary of Activities Performed During the OFA**

| Activity | Location | Task |
|---|---|---|
| Developer Presentation and Familiarization | Classroom | Overview of system design and operation |
| Engine Company | Interior Attack Prop | Three evaluators (simulating an engine officer and two firefighters), each with an SCBA, stretched a hose line into the interior attack prop and operated the line while performing duck walks, leg forward (outstretched leg) technique, and crawling. |

| Activity | Location | Task |
|---|---|---|
| Incident Command | Tent outside Interior Attack Prop | Evaluators served as incident commanders and observed operations being conducted by the engine company using Visual Command. They issued PAR checks as well as face-to-face and EVAC orders to test Visual Command functionality. |
| Ladder Company Search and Rescue | Truck Grinder House Prop | Evaluators navigated through the multistory Truck Grinder Prop using search tactics to locate a manikin simulating victims. |
| FAST/RIC | Interior Attack Prop | Evaluators enter the prop and rapidly search for a manikin simulating a downed fire fighter. |

## 2.4 DEVIATIONS FROM THE TEST PLAN

To resolve logistics and technical challenges during the OFA, NUSTL deviated from the OFA Plan. These deviations included the following:

- Due to the last-minute availability of additional prototypes, all evaluators wore C-THRU devices while in fire props, rather than only one. This condensed timelines as fewer repetitions were necessary.
- The FAST/RIC activity took place in the Interior Attack Prop, rather than the Truck Grinder Prop as initially planned, due to connectivity issues experienced during the dry run.
- Engine and Ladder Company scenarios were conducted in series, rather than parallel, due to staffing and equipment constraints.
- Due to connectivity issues inside the Truck Grinder Prop, all incident command and communication criteria were evaluated during the Engine Company and FAST/RIC activities.
- Evaluators conducted the Ladder Company scenario individually rather than in a group of three, as it was designed for multiple streams of C-THRU Navigator data to be pushed to incident command simultaneously. Based on the additional prototypes available and evaluators conducting the Engine Company and FAST/RIC activities in teams, it was not necessary to do so in Ladder.
- Data collectors were told not to enter the Truck Grinder Prop after the first rotation due to high carbon monoxide levels being present.
- Removed testing of the breadcrumbs feature as it was not available at the time of the OFA, (and therefore could not be assessed).
- Some evaluators did not complete all tasks associated with certain activities. When this occurred, evaluators did not answer survey questions regarding features or functions they did not personally get to assess.

# 3.0 RESULTS

This section contains feedback from the evaluators' questionnaires and group discussions for both C-THRU Navigator and Visual Command. Questionnaire responses relate directly to the usability, capability, and compatibility with the use of PPE. The group discussion at the conclusion of all scenario activities allowed evaluators to provide generalized feedback on C-THRU Navigator and Visual Command, as well as an opportunity to elaborate on any feedback given in the questionnaire.

## 3.1 C-THRU NAVIGATOR

### 3.1.1 USABILITY

Figures 3-1, 3-2, and 3-3 list responses to the questionnaire that was administered during the OFA. The following subsections provide a summary of the specific feedback that was given during the OFA with respect to comfort, ease of use, maneuverability, and overall usability.

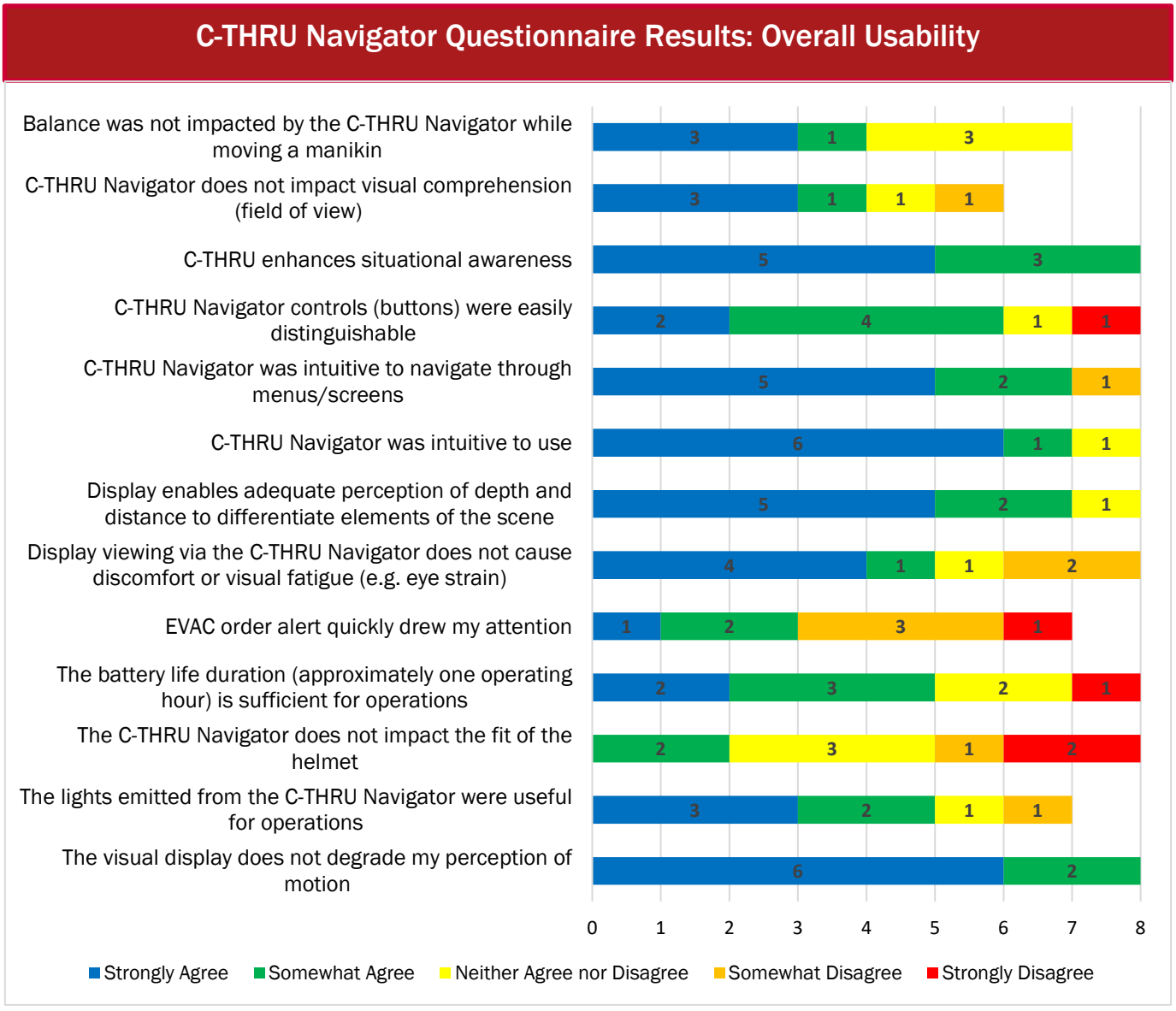


Figure 3-1 C-THRU Navigator Questionnaire Results: Overall Usability

## C-THRU Navigator Questionnaire Results: Engine Company Usability

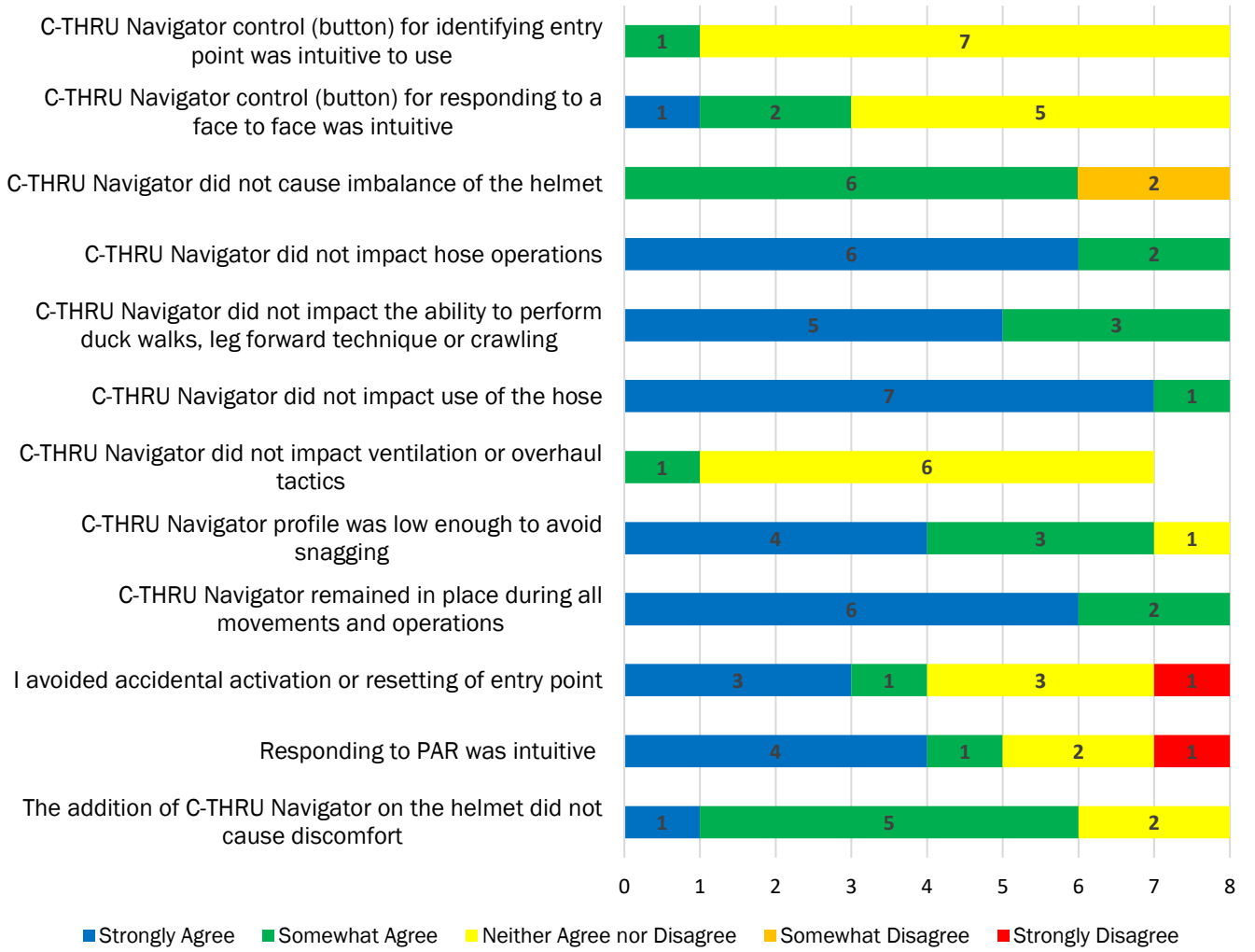


Figure 3-2 C-THRU Navigator Questionnaire Results: Engine Company Usability

## C-THRU Navigator Questionnaire Results: Ladder Company Usability

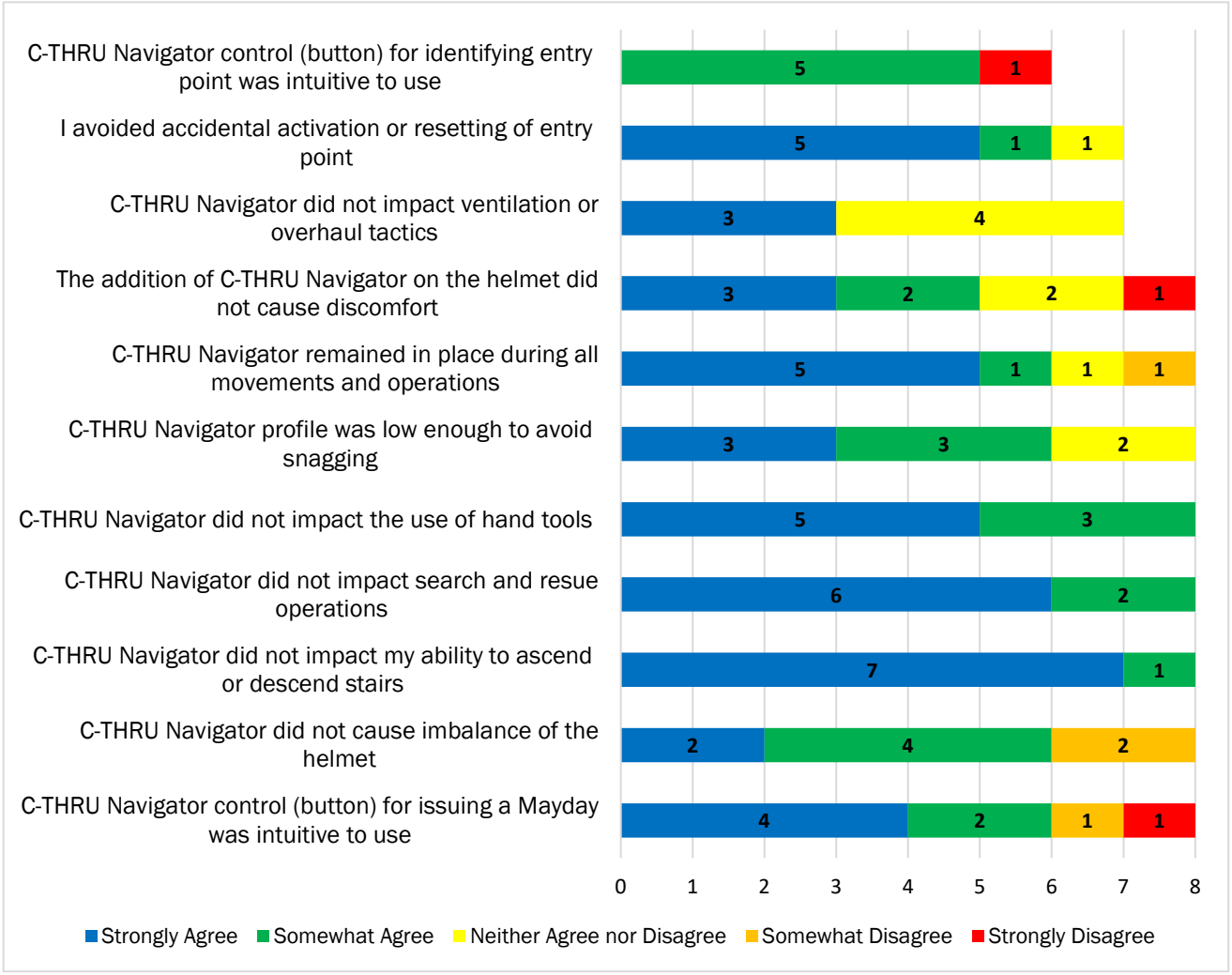


Figure 3-3 C-THRU Navigator Questionnaire Results: Ladder Company Usability

### 3.1.2 COMFORT

Evaluators had mixed feedback when asked if C-THRU Navigator did not impact the fit of the helmet. Three evaluators who neither agreed nor disagreed, stated that there was slight discomfort but would need to wear the helmet for an extended period of time to provide further feedback, and added that the additional weight resulted in the helmet sitting differently. Two evaluators strongly disagreed, stating that the additional weight was very noticeable. They noted that it was difficult to ratchet the helmet with the ear flap turned out to accommodate the system, which made it harder to reach the ratchet adjustment on the back of the helmet (Figure 3-4). Two evaluators somewhat agreed and one somewhat disagreed, noting that the system's weight pulls the helmet slightly; while the extra weight does not affect the fit of the helmet, it does affect how the helmet is worn and used. One evaluator added that the benefit of using C-THRU Navigator exceeds the slight discomfort and in time they would get used to the change in comfort.

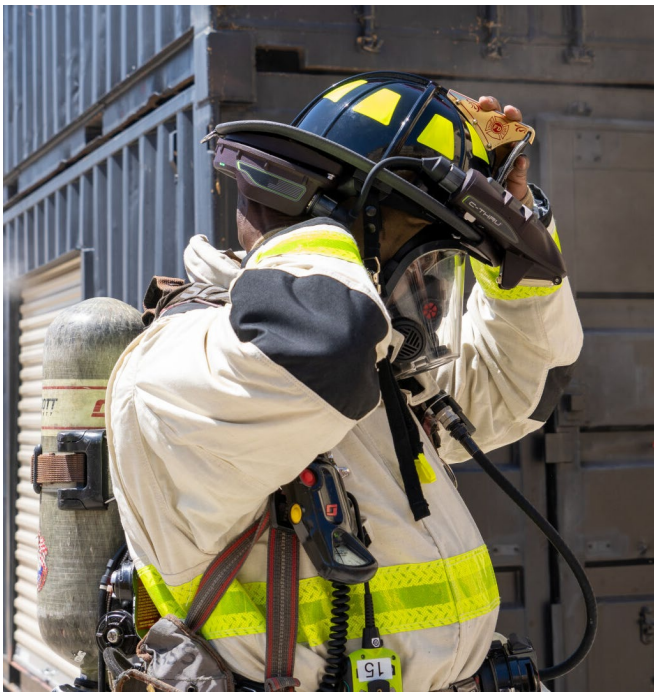

**Figure 3-4 Evaluator attempting to adjust helmet fit using the rachet under C-THRU Navigator hardware**

During the Engine Company scenario, five evaluators somewhat agreed and one strongly agreed when asked if the addition of C-THRU Navigator on the helmet did not cause discomfort. Evaluators noted that the weight of the helmet requires adjustment, mentioning that the helmet lacks left to right balance but is well balanced front to back. One evaluator stated that while conducting certain movements, they felt the helmet touch the collar of their turnout gear.

During the Ladder Company scenario, evaluators had mixed feedback when asked if the addition of C-THRU Navigator on the helmet did not cause discomfort. Two evaluators somewhat agreed and three strongly agreed, stating that no discomfort was felt during short term operations. An evaluator who neither agreed nor disagreed stated that the device was noticeably heavy. One evaluator strongly disagreed, noting that the location of the lens forced them to put their neck in a downward position in order to see straight ahead, which caused strain on their neck as they used the helmet throughout the day; they expressed concern about long-term use.

Four evaluators strongly agreed, and one somewhat agreed that the C-THRU Navigator did not cause eye strain or visual discomfort throughout the OFA. Two evaluators somewhat disagreed and one neither agreed nor disagreed. One evaluator who agreed mentioned they had no issues changing focus between the heads up display (HUD) and the actual environment because they are used to doing so with the Scott Sight In-Mask Thermal Imager. One evaluator mentioned that any eye strain due to refocusing was caused by the HUD fogging up during the OFA. The evaluators who disagreed mentioned that they had to tilt the position of the HUD to be able to focus their eyes without strain.

### 3.1.3 EASE OF USE

Throughout the OFA, evaluators used the buttons on the C-THRU Navigator device to identify their entry point into the building, issue a Mayday alert, respond to a face-to-face check, and respond to PAR checks. In general, evaluators found that the buttons were easily accessible and easy to operate but it was difficult to distinguish the buttons from each other. That being said, evaluators mentioned they would probably be able to locate the correct button for various functions intuitively with prolonged use and practice of the device. Evaluators also valued the button resistance and the need to press and hold buttons as a mechanism for preventing accidental activation of different functions.

During the Ladder Company scenario, evaluators noted that the existing ridges between the buttons are not pronounced enough and that the buttons were hard to find confidently with firefighting gloves on – further information compatibility with personal protective equipment can be found in Section 3.1.7. However, evaluators appreciated that there are only three buttons and believe locating them would get easier with more training and experience. This was evident in that evaluators were more confident in their ability to locate and identify buttons in later scenarios. One evaluator stated that it might be easier to find a button on a radio or lapel mic rather than the current placement. Most evaluators were able to avoid accidental activation or resetting of "entry point" and "Mayday" buttons; they noted that the buttons' resistance is strong enough to prevent accidental reset and that they need to be pressed and held. One evaluator noted that it is possible to activate an incorrect function as the wrong buttons could be pressed, but this could be resolved over time.

During the Engine Company scenario, one evaluator mentioned that the button to identify entry point was easy to use but not entirely intuitive to locate. It was again mentioned that location of the button would become more familiar with practice. Two evaluators provided the same feedback for face-to-face checks: the button to acknowledge the check was easy to use but not intuitive to locate. Evaluator feedback was slightly more positive for PAR checks, as they were more intuitively able to locate the correct button. However, three evaluators mentioned that the main difficulty they had in responding to PAR checks was that they could not see the PAR notification on the HUD. Despite this, four evaluators praised the ability of being able to simply press a button to respond to a PAR check without having to verbalize their status to an incident commander.

### 3.1.4 MANEUVERABILITY

During the Engine Company scenario, evaluators mentioned that visualization capability of C-THRU Navigator device improved hose operations. Hands-free operation of C-THRU Navigator allowed for better handling of the hose, and evaluators were able to see the hose line. Additionally, evaluators said that being able to see distinct objects in the room would help improve the accuracy of water placement in a real operation. Evaluators had to move more slowly while crawling and performing duck walks, as they were conscious of the added weight of the device to the helmet, especially during the Engine Company scenario.

During the Ladder Company scenario, evaluators said the visualization capability improved search-and-rescue operations by being able to distinguish specific objects in the room. However, evaluators also cited the relatively narrow field of view (FOV) of the display as something that would slow down the speed of a search and rescue operation, requiring firefighters to take a slower, more methodical approach to gain awareness of their surroundings. Evaluators carried but did not use hand tools in this scenario and praised the hands-free visualization capability of the device. Evaluators also said that the visualization capability helped them to ascend and descend stairs in low visibility environments.

Figure 3-5 Evaluators wearing C-THRU Navigators during the Engine Company scenario

In general, C-THRU Navigator had only slight impacts on maneuverability. Evaluators mentioned that the device caused a left-to-right imbalance in the helmet but did not create a front-to-back imbalance. One evaluator also noted the inability to adjust the system (i.e., move the screen up or down) impacted their balance because they had to lean their head forward to view the screen properly. Evaluators also said they were conscious of the added weight of the device to the helmet when first donning the device. However, they became more accustomed to the weight of the device throughout the OFA.

C-THRU Navigator devices remained in place during all movements and operations. Evaluators appreciated the sturdiness of the mounting mechanism. However, the HUD screen occasionally moved during the OFA, specifically when evaluators dropped to their knees. Evaluators said that it was easy to readjust though. In a real incident, firefighters would readjust the screen if time permitted. Otherwise, they would continue work as usual.

The device did not get caught on any snag points during the OFA. However, evaluators mentioned that it could get caught on snag points in particularly tight spaces, such as tunnels or when crawling through rubble piles, that may be encountered in operational responses.

### 3.1.5 LIGHTS

Evaluators had mixed feedback when asked if the C-THRU Navigator's lights – lasers on the front and taillights on back – were useful for operations. Evaluators found the taillights particularly beneficial when someone was in Mayday mode. The automatic shift in the light display from green to flashing red when in Mayday mode (Figure 3-6) caught their attention. Evaluators also found the taillights visible from a distance and appreciated them as a tool that assured them that signals were successfully transmitted. Some evaluators didn't notice or found less value in the front laser. Another evaluator found that the front laser interfered with their view.

**Figure 3-6 Laser in use during operational scenarios and taillight shift from green (left) to red (right) indicating Mayday mode**

### 3.1.6 CAPABILITY

Responses to the questionnaire related to the overall capability of C-THRU Navigator appear in Figure 3-7. Based on their experiences, evaluators stated that C-THRU could be used as a tool to enhance operations and improve fire service safety.

The majority of evaluators found that C-THRU Navigator allowed them to efficiently move through the fire props during the assessment. Feedback from evaluators included that the system assisted them in visualizing the area and therefore helped them determine in which direction to proceed. Evaluators also remarked that it provided a quick visual of the environment that increased their situational awareness.

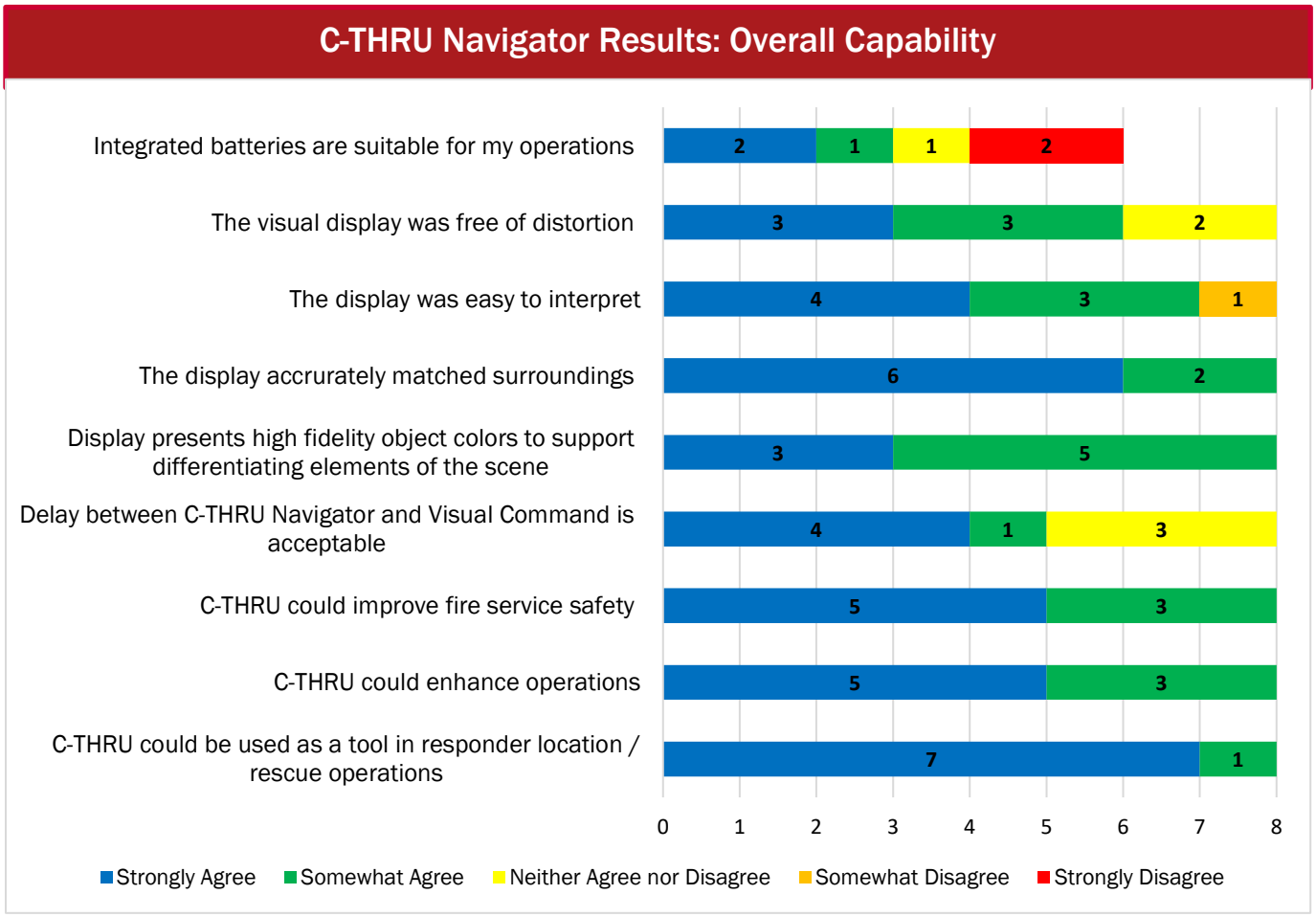


**Figure 3-7 C-THRU Navigator Results: Overall Capability**

During the Ladder Company scenario, one evaluator noted it was advantageous to be able to navigate stairs without having to hold a thermal imaging camera; still, they did need to adjust C-THRU Navigator while moving up the stairs. It was also noted that the darker the environment, the better the visuals on the HUD, which is the case with any thermal imaging camera. One evaluator who somewhat agreed when asked if they found C-THRU Navigator allowed them to efficiently move through the fire prop, as they found that the reduced depth perception negatively impacted them.

Responses to the questionnaire related to the capability of C-THRU Navigator during the Engine Company scenario are listed in Figure 3-8. The following subsections provide a summary of the specific feedback that was given during the OFA.

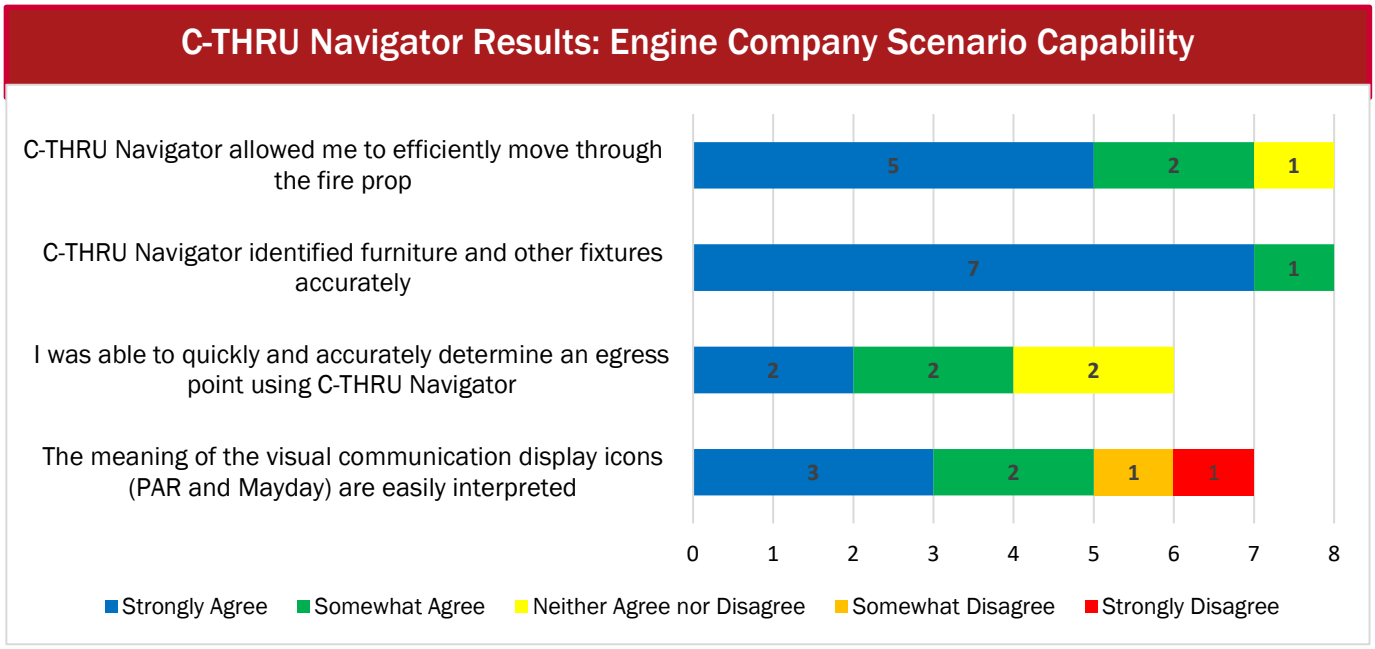


Figure 3-8 C-THRU Navigator Results: Engine Operations Scenario Capability

## Navigation and Identification

All evaluators found that C-THRU Navigator accurately identified furniture and fixtures throughout the fire prop. During the Engine Company scenario, the majority of the evaluators either strongly or somewhat agreed that C-THRU Navigator allowed them to efficiently move through the fire prop. The one evaluator who neither agreed nor disagreed that C-THRU Navigator allowed them to efficiently move through the fire props attributed their response to their being on the nozzle of the hose during operations which provided a narrow field of view. As a result, they resorted to their sense of touch in lieu of relying on the imaging provided through the display.

Figure 3-9 Evaluator wearing C-THRU Navigator in a fire prop during manikin search

## Icon Displays

All evaluators except one either strongly or somewhat agreed that the display was easy to interpret. One of these evaluators, however, noted that full horizontal field of vision was not always displayed and that the helmet had to be seated just right for the full display to be viewable. The evaluator who somewhat disagreed that the display was easy to interpret attributed their opinion to having looked in the wrong spot of the display based on information provided in the Familiarization Session presentation.

Evaluators gave mixed feedback on the visual communication display icons (i.e., PAR and Mayday) being easy to interpret. An evaluator who strongly agreed stated they could see the icons accurately and without distortion. However, the two evaluators who somewhat disagreed and strongly disagreed indicated they did not see the icons. Additionally, one evaluator noted that a preexisting medical condition resulted in their having to squint in order to decipher the three letters being displayed, then guess that it was a PAR check. Another evaluator suggested the icons should be larger to enhance effectiveness.

## Visuals

Overall, evaluators found C-THRU Navigator has good image clarity and the ability to accurately identify objects and details. The example in Figure 3-10 shows a bed frame and responder's SCBA tank as seen by responders wearing C-THRU Navigator and relayed to Visual Command.

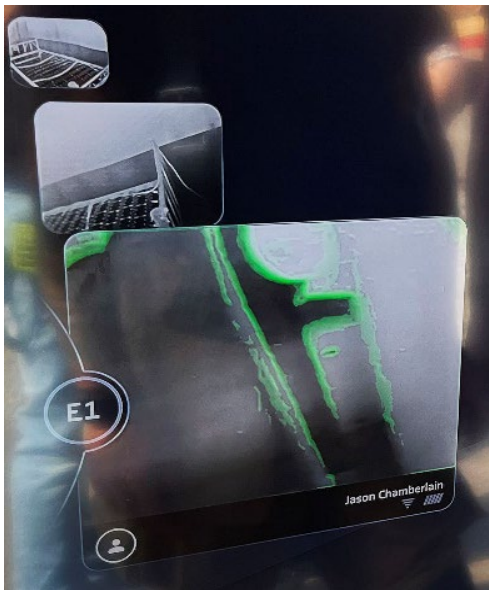


**Figure 3-10 Bedframe (upper and center) and SCBA tank images from C-THRU Navigator**

All evaluators strongly agreed or somewhat agreed that the display presented high-fidelity object colors to support differentiating elements of the scene. Two evaluators appreciated the object shading and found the colored lines to be helpful. Others noted that since the images are temperature based, the colors are limited, which could be problematic for those with vision issues. One evaluator reported that using the grayscale mode with the green was not as effective for them due to the more muted color contrast, however this is user preference.

When asked if the visual display was free of distortion, three evaluators strongly agreed, three somewhat agreed, and two neither agreed nor disagreed. Two who strongly agreed found C-THRU Navigator provided a clean image and the visuals transmitted matched what was in the fire props. Two participants who somewhat agreed noted that the visuals degrade when the projector lens gets dirty and mentioned fingerprints and debris from a fire response would impact the view. Two evaluators that neither agreed nor disagreed reported they experienced fogging; one of the two stated that it distorted the display.

All evaluators strongly agreed or somewhat agreed that C-THRU Navigator identified furniture and other fixtures accurately. One evaluator shared that there were some instances, however, when they needed to get close and touch the item to determine what it was. Another said they had to move their head and neck around in order to change their overall field of vision.

## Timeliness between C-THRU Navigator and Visual Command

Evaluator responses regarding whether the connectivity and delay time between C-THRU Navigator and Visual Command were acceptable ranged from strongly agree to neither agree nor disagree. Evaluators found there to be minimal, if any, delay in relaying information.

This prompted a broader range of discussion and issues identified that relate to information sharing between C-THRU Navigator and Visual Command. One evaluator noted that they lost the video feed when the iPad timed out – which can be potentially addressed by changing the iPad settings for timing out; another experienced a small delay when toggling between people on the iPad. There was concern that cellular connectivity is environment dependent and could cause delays, particularly in rural environments or areas with limited communications infrastructure. The amount of Visual Command tablets running could also impact the connectivity.

The test environment lacked a range of realistic environmental factors to fully stress the reliability of the system's connectivity. Nonetheless, some connectivity issues were encountered during the dry run at one fire prop as indicated in the Deviations Section (2.4). While a number of other variables can impact cellular connectivity, some of the environmental factors of concern include:

- the distance between the incident command stations equipped with Visual Command and evaluators wearing C-THRU Navigators
- the number of C-THRU Navigators assigned to one tablet
- the number of parallel teams making use of multiple C-THRU Navigators and Visual Command pairings in the same area
- LTE phone signal strength and connectivity
- the number, size, and types of buildings and other obstructions which a cell phone signal needs to reliably connect into, through and around

Consequently, a number of evaluators requested that the system provide an option for lower resolution video or other ways to increase the reliability of video feeds (e.g., video compression) in situations where they would expect to have cell phone signal reliability issues in operational settings. For the purposes of the OFA, in a benign setting for the factors mentioned above, evaluators noted that the video feed worked fine and no cut-out was experienced.

## Power Source

Evaluators were advised that battery life of the C-THRU Navigator was one hour with a one-to-one charge time. Evaluators gave mixed feedback on the integrated battery that powers the C-THRU Navigator. When asked if integrated batteries were suitable for their operations, two strongly agreed, one somewhat agreed, one neither agreed or disagreed, and two strongly disagreed. Evaluators who strongly agreed want to see the developer invest effort into a rapid charging method. The current charging method is shown in Figure 3-11. The evaluator who neither agreed nor disagreed noted charging needs/battery suitability is situational and would need to be a consideration in a department's CONOPS, but a swappable battery would be beneficial. Those who strongly disagreed stated two hours would be an optimal run time, with 30 minutes optimal for recharging.


Figure 3-11 C-THRU Navigator Charging Method

### 3.1.7 COMPATABILITY WITH PPE

Responses to the questionnaire related to C-THRU Navigator's compatibility with personal protective equipment (PPE) appears in Figure 3-12.

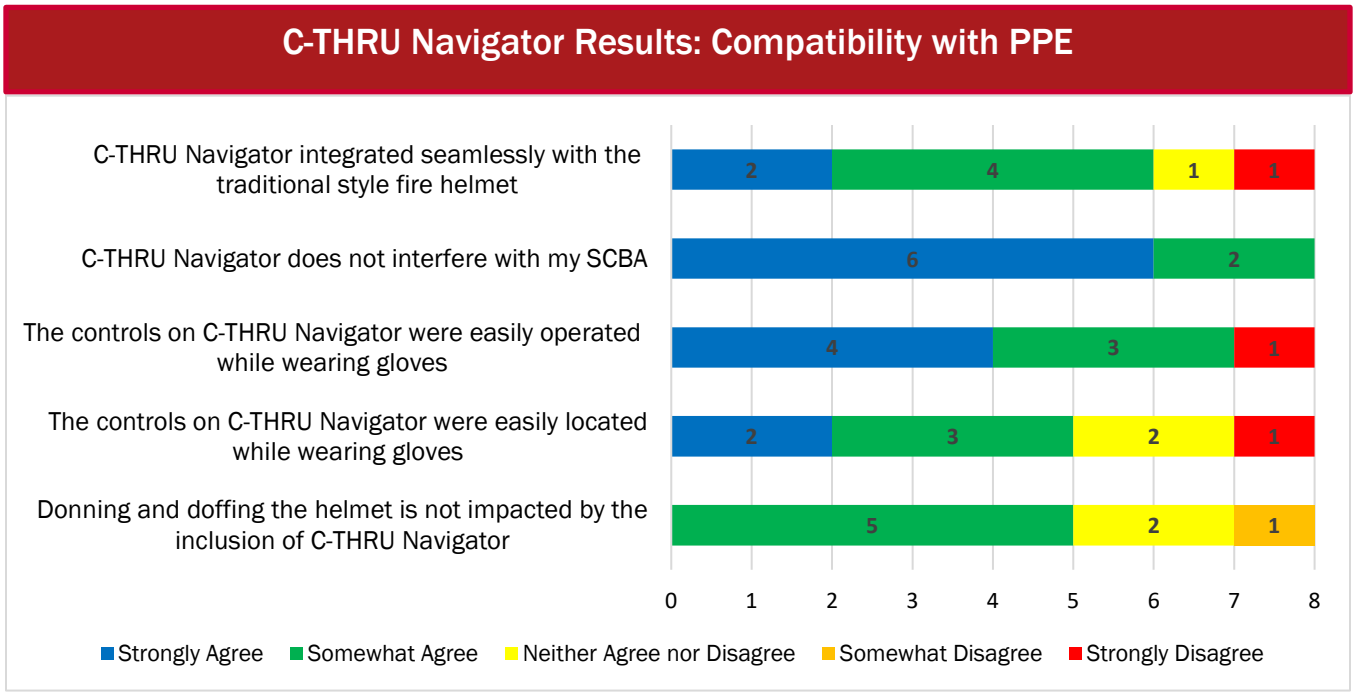


Figure 3-12 C-THRU Navigator Results: Compatibility with PPE

Six evaluators strongly or somewhat agreed that C-THRU Navigator integrated seamlessly with the traditional style fire helmet. One evaluator neither agreed nor disagreed, while another strongly disagreed with the statement. The evaluator who strongly disagreed was concerned that the device would not be able to be integrated based on their department's current configuration, specifically due to the use of visor style eye shields (Figure 3-13). One evaluator commented that the device is not a "one option fits all" solution; they added that they appreciate the integration with PPE due to helmets varying from department to department and person to person. Another evaluator brought up that the device makes the helmet heavier and out of balance; further discussion on balance can be found in Section 3.1.4.

Figure 3-13 Example visor-style eye shield

Five evaluators somewhat agreed that donning and doffing the helmet was not impacted by the inclusion of C-THRU Navigator. Two evaluators neither agreed nor disagreed, while one somewhat disagreed, noting it was harder to get to the screw/rachet to tighten the basket in the helmet. Figure 3-14 shows the placement of C-THRU hardware in relation to the rachet.

Figure 3-14 Rachet in relation to C-THRU Navigator hardware while worn (left) and in hand (right)

All evaluators agreed that C-THRU Navigator did not interfere with their SCBA. One evaluator noted that they did not feel any contact with the SCBA when moving their head around in multiple directions. One evaluator did express concern about the impact when throwing up a ladder, though they did not experience any issues during the OFA.

Evaluators offered mixed feedback on the ease of locating C-THRU Navigator controls while wearing gloves. Two evaluators strongly agreed the controls were easily operated while wearing gloves, one of whom thought the buttons were also easily distinguishable from each other. They commented that locating the controls got easier with each use. Three evaluators somewhat agreed: they also found that the ability to locate the controls became easier with each use. Two evaluators neither agreed nor disagreed and another strongly disagreed. Multiple evaluators wanted the control button configuration (Figure 3-15, left) to have a defined, tactile landmark for the middle button (like the bump on the F and J keys on a computer keyboard). Another suggested a better physical separator between buttons is needed to help wearers find the correct button. One evaluator remarked it was difficult to confidently locate the control buttons. Another concurred saying that the buttons were very hard to landmark quickly and efficiently with gloves (Figure 3-15, center and right).

Nevertheless, the majority of evaluators either strongly agreed or somewhat agreed that the controls on C-THRU Navigator were easily operated while wearing gloves, while one strongly disagreed.


Figure 3-15 Control buttons configuration (left) and view of gloved hand on control buttons from the front (center) and profile (right)

## 3.2 VISUAL COMMAND

The subsections that follow provide summaries of the specific feedback given during the OFA as it relates to the capability and usability of Visual Command.

### 3.2.1 CAPABILITY

Figure 3-17 lists responses to the questionnaire related to Visual Command's Capability. Overall, evaluators strongly agreed or somewhat agreed that Visual Command increased their ability to manage the scenario responses, and found the live feed to be valuable for incident command. They highlighted that the views available through Visual Command are critical to the success of operations and provide a collaborative response environment, as well as insights they wouldn't otherwise have such as position of a firefighter (e.g., stationary or moving) and layout of a response area. They added that Visual Command had good image clarity with discernible features and objects. Responders provided a response varying from "somewhat agree" to "strongly agree" that the time between EVAC order issued and action by responders to evacuation was sufficient for their operations, with one responder noting that some of the firefighters did not respond right away, another noting that he didn't immediately see the order, and another noting that it would depend on unit-specific procedures. Evaluators found the display to accurately match the actual surroundings with good image quality and discernible features. Most responders said the relay time between the C-THRU and visual command was acceptable, with one firefighter caveating that additional testing in more challenging building environments would provide more insight.

Figure 3-16 Evaluators using Visual Command to view responder status (top) and issuing events using Visual Command (bottom)

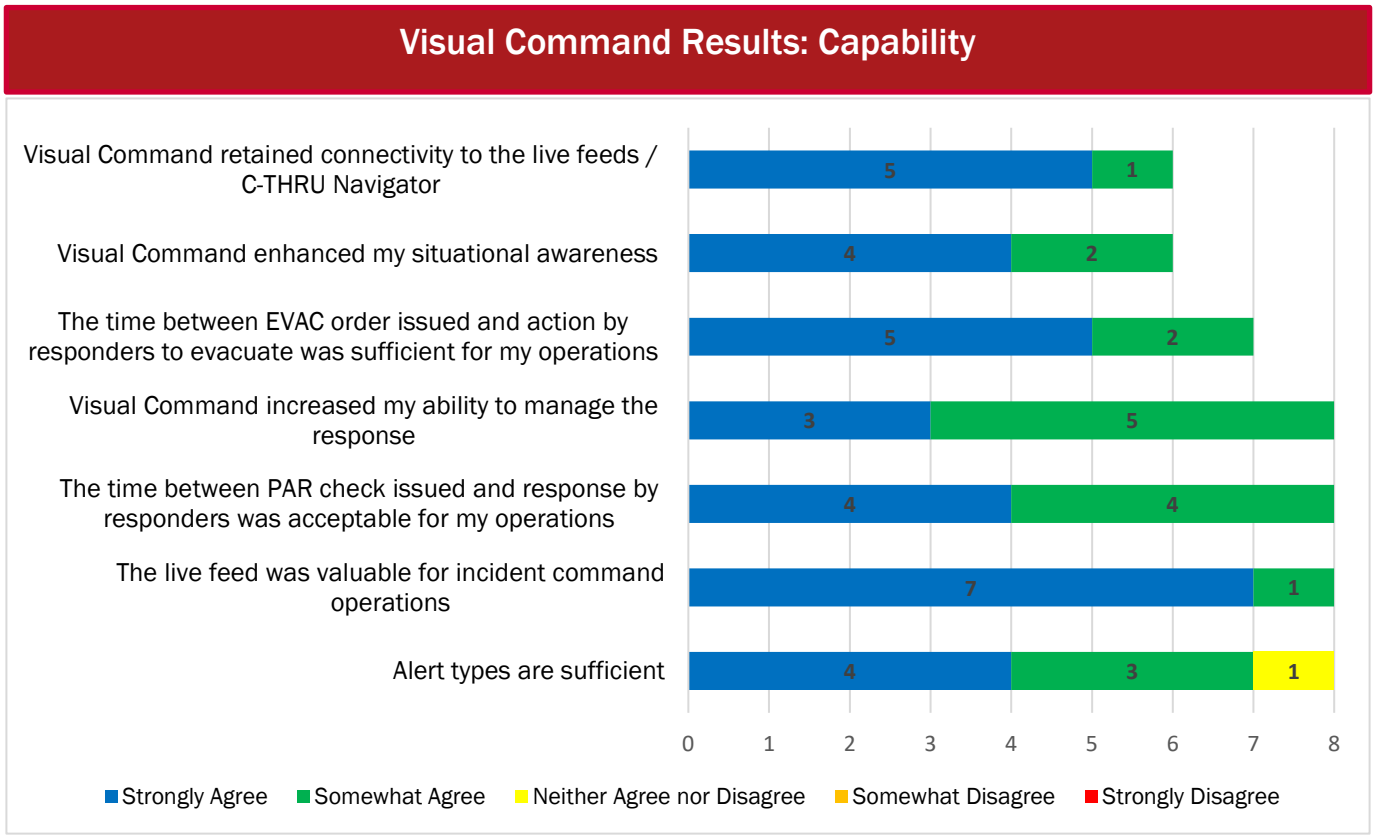


Figure 3-17 Visual Command Results: Capability

## Alert Types

The majority of evaluators either strongly agreed or somewhat agreed that provided alert types were sufficient. One evaluator, who neither agreed nor disagreed, suggested improvements such as adding a flashing element for users in Mayday. Additionally, five evaluators indicated the inclusion of audible alerts could be useful, especially if connectivity is limited, if the incident commander is performing an alternative role, or if they are unable to view the Visual Command screen. Evaluators specifically suggested providing an audible alert for Mayday and when any personnel changed status (i.e., PAR acknowledged).

## Timeliness of Event Receipt and Action

Feedback about the timing of firefighter responses to PAR checks being acceptable ranged from somewhat agree to strongly agree, with three evaluators suggesting that this method should be leveraged as a way to save time when managing a large team as it would offset challenges of listening to and responding to individual firefighters over radio. Responders either somewhat or strongly agreed that the time between EVAC order issued and action by responders to evacuation was sufficient for their operations. One responder noted that some of the evaluators did not respond immediately, and another responded that they didn't immediately see the order. One evaluator suggested including a timer at the bottom Visual Command screen to track the length of time of the response. Other feedback stressed that PAR checks and EVAC orders should be adaptable and customizable to a unit's tactics and procedures that are unique to each team and potentially different for certain settings and use cases.

## Situational Awareness

Evaluators stated that Visual Command could improve situational awareness and help enhance incident commanders' ability to manage a response. They indicated that the system's real-time updates on responders and displays of their overall surroundings (e.g., building orientation and interior aspects such as doorways, furniture, or staircases) added value to the overall command presence (Figure 3-18). All evaluators strongly agreed or agreed that Visual Command retained connectivity to the live feeds and C-THRU Navigator. Evaluators also appreciated the ability to identify egress points and use tactical timestamps. A number of evaluators recommended additional features to further enhance situational awareness. This included a grid view of video feeds and the ability to focus on one video feed.

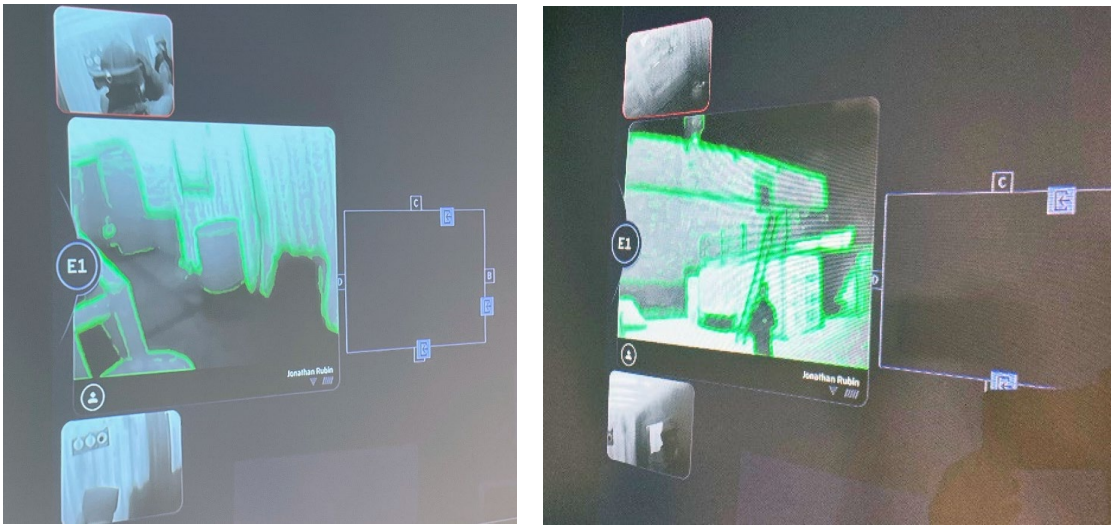


**Figure 3-18 Visual Command display of a building interior (left) and exterior (right)**

## Usability

Responses to the questionnaire related to the usability of Visual Command appear in Figure 3-19. Overall, evaluators found Visual Command intuitive to use and appreciated the volume of information provided in a non-overwhelming fashion. One evaluator highlighted the accommodations for thumbs on the tablet, and how they aligned with the interface for issuing actions. Additionally, they found it easy to view as well as toggle between live feeds. While all evaluators either strongly agreed or somewhat agreed that toggling between C-THRU Navigator live feeds was intuitive, one noted that they would prefer the ability to see all users of C-THRU Navigator simultaneously instead of seeing one company at a time. Most evaluators said Visual Command provided useful situational awareness information; they appreciated the ability to see what the responders were doing and to home in on an individual. Another stated Visual Command worked well on the premise of providing information and tools to an incident commander without an overload of information. However, one somewhat disagreed and contradicted that the display was cluttered due to the limited spacing on the screen; they expressed concern about how readable the screen would be when viewing multiple companies.

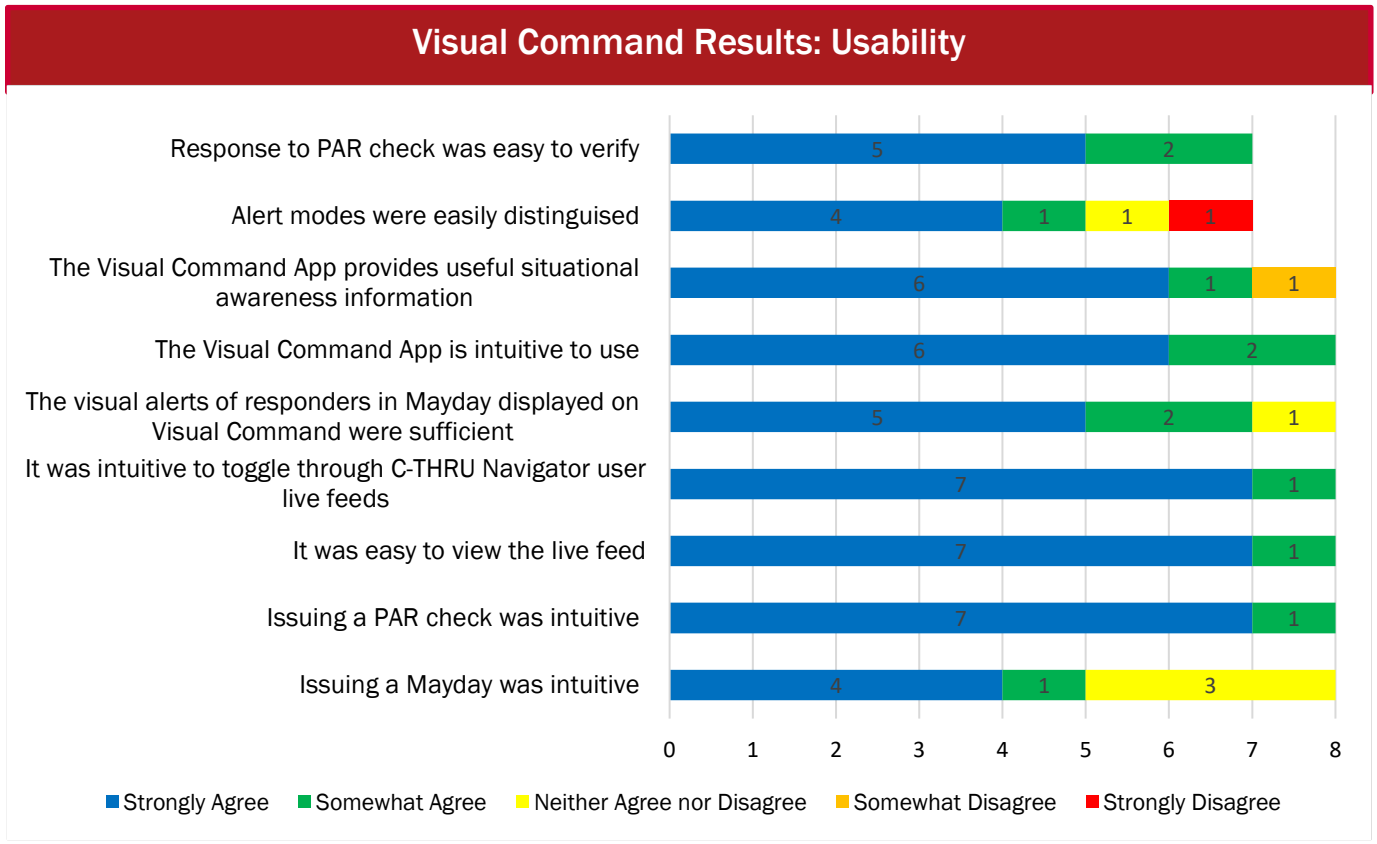


Figure 3-19 Visual Command Results: Usability

## Issuing Events

Evaluators found issuing PAR checks was intuitive. One evaluator appreciated that the button needed to be held down for a few seconds to initiate a PAR since this could greatly reduce the risk of accidental initiation. Evaluators also noted that initiating a PAR check was easily to perform, acknowledge, and cancel. They also valued the options to issue a PAR to an individual or group. One evaluator commented that response to a PAR check was easy to verify on screen.

The majority of evaluators strongly or somewhat agreed that issuing a Mayday alert was intuitive (Figure 3-20). One appreciated the intentional delay in activation that prevented accidental activations. Another stated it was easy to use. One evaluator suggested adding an audible alert when a Mayday was issued as another method of confirmation. Evaluators also stated that the ease of operation improved with practice, noting that operations would become easier to use over time.


Figure 3-20 Evaluator issuing a Mayday using Visual Command

### Alerts Displays

Evaluators had mixed feedback on Visual Command's alerts being easily distinguishable. Two evaluators who strongly agreed noted that the icons being color coded helped make them easy to see and read. One evaluator strongly disagreed with this statement, countering that the alerts were small and difficult to see. They suggested increasing the size of the icons or making them bold.

Figure 3-21 Mayday alert displayed on Visual Command

Evaluators indicated enhancements to the Mayday alerts were needed to ensure they draw users' attention. Suggestions included adding a bolder red outline to the firefighter's live feed display in Mayday mode and adding flashing visuals or an audible alert. Mayday is currently indicated on the incident command's video feed by an icon at the top center, a red outline that appears around the image of the user's feed, and the symbol, a circle, next to their name in red (Figure 3-21). One evaluator said that the use of one symbol, a circle, to represent all actions and signaling those with only a color change (e.g., circle changes to red when in Mayday, green when PAR request is confirmed) could lead to confusion because multiple alerts could be needed simultaneously.

Evaluators stated that having a color-coded icon next to the responder's name was a great feature. They appreciated the instantaneous updates to a responder's status changes. Some evaluators noted that being able to view the time of each event (e.g., Mayday) could be critical in reconstructing events by reviewing video post-event.

## 3.3 GROUP DISCUSSION

This section covers the evaluators' overall assessment of C-THRU Navigator and Visual Command, including suggestions for improvements as recorded during the group discussion.

### 3.3.1 OVERALL PERFORMANCE

Evaluators saw a benefit to C-THRU and believed that it has potential to be a safety tool for fire response operations. All evaluators found C-THRU Navigator's display had high-fidelity object colors that support differentiating elements of the scene. They also found object shading and colored lines helpful. Feedback included that C-THRU assisted them in visualizing the area and therefore helped them determine the direction in which they wanted to proceed. They also shared that the system provided a quick visual of the environment that increased situational awareness. The visualization capability was found to improve search and rescue operations by helping users distinguish specific objects in the room. However, evaluators were also concerned that the relatively narrow FOV of the display could slow down the speed of an operation as it would require firefighters to take a slower, more methodical approach to gain awareness of their surroundings.

Evaluators had mixed feedback when asked if C-THRU Navigator's visual display was free of distortion. Some found it had a clean image and visual transitions that matched what they saw with the naked eye in the fire props. Others were concerned, however, that the projector lens could degrade when it became dirty, impacting the image. Two evaluators experienced fogging during the OFA, one of whom stated that it resulted in a distortion of the display.

The majority of evaluators found C-THRU Navigator compatible with SCBAs and traditional style fire helmets however there was concern about adaptability with visor-style eye shields. Evaluators had mixed feedback on the ease of locating C-THRU Navigator controls while wearing gloves; they suggested enhancements be made to the ridges between the buttons or to the buttons themselves to address this issue.

Evaluators also voiced concerns about the comfort, weight, and placement of C-THRU Navigator. The increase in weight was noticeable and introduced neck strain that could cause discomfort over time. Some evaluators experienced balance issues with the helmet as it slipped and required readjustment to ensure the visual display was within their line of sight. This was also attributed to the additional weight that C-THRU Navigator introduced to the helmet. The helmet's ear flap was turned out to accommodate C-THRU Navigator, which made it difficult to reach the ratchet adjustment on the back of the helmet; this was attributed to the size and location of C-THRU Navigator.

Evaluators also had concerns about the cellular connectivity, transmission of data, and streaming capabilities, particularly in rural environments or areas with limited communication infrastructure. The test environment lacked a range of realistic environmental factors to fully stress the system's connectivity reliability. Therefore, evaluators would like to see the results of additional testing in a more complex environment for response operations.

Evaluators indicated that the system's capability added value to the overall command presence as it provides real-time updates on responders, as well as displays of their overall surroundings. They highlighted that the views available through Visual Command are critical to the success of operations and provide a collaborative response environment as well as insights they would not have had otherwise, such as the position of a firefighter and layout of a response area. They added that Visual Command had good image clarity with discernible features and objects. Most evaluators also found the alerts in Visual Command sufficient, however they desired a more prominent display for Maydays.

### 3.3.2 OPPORTUNITIES FOR IMPROVEMENT

Evaluators made suggestions for improving various aspects of both C-THRU Navigator and Visual Command, which are listed below.

#### Suggestions to improve C-THRU Navigator:

- Make buttons more identifiable (e.g., increase ridge size between buttons, add a bump to the center button) to increase usability
- Increase size of alert displays (evacuation in particular) to enhance situational awareness
- Add the ability to adjust or move the screen up and down to better align visual displays to enhance usability and fit

- Include an option for lower resolution video – or an alternate method to increase the reliability of video feeds (e.g., video compression) – to improve communication in low connectivity environments
- Explore swappable batteries and/or rapid charging methods
- Design a storage method with a charging capability option specifically for use in apparatus for helmets outfitted with C-THRU Navigator

## Suggestions to improve Visual Command:

- Enhance Mayday alert (e.g., making current red outline bolder, adding a flashing component, including audible alerts, changing the symbol to something other than a circle) to ensure it grabs the attention of incident command
- Add capability to display all companies using C-THRU Navigator simultaneously for increased situational awareness
- Increase the size or bold the font of alerts to enhance ease of use
- Add audible alerts for increased situational awareness for wearers
- Include a timer at the bottom of the display to track length of alert response time and for event reconstruction
- Add a library of basic building outlines (e.g., rectangular, "I"-shaped, "T"-shaped) for incident command to better visualize responder locations on scene

# 4.0 CONCLUSIONS

On August 24, 2023, NUSTL led an OFA of the C-THRU system. C-THRU is a real-time visualization system intended to provide firefighters with technology that can minimize disorientation in smokey, low-light or otherwise challenging response environments by offering a suite of imaging, navigation, and visual communication applications via the helmet-mounted C-THRU Navigator and corresponding Visual Command platform. The OFA was conducted at the San Diego Fire-Rescue Department's Training Facility in San Diego, California and consisted of eight firefighter evaluators using C-THRU Navigator and Visual Command while conducting job tasks typically encountered during fire response and incident command operations.

Evaluators appreciated the development of C-THRU as a method of advancing navigation and situational awareness capabilities in the fire service. They praised the clarity of images being displayed, as they were easily identifiable almost instantaneously, and the system's hands-free thermal imaging capability. However, evaluators also voiced concerns about the comfort, weight, and placement of C-THRU Navigator. They stated the increase in weight was noticeable and introduced neck strain, which could cause discomfort if worn for longer periods of time. Some evaluators experienced balance issues with the helmet as it slipped and required readjustment to ensure the visual display was within their line of sight; this was also attributed to the additional weight that the C-THRU Navigator introduced to the helmet. The helmet's ear flap needs to be turned out to accommodate C-THRU Navigator, which makes it difficult to reach the ratchet adjustment on the back of the helmet; this was attributed to the size and location of C-THRU Navigator.

Additionally, there were concerns about the cellular connectivity, transmission of data, and streaming capabilities, particularly in rural environments or areas with limited communication infrastructure. The test environment lacked a range of realistic environmental factors to fully stress the system's connectivity reliability. Therefore, evaluators would like to see the results of additional testing in a more complex environment and response operation. More complex factors suggested by the evaluators included increased distance between the incident command stations equipped with Visual Command and evaluators wearing C-THRU Navigators; increasing the number of C-THRU Navigators assigned to one tablet; increasing the number of parallel teams making use of multiple C-THRU Navigators and Visual Command pairings in the same area; varying LTE phone signal strength, as well as increasing the variety of buildings and other obstructions that a cell phone signal needs to reliably connect into, through and around.

Overall, evaluators saw value in Qwake Technology's C-THRU system as a resource for fire response operations. Evaluators suggested improvements related to alerting, visual displays, and button form factor to enhance usability, and to aid technology adoption by first responders.

# 5.0 REFERENCES


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