

# Comparing Live and Virtual Simulation for Multi-Agency UAS Operations

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## ABSTRACT

As emergency response organizations implement Unmanned Aerial Systems (UAS), the complexity of multi-agency incident scenes increases, requiring targeted training for incident commanders. This study compares two exercise formats: Live Simulation (LS) and Virtual Simulation (VS), using five predefined UAS coordination events to examine their distinctive values and inform exercise design. Data were collected from 30 subjects over 2 days in both formats using a multiple-case study design. VS offered superior controllability and cue salience for complex scenarios, while LS provided authentic use of UAS it was constrained by logistics and unpredictability. Neither environment triggered systematic UAS risk assessment or explicit airspace coordination, revealing training gaps beyond simulation fidelity. Findings highlight the complementary strengths of both formats: VS excels in building foundational skills and ensuring scenario control, while LS fosters equipment familiarity and operational confidence in real-world conditions, providing actionable insights for designing effective UAS-integrated multi-agency exercises.

## Keywords

Training, Virtual Reality, Virtual Simulation, Live Simulation, Unmanned Aerial Systems (UAS).

## INTRODUCTION

Unmanned aerial systems (UAS), or drones, are increasingly integrated into emergency response operations (Glantz et al., 2020). Organizations investing in drone capabilities must ensure not only pilot proficiency but also that Incident Commanders (ICs) understand how to effectively integrate UAS into incident management. Drones provide rapid imagery, real-time data, and sensor-based insights, enabling situational awareness, hazard assessment, and operational support for reconnaissance, search and rescue, and logistics, making them a transformative resource for efficient and safe emergency response (COLLARIS Drone Foresight Report, 2024). However, effective use of UAS requires clear tasking, communication, and coordination between UAS pilots and ICs, as well as an understanding of UAS capabilities, limitations, and operational risks. This calls for training that deepens mutual understanding of roles and operational constraints in UAS-supported contexts.

As UAS operations become more embedded in multi-agency emergency environments, training must evolve to prepare ICs and UAS pilots for coordinating multiple simultaneous UAS across organizational boundaries. Current UAS training often focuses on equipment handling, neglecting the cognitive and collaborative dimensions of real-world drone use in multi-agency contexts. Live simulation (LS) using real equipment (e.g., drones), people, and controlled-fire scenarios is often considered the “real” training format, but is resource-intensive and constrained by safety and logistics (Engelbrecht et al., 2019; Wijkmark et al., 2021). Virtual simulation (VS), supported by virtual reality (VR) technology, provides controllability, repeatability, and dynamic scenario design; however, questions remain about its fidelity and its ability to deliver learning outcomes comparable to LS (Abich

et al., 2021; Engelbrecht et al., 2019). So far, we have found no published studies that directly examine how LS and VS training contexts address UAS-related training challenges in practical multi-agency settings, with particular focus on the IC role.

Despite the growing interest in VS, hesitation persists due to concerns, for example, about managing technological complexity, achieving high fidelity, and transferring VS training results to operational contexts. Comparing LS and VS is challenging, and evaluations often focus on cost, time, or participant experience; however, these do not reveal how well each format supports the intended learning objectives. Measuring learning effectiveness and assessing the transfer of training performance outcomes to the operational context can be challenging but beneficial.

Directly comparing LS and VS is inherently challenging because the two formats differ fundamentally in their affordances and constraints. LS offers authentic interaction with real equipment but is limited by resource availability and safety restrictions, while VS provides high controllability and repeatability but lacks full sensory fidelity and requires technical proficiency. Traditional evaluation criteria, such as cost, time, or participant experience, do not reveal how well each format supports intended learning objectives. To address this, the study adopts an event-based approach within a multiple-case design, focusing on predefined UAS coordination challenges (“Events”) that represent critical learning points intended to stimulate higher-order cognitive processes such as decision-making, risk assessment, and interagency coordination. This structured approach enables systematic comparison of how LS and VS support these challenges, offering actionable insights for evidence-based training design. While the training included more than 80 participants, only the ones responsible for UAS coordination were observed.

The aim of this study is to inform evidence-based training design and to guide decisions on the selection and/or combination of live simulation (LS) and virtual simulation (VS) in multi-agency exercises involving UAS coordination. Rather than comparing participant performance, the study focuses on how each simulation modality addresses specific UAS coordination challenges and their distinctive value from a training and learning perspective. This approach provides insights into how LS and VS can complement each other in preparing ICs for UAS-supported multi-agency operations. Accordingly, the study is guided by the research questions: “*How can live and virtual simulation environments enable UAS coordination challenges for incident commanders in multi-agency emergency response?*” Since the simulation training modality depends on the environment, including available objects and possible interactions, a second research question that guided this study was: “*What is the role of the affordances of objects in the training context utilized (LS or VS)?*”

## BACKGROUND

### Increasing Use of UAS and Training Needs in Emergency Response

The need for training when implementing new technology in rescue operations, not only for individual UAS (drones) operators but also for teams and multi-agency settings, is underscored by Murphy et al. (2016). Emergency response often involves multiple agencies, many of which now use or are introducing drones, raising the challenge of integrating a multi-agency perspective on drone use within a limited geographical area. This integration of UAS into multi-agency emergency response introduces coordination challenges that extend beyond single-agency operations. When multiple agencies deploy UAS simultaneously, such as Fire and Rescue Services (FRS), police, emergency medical services (EMS), and specialized units, ICs face compounded complexity related to risk assessments, air traffic management, information integration, and resource allocation. Unlike ground-based resources, UAS operations require three-dimensional spatial awareness and real-time coordination to prevent mid-air collisions, maintain safe separation distances, and avoid interference with manned aircraft such as helicopters. A recent literature review on the role of drones in disaster response highlights several research gaps related to coordination, collaboration, and synchronization in disaster relief, incorporating multiple agencies and UAS (Yucesoy et al., 2025). Drones have been shown to be beneficial for emergency response operations, supporting situational awareness, search and rescue, hazard assessment, and evidence gathering (Bruzzone et al., 2016). They can be deployed quickly, arrive at an incident scene before other emergency response units, and provide dispatch centers with on-site photos or deliver automated external defibrillators (Kristiansson et al., 2024). Effective UAS deployment requires more than technical piloting proficiency: it demands collaboration between the UAS pilot and the IC in charge, rapid interpretation of aerial imagery and other sensor data, air traffic management, and risk assessment (Bird et al., 2025; Clausen et al., 2024). Bruzzone et al. (2016) argue that UAS training must be tailored to the operational context and that simulation offers significant potential for safely replicating hazardous or complex environments that are difficult or dangerous to reproduce in the field. Despite the growing operational relevance of drones, there exists limited research on training UAS teams, particularly on pilot–commander coordination and multi-agency coordination across multiple drones.

When multiple UAS are available at the same incident site, ICs need to know how to use them for task assignments, when to deploy or recall them, and how to prioritize actions and interpret competing information, decisions that often must be made under pressure and uncertainty. This requires sophisticated skills that current IC training may not adequately address, including multi-agency UAS coordination competencies, with emphasis on decision-making and communication rather than solely on single-pilot technical proficiency.

### VR for UAS-related training

VR-based simulation has been explored for individual training in technical inspection and infrastructure contexts, for example, in Albeaino et al. (2022) and Li et al. (2022). These studies highlight the potential of VR-supported training to enhance visual perception, task rehearsal, and environmental immersion, but they do not address emergency response dynamics. Velev et al. (2019) discuss the possibilities of VR and Augmented Reality (AR) for disaster management training, emphasizing scalability, safety, and the ability to train large numbers of responders. They do not provide empirical examples of the role of VR in UAS-supported multi-agency emergency management operations, while a more extensive literature exists on VR for emergency management and IC training (e.g., Feng et al., 2018; Polikarpus et al., 2023). VR has been shown to realistically represent situational complexity, enabling a higher sense of presence, increased cognitive engagement and sense-making, and the safe, resource-efficient repetition for IC training (Wijkmark et al., 2021). This suggests that VR could be similarly valuable for training UAS operations, where perception, information processing, search tasks, and spatial understanding are critical. To date, we are not aware of any published studies that specifically evaluate how different simulation training environments address UAS-related challenges in multi-agency contexts, or how VR-supported VS training environments compare with physical LS training environments.

### Affordances and Constraints of Training Environments

Affordances and constraints are important background concepts for this study, particularly in the context of LS and VS training for UAS. LS often involves a large environment, limited objects, and stringent safety requirements that constrain realism. For UAS training, dividing the invisible *bandwidth* must be considered, which adds requirements for the training (Jhajj et al., 2025; Ray et al., 2022). In VS, these can be visualized. Because visualization fidelity may not be exact, many practitioners argue that this can limit realism. On the other hand, abstract information about distances, measurements, and invisible things (e.g., bandwidth, environmental pollution, statuses) can also be visualized, though this may disrupt the experience or increase cognitive load (Alessi, 1988; Frøland et al., 2025).

The concept of affordance for training, after Gibson's (2014) is an attribute of the environment that creates opportunities for action, and offers a valuable lens for understanding how different training environments enable or constrain learning opportunities. In educational contexts, an affordance is a characteristic enabling specific learning behaviors (Bower, 2008) or a property that shapes how an object can be used (Norman, 1988). In the context of emergency management simulation training, each learning environment offers distinct opportunities to experience operational challenges while imposing constraints. Training exercises in LS provide real-world, physical environments in which participants interact with equipment, experience actual weather conditions, and use authentic communication systems. The nature of LS affords embodied learning, in which participants physically move through space, experience sensory richness (sounds, smells, visual complexity), and use and encounter genuine equipment functionality and limitations, such as battery life and communication range. However, LS is constrained by logistical complexity, cost, safety concerns, and limited control over dynamic variables (Berlin & Carlström, 2011).

Computer-based VS affords high controllability, repeatability, and safety, by allowing scenario customization, frequent reuse, and risk-free practice compared to LS (Hsu et al., 2013). The environmental variables can be adjusted to target specific learning objectives. VS can involve participants in scenarios that would be impractical or impossible to stage in LS (Tate et al., 1997), such as large-scale disasters, hazardous material incidents, or complex coordination, but may be limited in psychological and sensory fidelity, affected by design/technical disruptions, and questioned regarding transferability to real operational contexts (Alison et al., 2013). This study examines how these theoretical affordances manifest in practice during the training of ICs for multi-agency UAS coordination.

## METHODOLOGY

### Study Design

This study examined a multi-agency exercise in which the Fire and Rescue Service (FRS), the Police, and the Emergency Medical Services (EMS) coordinated drone operations. The aim was to explore how LS and VS enable

key (necessary) UAS coordination challenges (Events), with a primary focus on the FRS Incident Commander (IC) role. The research adopted a multiple-case study approach (Yin, 2011) around Events 1–5, first in LS and then in VS.

Two distinct participant groups completed these scenarios on consecutive exercise days, with LS conducted in the morning and VS in the afternoon, in 20 cases in total (see Table 1). Each Event was tested in both formats (LS and VS) with two different participant groups.

**Table 1. Multiple-case study set up**

<b>Exercise 1</b>	<b>Exercise 2</b>	<b>Exercise 3</b>	<b>Exercise 4</b>
<b>Day 1 morning</b>	<b>Day 1 afternoon</b>	<b>Day 2 morning</b>	<b>Day 2 afternoon</b>
<b>LS Group 1</b>	<b>VS Group 1</b>	<b>LS Group 2</b>	<b>VS Group 2</b>
Event 1_LS1	Event 2_VS1	Event 1_LS2	Event 1_VS2
Event 2_LS1	Event 2_VS1	Event 2_LS2	Event 2_VS2
Event 3_LS1	Event 3_VS1	Event 3_LS2	Event 3_VS2
Event 4_LS1	Event 4_VS1	Event 4_LS2	Event 4_VS2
Event 5_LS1	Event 5_VS1	Event 5_LS2	Event 5_VS2

The exercises were conducted as a collaboration between the EU-funded COLLARIS project<sup>1</sup> and the FRS Skaraborg, the Swedish Police, and the EMS in the Västra Götaland Region, involving a total of 80 subjects, but only 30 with roles influencing UAS coordination. The LS took place in designated indoor and outdoor training areas, while VS was conducted in a temporary four-room simulation center using on-site computers and XVR On Scene<sup>2</sup> software.

Five evaluators with experience in emergency management exercise evaluation observed, discussed, and assessed whether the five predefined UAS coordination events were successfully triggered in each training format. They first assessed individually, then discussed their observations in short group workshops. This set-up enabled a systematic comparison of simulation environment affordances for the UAS coordination challenges under near-identical scenario-challenge conditions.

Qualitative data were derived from exercise-planning discussions, observations, and debriefing sessions. The first author participated in exercise design, took field notes during exercise planning, and acted as an exercise facilitator. The second author was one of the evaluators. Both authors participated in debriefing workshops. The third author was present during one exercise to develop contextual understanding for the study.

Multiple cases support the identification of recurring patterns, contextual variations, and underlying mechanisms, which are difficult to observe in a single case. By systematically replicating observations across multiple cases, we aimed to strengthen the analytic generalizability of our findings towards theoretical insights.

### Data Collection: Events and Observations

The five multi-agency UAS coordination challenges, referred to as Events 1 to 5, were identified as relevant learning goals and used to evaluate the simulation environments. The Events and how they were designed to occur in the LS and VS scenarios were discussed by key representatives from the participating organizations and the evaluators prior to the exercise days, as described in Table 2.

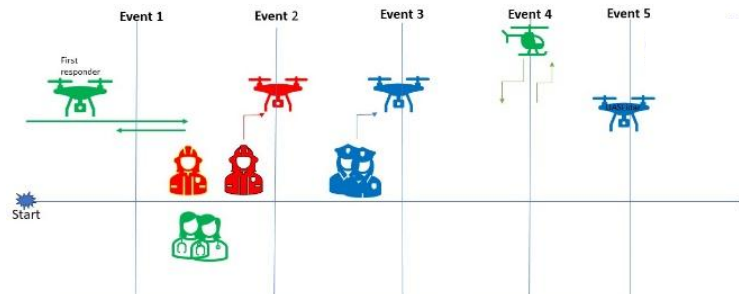
Table 1 presents the events that served as analytical categories for examining how LS and VS support triggering the intended challenges and for answering the research question. Limited experience with multi-agency UAS and the lack of protocols meant these events served as analytical anchors for investigating how multiple UAS are coordinated during a scenario, as documented through structured observations. Each event was designed to trigger specific behaviors, decisions, communication, or coordination demands related to risk assessment, task definition, information sharing, and air traffic management.

During the training, the evaluators were free to move within the exercise locations and listen to communication without interfering with the participants. They were equipped with two radios to listen to communications among

<sup>1</sup> <https://civil-protection-knowledge-network.europa.eu/projects/collaris-network>

<sup>2</sup> <https://www.xvr.com/en/platform/>

commanders from all organizations, the FRS IC, and the pilot, and an earpiece connected to the FRS IC's microphone. Given the complexity of communication within and across organizations, the evaluation focused mainly on the FRS. Participants were debriefed after each session, followed by evaluator debriefings to jointly discuss and analyze observations.



**Figure 1.** The Events (1-5) illustrate the UAS and commander's arrival at the scene, and corresponding coordination challenges on the scenario timeline. The UAS and their pilots are illustrated as follows: EMS first-responder UAS (green); FRS UAS (red); Police UAS (blue in Event 3); EMS helicopter in LS; unknown helicopter in VS; and police lidar UAS (blue in Event 5).

## Participants

Professional operational personnel from three organizations participated in the exercises:

- FRS Skaraborg (FRS): firefighters, IC level 1 (operational command of one team), IC level 2 (command of multiple crews), IC level 3 (tactical command), and IC level 3 (tactical command and coordination of resources and inter-agency working becomes critical), and UAS pilots (three pilots, two UAS systems).
- Swedish Police: incident officers and UAS pilots (four pilots, several UAS systems).
- Region Västra Götaland EMS: ambulance teams, a disaster medicine unit, dispatchers, and an EMS first-responder UAS pilot.

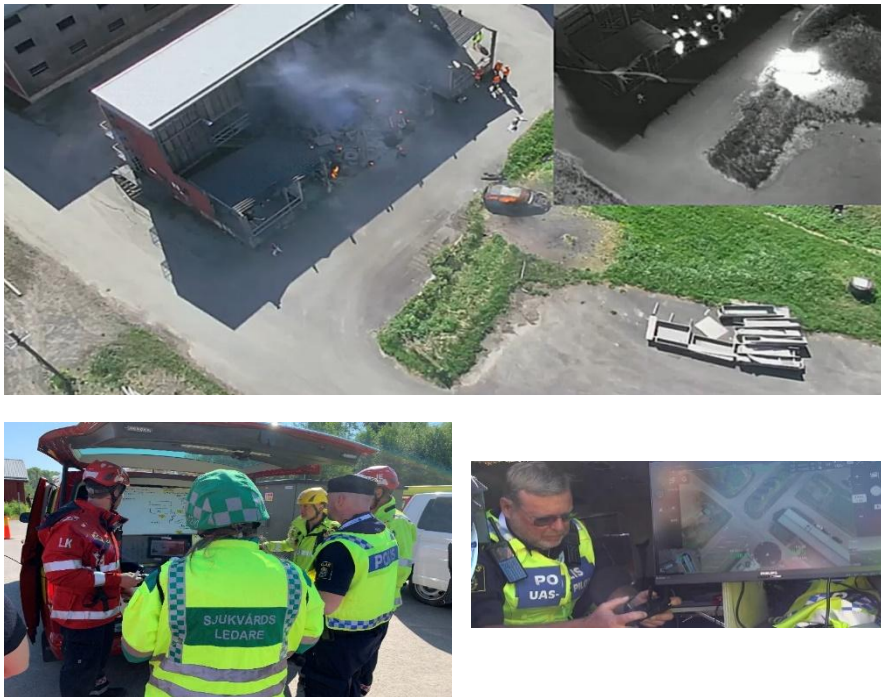
Event 4 involved an EMS helicopter with crew and a specialized medical team in LS, while in VS this event involved an unknown helicopter. Event 5 involved the police lidar UAS team (two pilots), who supported command with 3D imagery.

The LS included all operational personnel (three firefighter teams, ambulance crews, and police teams), along with 40 high-school students acting as injured individuals, a total of ~80 individuals across both days.

The VS included only commander roles and UAS pilots involved in UAS coordination: FRS level 2 and 3 commanders (Figure 1, red icons), police commanders (blue icons), and EMS commanders (green icons). VS also included five role-players as team leaders and one technical operator. Data collection involved 15 subjects per day (30 total).

## Simulation Scenarios

Both the LS and VS scenarios were designed as distinct, unfamiliar emergency scenarios aimed to trigger the events correspondingly, i.e., the UAS coordination challenge in each even were similar, but the scenarios in LS and VS differed, motivating the use and requiring the coordination of first-responder UAS, UAS from the FRS, police, and a lidar-equipped UAS, all within shared airspace alongside manned aircraft. The LS scenario simulated an explosion in a residential area, causing building collapses and multiple fires. As the response unfolded, firefighters were expected to identify unexploded ammunition in the debris, receive reports of missing persons, and manage escalating fire conditions (see Figure 2).



**Figure 2.** UAS video stream covering one part of the LS area (upper), Command post (lower left), and the police UAS pilot operating UASpolice, with the live stream on the screen in the UAS vehicle (lower right).

The VS scenario simulated a terrorist attack at a hospital, involving explosions, multiple casualties, active threats, and a helicopter extraction of terrorists from the hospital roof (see Figure 3). Participants operated from separate organizational rooms, mirroring real distributed command structures. In the virtual simulation exercises, only incident command officers and UAS pilots from each organization (FRS, police, and EMS) participated. All field personnel were represented by virtual avatars. For communication, they used their usual communication devices.



**Figure 3.** UAS video stream covering one part of the VS area (upper), Command post (lower left), and the police UAS pilot operating UAS police, with the live stream on the screen in the UAS vehicle (lower right).

**Table 2. Summary of the scenario setup, intended triggers, and evaluation focus for each event**

Event	Scenario Setup	Intended Triggers	Evaluation Focus: FRS (Simulation Environment Effects)
<b>Event 1</b> Arrival of the EMS First-Responder UAS	An EMS-operated first-responder UAS was launched to provide early aerial imagery to the dispatch center, enabling verbal information or a video stream to all arriving commanders.	<ul style="list-style-type: none"> <li>- Early cross-agency communication on the shared command radio channel</li> <li>- Identification and communication of immediate risks and hazards</li> <li>- Consideration of aerial imagery by the first-arriving FRS commander to adjust initial orders (via dispatcher interpretation or first-hand video viewing)</li> </ul>	Whether and how the simulation environment triggered and enabled the FRS commander to integrate the first responder UAS information into initial command actions.
<b>Event 2</b> Deployment of the Fire and Rescue UAS (UASfrs)	The incident involved a large area with multiple buildings, fire, smoke, and numerous casualties, necessitating support for information gathering and situational awareness beyond ground-based observation.	<ul style="list-style-type: none"> <li>- Justification for deploying UASfrs (e.g., reconnaissance, search, structural assessment)</li> <li>- Consideration of safety measures and risk assessment</li> <li>- Assignment of clear initial tasks to the UAS pilot</li> <li>- Communication of UAS findings to the FRS commander</li> <li>- Reallocation of tasks as the incident evolved</li> </ul>	Whether and how the simulation environment triggered and enabled the FRS commander to deploy UASfrs early, coordinate with the departing first-responder UAS, conduct risk assessment, articulate clear tasks, and integrate UASfrs as a coordinated resource.
<b>Event 3</b> Deployment of Police UAS (UASpolice) and Simultaneous Use of UASfrs and UASpolice	Police units arrived after the FRS. Information from role-players indicated missing persons in collapsed structures and others fleeing into nearby wooded areas, prompting police search operations using UAS.	<ul style="list-style-type: none"> <li>- Explicit airspace coordination (altitude, sectors, sequencing)</li> <li>- Discussion of flight-safety risks</li> <li>- Inter-agency task differentiation (e.g., fire UAS for damage assessment, police UAS for search/threat detection)</li> <li>- Communication between pilots and commanders</li> </ul>	Whether and how the simulation environment triggered and enabled FRS and Police to coordinate, communicate, and manage concurrent UAS operations across organizational boundaries. Clear tasks to UAS pilots and risk assessment.
<b>Event 4</b> Arrival of a Helicopter and coordination of UASpolice, UASfrs, and Helicopter.	A helicopter was scripted to arrive while both FRS and Police UAS were operating in the same airspace (EMS helicopter in live simulation; scripted helicopter in virtual simulation).	<ul style="list-style-type: none"> <li>- Communication between commanders and UAS pilots about incoming manned aircraft</li> <li>- Initiation of formal air traffic coordination</li> <li>- Decisions regarding grounding UAS or dividing airspace</li> <li>- Explicit safety and risk discussions</li> </ul>	Whether and how the simulation environment triggered and enabled the coordination, communication, and risk assessment between the UAS and the manned helicopter in the airspace.
<b>Event 5</b> Deployment of the lidar UAS (UASlidar) and coordination of UASfrs, UASpolice and lidar UAS	A specialized police LIDAR LIDAR UAS team arrived later in the response to conduct 3D mapping and scanning of the incident scene, requiring integration with existing aerial assets.	<ul style="list-style-type: none"> <li>- Renewed airspace coordination involving three UAS with different operational purposes</li> <li>- Updated risk assessment and safety discussions</li> </ul>	Whether and how the simulation environment triggered and enabled the coordination, communication, and risk assessment to include a third UAS in the airspace.

## RESULTS

All five events were either fully or partially achieved, due to time constraints, during the LS and VS on both days. As argued earlier, the results are presented with the focus on FRS training. As the events were replicated in LS and VS and across two exercise days, multiple cross-case analyses were possible with the given dataset for each event, e.g., LS day one versus VS day one, and VS day one versus VS day two.

### Event 1 – Arrival of the EMS First-Responder UAS

**Scenario trigger:** The EMS first-responder UAS arrived at the scene ahead of emergency services, providing an early aerial imagery stream to the dispatcher at the emergency medical dispatch center. The UAS pilot operated remotely, and the dispatcher interpreted the live video feed and relayed this information as a METHANE report (*M/ETHANE*, 2026) via radio to all unit commanders (FRS, Police, EMS) en route.

**LS Observations:** The dispatcher transmitted interpreted UAS imagery indicating “an explosion,” “many injured persons,” and the “presence of severe fire.” EMS and FRS officers adopted a cautious approach and stopped at a distance. Day 1, the first arriving FRS officer listened to the dispatcher’s report but did not view the video sent via smartphone. He made the safety decision to stop vehicles at a distance and delivered the first “window report” based solely on the fire truck’s limited line of sight, thereby confirming the dispatcher’s information. On Day 2, the FRS commander received the dispatcher’s report and also viewed the streamed video on the smartphone. This enabled a revised risk assessment and a decision to position vehicles closer to the incident site, resulting in quicker initial FRS actions. Due to fire safety and environmental fuel regulations, visual cues (smoke, fire) diminished over time, challenging the realism of continuous fire spread. The commander who viewed the first-responder video gained a better overview of fire conditions and building collapse, which supported situational awareness and risk assessment, though, from an FRS perspective, he noted that the dispatcher overstated fire severity.

**VS Observations:** The dispatcher communicated and interpreted UAS imagery using the METHANE framework, mirroring LS reports. Similar safety-driven behavior was observed on both days. On Day 1, the FRS commander relied solely on the verbal report, ignoring the video stream. On Day 2, the commander viewed the video firsthand, judged the fire situation as less severe than the dispatcher’s assessment, and made faster initial decisions. The virtual environment provided consistent visual cues, including stable and advancing fire and smoke throughout the scenario, with effects dynamically adjusted to reflect fire-extinguishing actions. Commanders arrived at the exact same location, enabling comparable “window reports.” Despite this, the commander who viewed the video before arriving at the scene acted more quickly than the one who did not.

### Evaluators Debrief on the Interpretation of Observations

Both simulation formats successfully triggered and achieved the event. The report structure (METHANE) communicated by the dispatcher (EMS) emphasized casualties, whereas details on building damage and fire were limited, thereby affecting the FRS risk assessment. Based on this information, the IC (day 1) decided to stop the vehicles farther from the incident scene, thereby providing a very limited view and necessitating that a firefighter team be sent closer on foot to collect additional information. On day 2, the commander viewed the UAS video directly and demonstrated the value of first-hand visual information, which supported a more accurate risk assessment and earlier operational engagement. The FRS commander could assess the fire and the extent of explosion damage based on their own knowledge and experience, rather than relying solely on the EMS dispatcher’s interpretation of the first-responder drone video. The LS visual cues, including small fires in barrels, a burned-out car, and a collapsed building (familiar to the FRS commanders from numerous previous exercises), and the difficulty in harmonizing these in time, may also have influenced risk assessment.

Both formats successfully triggered the event. The METHANE report emphasized casualties; details on building damage and fire were limited, thereby influencing the FRS risk assessment. On Day 1, reliance on the EMS dispatcher’s verbal interpretation of the video led to conservative positioning and delayed engagement. On Day 2, direct video access supported more accurate FRS perspective risk assessment and earlier action. The LS fires, constrained by the fuel regulations, were limited in size, and the training ground facilities, well known by the FRS, also affected their interpretation of the fire and risk assessment. At the same time, fuel limitations required precise fire-ignition timing to achieve the maximum possible and intended extent of fire at the first-responder UAS and FRS arrival. On Day 1, a delayed first-responder UAS deployment resulted in smaller fires than intended; although imagery still showed visible flames, the EMS dispatcher interpreted it as severe. On Day 2, the LS fire was at the maximum possible level, interpreted by the EMS dispatcher as severe and by the FRS IC as less severe, illustrating the importance of access to images for one’s own assessment. VS provided stable and dynamic fire and smoke effects, unrestricted by safety constraints, and introduced unfamiliar building layouts, leaving not precious experiences of the environment to affect the interpretation of the video or the direct view of

the incident site upon arrival, enhancing the realism of a new situation. One participant described VS as “what you see is what it is,” in contrast to LS’s staged environment. VS also allowed fire spread and secondary explosions, which were not feasible in LS.

## Event 2 – Deployment of the Fire and Rescue UAS (UASfrs)

**Scenario trigger:** The extent of the incident scene (several large and collapsed buildings, many injured people) indicated the value of having a drone video supporting the FRS IC’s situational awareness, supplementing the first responder UAS providing continuous monitoring of the scene after the first responder UAS has left the scene due to limited battery time. The FRS commander first on site was expected to deploy the UASfrs, coordinate with the dispatch center in charge of the present first responder UAS, and initiate parallel information gathering.

**LS Observations:** On day 1, the FRS commander chose not to deploy UASfrs, citing personnel limitations and prioritizing lifesaving tasks over having a single personnel member pilot the UASfrs. The FRS commander relied on UASpolice to provide aerial imagery, expecting to have access to the video when needed. To emphasize the trigger to deploy UASfrs on day 2, the pre-exercise information provided to participating commanders included drone availability and the exercise safety measures in place to permit simultaneous flights of multiple UAS. The UASfrs was deployed on day 2, but not until the first responder UAS left the scene. The first responder UAS battery time was too limited to continue flying until the UASfrs was deployed. Evaluators noted that the UASfrs pilot had no clearly defined tasks beyond “deploy the drone to have an overview of the scene”. No UAS-related risk assessment was performed.

**VS Observations:** On day 1, the UASfrs was not deployed, while in LS, after the pre-exercise changes, the event was successfully achieved. On day 2, the UASfrs was deployed initially. As in the LS, the task for UASfrs remained vague. The virtual environment allowed the first-responder UAS to remain airborne (with no battery-time limitation) until UASfrs was deployed, thereby enabling coordination. However, no consideration was given to drone coordination, and no risk assessment was conducted.

## Evaluators Debrief on the Interpretation of Observations

Both simulation environments achieved the event after adjustments to pre-exercise information. This might also have emerged without adjustments. The use of the drone may be related to personal IC preferences and experiences. As explained by the day 1 IC, the decision not to deploy the UAS was shaped by workload, perceived resource limitations, and role priorities—not by the simulation environment. VS enabled more controllable timing (e.g., extended first-responder UAS endurance), allowing training challenges to be encountered more reliably. The absence of clear tasking for UASfrs was consistent across environments. It may reflect organizational routines and/or individual IC’s familiarity and experience with UAS use, rather than simulation constraints.

## Deployment of Police UAS (UASpolice) and Simultaneous Use of UASfrs and UASpolice

**Scenario trigger:** Multiple incident factors—such as missing persons, suspected explosives, and multiple injuries and fires—prompted the simultaneous use of UASpolice and UASfrs. When UASpolice was deployed while UASfrs was already airborne, the two services were expected to conduct a joint risk assessment, coordinate initial tasks and flight patterns, and share information.

**LS Observations:** Day 1, the event did not occur because UASfrs was not deployed. Day 2, the event emerged. The police commander coordinated the deployment of UASpolice with the FRS commander and instructed both UAS pilots to operate from the same location. The police commander provided explicit tasking for UASpolice (“search for missing persons in the marked area”), while UASfrs received only vague guidance (“overview of the building”). No inter-agency discussion on airspace safety or risk assessment was observed. Although the pilots were positioned near the command post, enabling face-to-face communication, such interaction was not utilized.

**VS observations:** Day 1, the event did not occur because UASfrs was not deployed. Day 2, the event resembled LS. The police commander assumed command and initiated coordination with FRS, assigning UAS pilots to coordinate their flights. UASpolice received explicit tasking (“identify suspected individuals”), whereas UASfrs tasking remained vague (“overview of the building on fire”). Coordination included some direct communication between pilots but no risk-assessment discussions.

## Evaluator Debriefs on the Interpretation of Observations

Both simulation environments supported the event only when it occurred, and its occurrence depended on the previous event. Task clarity varied across agencies but not across simulation formats, suggesting that

organizational or commander experience may influence coordination more than the simulation environment. The absence of joint risk assessment and airspace coordination indicates that current practices do not naturally prompt such collaboration. Both LS and VS provided clear visualizations of UAS operations; however, this alone did not trigger interagency coordination.

#### **Event 4 – Arrival of a Helicopter and coordination of UASpolice, UASfrs, and Helicopter**

**Scenario trigger:** This event was designed to raise awareness of manned aircraft entering shared airspace and to trigger coordination between UAS pilots and command functions. In LS, an EMS helicopter was scheduled to arrive at a set time, requiring coordination between the UASfrs pilot, UASpolice pilot, and the helicopter pilot. Coordination could be achieved in different ways: either by requiring all UAS to land or by separating the airspace into altitude layers or sectors to allow simultaneous operations. At the time of the exercise, no standardized protocol for such coordination existed, and no shared air traffic radio channel was available to both UAS and helicopter pilots, leaving communication dependent on commanders.

In contrast, the VS scenario introduced an unannounced helicopter arrival—a hostile aircraft scripted to extract terrorists—requiring UAS pilots to detect the helicopter visually and audibly and coordinate their drone operations accordingly. Both LS and VS aimed to trigger awareness of manned aircraft and the need for airspace separation in a similar way.

**LS Observations:** On Day 1, the planned EMS helicopter was redirected to an actual incident, necessitating the redesign of the scenario. An “unknown UAS” was introduced in its place and approached the command post. Neither the IC nor other participants acknowledged or questioned its presence. During the debrief, participants explained that they assumed the unknown UAS belonged to exercise management for documentation purposes, not as part of the scenario. For Day 2, pre-exercise instructions clarified that all unmarked objects should be treated as scenario elements. On Day 2, the FRS commander identified the unknown UAS and informed the UASfrs pilot, raising awareness, but no further coordination or risk discussion occurred.

**VS Observations:** The arrival of the scripted helicopter was highly salient, with strong auditory and visual cues. The event occurred on both days. The helicopter was detected and identified as unknown by the UASpolice pilot, who informed the police commander. The commander classified it as “suspected” and assigned UASpolice to monitor, record video, and track the helicopter. No explicit risk assessment or airspace separation discussion was observed.

#### **Evaluator Debriefs on the Interpretation of Observations**

The LS was constrained by real-world resources (a helicopter), as cost limited the feasibility of engaging an off-duty helicopter in the exercise. Scenario ambiguity—uncertainty about which objects were part of the exercise—affected participants’ recognition of the unknown UAS. This demonstrates the sensitivity and challenge of LS where the physical environment often includes objects and cues that have to be ignored (service personnel vehicles, observers) as well as imagined (spreading of the fire, more smoke). LS realism for fire and smoke was also limited by fuel, weather, and strict timing requirements. In contrast, VS ensured equal exposure and consistent timing, supporting dependable event emergence.

These constraints illustrate how LS realism does not always translate into clear scenario cues. This illustrates a key challenge in LS: the physical environment includes both irrelevant cues (e.g., service vehicles, observers) and imagined elements (e.g., spreading fire, smoke), which can reduce the salience of the scenario.

#### **Event 5 – Deployment of LIDAR UAS (UASlidar) and coordination of UASfrs, UASpolice, and LIDAR UAS**

**Scenario trigger:** The event was initiated when a LIDAR UAS pilot approached the police command post to request authorization to fly and coordinate with other airborne units. The LIDAR drone, a police resource, is typically used to create 3D models of incident scenes for investigative purposes. Its deployment required altitude layering above other drones performing tasks such as fire monitoring, casualty search, or unexploded ammunition detection. This situation introduced a coordination challenge between the LIDAR UAS, UASpolice, and UASfrs.

**LS Observations:** The event was successfully achieved on both days. The LIDAR UAS pilot followed standard police procedures, seeking authorization prior to flight, and initiated verbal coordination and proposed altitude separation to avoid conflicts. The pilot positioned near the UASpolice operator to enable rapid communication, and the UASfrs pilot accepted the lead and followed it.

**VS Observations:** The event was achieved on both days. Similar to LS, the lidarUAS pilot adhered to expected procedures, presented a clear airspace management plan (including higher-altitude flight), and conducted a risk assessment prior to deployment.

#### **Evaluator Debrief on the Interpretation of Observations**

Both LS and VS supported the event equally, as coordination relied primarily on procedural interaction rather than environmental fidelity. The lidarUAS pilots were experienced in coordination at incident scenes and demonstrated strong leadership in managing airspace and facilitating interagency coordination, which likely contributed to the smooth execution of this event and supported learning for the UASfrs pilots

#### **SUMMARY OF RESULTS**

Table 3 summarizes the trigger success for all predefined UAS coordination events across LS and VS. While both formats achieved all events, differences emerged in reliability and realism. Event 1 (arrival of first-responder UAS) was achieved in both formats. VS provided consistent fire and smoke dynamics, while LS realism was constrained by safety and fuel limitations. Event 2 (deployment of FRS UAS) was achieved but required adjustments in both formats. VS allowed extended UAS endurance, whereas LS reflected real-world constraints such as battery limits and deployment delays. Event 3 (simultaneous use of FRS and police UAS) depended on Event 2, but no major differences were observed once triggered. Coordination remained limited in both environments. Event 4 (coordination with the helicopter) was reliably triggered in VS through salient cues and controllable timing. LS failed on Day 1 and partially succeeded on Day 2 due to resource limitations and ambiguity. Event 5 (arrival of lidarUAS) was fully achieved in both formats with negligible differences, as coordination relied on procedural interaction.

Overall, LS offered natural realism through physical environments and real equipment but was sensitive to uncontrollable or hard-to-control variables and safety constraints. VS provided greater controllability, consistent scenario dynamics, and exposure to unfamiliar environments, reducing bias and ensuring reliable exposure to intended challenges. These findings provide insights to inform decisions on exercise format selection, suggesting that VS can complement LS by ensuring reliable event emergence and dynamic realism, particularly for complex coordination scenarios involving multiple aerial assets.

**Table 3. Trigger success for UAS coordination events across live simulation (LS) and virtual simulation (VS) exercises, with key differences observed. Each event represents a predefined coordination challenge tested in both formats with two participant groups. The green indicates whether a challenge was achieved, the yellow indicates partial achievement, and the red indicates non-achievement.**

LS		VS		Key Differences
Exercise 1 Day 1 Group 1	Exercise 3 Day 2 Group 2	Exercise 2 Day 1 Group 1	Exercise 4 Day 2 Group 2	
Event 1 _LS1 Achieved	Event 1 _LS2 Achieved	Event 1 _VS1 Achieved	Event 1 _VS2 Achieved	VS offered consistent fire/smoke dynamics. LS realism was constrained by safety and fire-fuel restrictions, which limited fire and smoke.
Event 2 _LS1 Not Achieved	Event 2 _LS2 Achieved	Event 2 _VS1 Partly Achieved	Event 2 _VS2 Achieved	VS allowed extended UAS endurance to enable coordination of the first responder drone and the UASfrs. LS reflected real-world constraints on battery limitations, whereof the coordination of UASfrs and first responder UAS was not achieved due to the time taken for UASfrs to be deployed.
Event 3 _LS1 Not Achieved	Event 3 _LS2 Achieved	Event 3 _VS1 Achieved	Event 3 _VS2 Achieved	No major differences once triggered. UASpolice and UASfrs were deployed, but no clearly stated safety measures were pronounced by the FRS, and no clear task was expressed.
Event 4 _LS1 Not Achieved	Event 4 _LS2 Partly Achieved	Event 4 _VS1 Achieved	Event 4 _VS2 Achieved	VS provided stronger cue salience and controllability.
Event 5 _LS1 Achieved	Event 5 _LS2 Achieved	Event 5 _VS1 Achieved	Event 5 _VS2 Achieved	No meaningful differences: procedural interaction dominated.

## DISCUSSION

This study examined how LS and VS afford exposure to key UAS coordination challenges in multi-agency emergency response. By observing five predefined events, we identified patterns in how each environment enables or constrains learning opportunities.

### Environment-Specific Affordances and Event Triggering

Our findings show that the choice of simulation format should be based on the nature of the planned coordination challenge. Events (1 and 5), primarily driven by procedural interaction and interpersonal communication, where a UAS was operated by a task-specific, dedicated pilot (the first responder UAS pilot and the UASlidar pilot), were successfully triggered in both LS and VS. This suggests that for well-structured, experience-driven tasks, environment choice may be less critical. The experienced lidar UAS pilot's leadership in Event 5 further illustrates how expertise can compensate for environmental limitations.

In contrast, Event 4 (helicopter coordination) demonstrated strong dependence on simulation affordances. VS ensured consistent triggering via salient cues and controllable timing, whereas LS failed on Day 1 and only partially succeeded on Day 2 due to resource constraints and ambiguity regarding scenario elements. High physical realism did not guarantee reliability, highlighting LS's vulnerability to uncontrollable variables.

### Realism–Control Trade-off

This study also recognized that LS provided natural sensory fidelity but limited controllability, with diminishing fire intensity and logistical constraints. VS inverted this trade-off, offering consistent conditions and dynamic

scenario control but lacking full sensory realism. Psychological fidelity also mattered: LS environments required less orientation, whereas VS provided a novel environment and greater insight into the effects of building.

Thus, training design should prioritize matching the environment to learning objectives rather than prioritizing the realism the format allows or the control over each event. Foundational coordination concepts and iterative practice may be best delivered via VS, while LS is suited for validating procedures under realistic conditions and building technical and operational confidence.

### *Environment-Independent Gaps*

Neither environment supported systematic UAS risk assessment, explicit air traffic coordination, or clear tasking for UAS pilots—indicating gaps in IC competencies or operational procedures rather than limitations in simulation. Addressing these requires deliberate instructional design, including decision-forcing scenarios, pre-exercise priming, structured debriefings, and graduated complexity. Established standard operating procedures for multi-UAS coordination could have enabled more effective testing and assessment.

### *Methodological and Practical Contributions*

Our event-based evaluation moves beyond “which training format is better” and replicable framework built on predefined events to analyze simulation affordances. Direct comparison of LS and VS is inherently problematic because of their fundamental differences in affordances and constraints in configuring the two environments for training. This study demonstrates that an event-based approach, anchored in predefined coordination challenges, provides a structured, replicable method for assessing learning objectives. This method shifts the focus from format superiority to format suitability, enabling more nuanced insights for training design and providing a pathway for future research on simulation-based learning. Findings support viewing LS and VS as complementary: LS for realism and equipment handling, and VS for controllability and iterative practice. The identification of environment-independent gaps underscores that simulation fidelity alone does not drive complex behavioral outcomes—explicit competency development and instructional scaffolding are equally critical.

### **Limitations and Future Research**

This study focused on Swedish responders and a specific scenario and exercise type, limiting generalizability to other countries or environments. However, the complexity of defining such training days, including the large number of people with appropriate roles and technologies, makes it difficult to translate them into a controlled study. To address resource constraints, we centered the evaluation on clearly defined events and precisely described LS and VS training environments. Future research should, however, include a cost-benefit analysis associated with the defined framework. Further, we plan to examine diverse contexts, participant experience levels, and long-term learning outcomes. Emerging VR capabilities (e.g., haptics, mixed reality) and cognitive process measures (e.g., eye-tracking) warrant investigation, alongside cost-benefit analyses to inform resource allocation. Quantitative approaches could complement this study by mapping communication and decision-making patterns during multi-UAS coordination.

### **CONCLUSION**

This study examined how LS and VS facilitate exposure to predefined UAS coordination challenges during multi-agency emergency response training, thereby informing evidence-based exercise design and simulation format selection. Using an event-based, multiple-case approach, we analyzed how each environment’s affordances support the emergence of critical learning opportunities rather than focusing on participant performance.

Findings show that LS and VS offer complementary strengths but differ in reliability and controllability. VS consistently achieved all events and provided dynamic scenario control, making it particularly suitable for learning objectives that depend on hard-to-control resources (e.g., helicopters, fire dynamics) or precise timing. LS delivered authentic physical realism and equipment interaction, which is valuable when tactile experience and adaptation to real-world constraints are central to the learning goal. However, LS was vulnerable to uncontrollable factors such as resource availability and environmental variability.

These results inform practical decisions on simulation format based on learning objectives:

- If the learning objective requires complex coordination involving multiple aerial assets or precise environmental cues, VS should be prioritized—especially when resources for LS are limited.
- If physical realism and equipment handling are critical, LS remains essential.
- When both formats are feasible, a blended approach offers the most effective pathway, combining VS for foundational coordination and LS for validation under real-world conditions.

These findings address common hesitation toward VS by demonstrating that multi-agency exercises focusing on management, coordination, communication, and command can be delivered in VS with similar effectiveness in achieving predefined learning goals, while being significantly more resource-efficient in training planning. In contexts where LS is impractical, VS provides a viable and reliable alternative for achieving the core learning objective related to command, communication, and coordination in multi-agency UAS-supported exercises. Scenarios requiring precise timing, salient cues, or complex multi-asset, multi-agency coordination may be better suited to VS, where controllability ensures reliable learning opportunities while LS remains valuable for training that emphasizes equipment handling, physical skill integration, and adaptation to real-world constraints.

Finally, this study advances the discussion by applying the concept of affordances for simulation-based training. Viewing LS and VS through the lens of affordances clarifies how each environment creates opportunities for action and imposes constraints, shaping learning behaviors.

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