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Beyond the Range: Merging Simulation and Reality

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ABSTRACT

Teams utilizing live radio and tactical messages, seamlessly connected to network radios within simulated environments, deliver an exceptionally immersive and enriching training experience. The integration of realistic communication and video feeds not only expands the scope of information available but also surpasses the limitations of what an individual can perceive in their immediate surroundings on the training range. By creating advanced simulated environments, we significantly enhance operational effectiveness, enabling coalition tactical warfare—regardless of platform constraints—at a fraction of the usual cost.

The Bold Quest (BQ) 24 Coalition Capability and Demonstration Assessment presented a remarkable opportunity for coalition participants to elevate their synthetic environment capabilities and interoperability. One of the most impressive initiatives during this event was spearheaded by the Royal Netherlands Army Land Simulation Center, which successfully transmitted virtual Intelligence, Surveillance, and Reconnaissance (ISR) Full Motion Video (FMV) directly to live ground forces. Dutch troops accessed this vital FMV through Android Tactical Assault Kit (ATAK) devices, harnessing the power of TrellisWare's advanced TSM Waveform radio technology. This innovative live-virtual integration enabled them to receive real-time simulated intelligence and situational awareness stimulation, thereby enhancing their operational effectiveness on the battlefield. These cutting-edge advancements are not merely reshaping modern training; they are establishing a new standard where the fusion of live and virtual elements defines the future of training and reality for military operations.

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INTRODUCTION

Modern military operations are becoming increasingly complex due to the integration of advanced technologies, multi-domain environments, and the emergence of coalition warfare. Today's modern warfighter requires a new and evolving skillset. Information flow on the battlefield is now a dynamic blend of cutting-edge technologies and established warfighting tactics, demanding adaptability and expertise in both realms. Traditional training methods often fall short in replicating these complexities, leading to a need for more immersive and adaptable training solutions (Creamer, 2021).

To address these shortcomings, the defense community is increasingly turning to Live, Virtual, and Constructive (LVC) training solutions. LVC environments combine real-life operational scenarios with virtual simulations and constructive inputs, bridging gaps in realism while keeping costs and logistical burdens manageable. This hybrid approach allows military personnel to engage in scenarios that replicate the complexities of modern warfare, including cyber threats, space operations, and multi-domain coordination in a controlled and secure environment.

LVC training solutions have gained global acceptance, with worldwide defense agencies embracing their flexible innovation. These solutions enable the simulation of joint operations that demand precision, coordination, and adaptability. They are designed to integrate diverse operational domains, including land, air, sea, and cyber, into cohesive scenarios that mirror the complexity of real-world missions (Marler, Lewis, Toukan, Kochhar, Haberman, Downing, Andrews, 2020).

The integration of live and virtual elements, such as live radio communication, tactical messaging, and simulated video feeds into training environments significantly enhances operational effectiveness and interoperability. By creating advanced simulated environments, military personnel can experience realistic multinational scenarios that expand their situational awareness beyond their immediate surroundings. This approach not only broadens the scope of information available but also surpasses the limitations of what an individual can perceive in their immediate surroundings in the training range. By creating advanced simulated environments, we significantly enhance operational effectiveness, enabling coalition tactical warfare—regardless of platform constraints—at a fraction of the usual cost (Dekker, Gubbels, & Kalloniatis, 2024). Crucially, this training format cultivates essential modern warfare skills by forcing trainees to synthesize diverse data streams – from live radio and tactical messaging to simulated video feeds – with their direct observations, enabling them to formulate cohesive and informed tactical responses.

THE LIMITATIONS OF TRADITIONAL TRAINING

Traditional military training exercises, while essential, come with several constraints that limit their effectiveness in preparing forces for the complexities of modern warfare. One of the primary limitations is the limited scope of these exercises. Traditional training often focuses on specific scenarios or skill sets, which may not fully encompass the diverse and dynamic nature of real-world operations. This narrow focus can leave gaps in readiness, as personnel may not be exposed to the full range of challenges they might face in actual combat situations (Mackley, 2024).

Cost is another significant constraint. Conducting large-scale live training exercises requires substantial financial resources. As an example, the DEFENDER-Europe training event, a large-scale multinational exercise involving 18 nations, was projected to cost over \$340 million in 2020 for the U.S. participants alone (Judkins, 2019); the exercise

was ultimately modified due to the COVID-19 pandemic, though much of the prepositioned forces and equipment had already been deployed. These costs include not only the direct expenses of deploying troops and equipment but also the indirect costs associated with logistics, maintenance, and support. The high cost of traditional training can limit the frequency and scale of exercises, reducing the opportunities for personnel to practice and refine their skills.

Logistical challenges further complicate traditional training exercises. Coordinating the movement of troops, equipment, and supplies to and from training locations can be a complex and time-consuming process. Additionally, securing suitable training environments that can accommodate the scale and scope of the exercises can be difficult. These logistical hurdles can lead to delays and disruptions, impacting the overall effectiveness of the training.

Replicating complex, multi-domain operational environments in traditional settings is particularly challenging. Modern military operations often involve the integration of land, air, sea, cyber, and space domains, each with its own unique set of challenges and requirements (Reuters, 2018). Creating a training environment that accurately simulates the interactions and dependencies between these domains is difficult with traditional methods. Traditional training methods, by their linear nature, often cultivate a similarly linear skillset. Logistical and cost constraints further narrow the training focus, resulting in a limited scope of expertise. However, modern and future warfare demands a more diverse and interconnected ("three-dimensional") skillset, highlighting the inadequacy of traditional approaches.

Given these constraints, there is a clear need for more immersive and adaptable training solutions. LVC training environments offer a promising alternative. By integrating live, virtual, and constructive elements, LVC training can create realistic and dynamic scenarios that closely mimic real-world operations (U.S. Navy, 2020). This approach allows for the simulation of complex, multi-domain environments, providing personnel with a more comprehensive and immersive training experience. Virtual and constructive simulations reduce the need for physical resources and infrastructure, allowing for more frequent and diverse training opportunities. Additionally, the adaptability of LVC environments allows for easy modification and updating of training scenarios to reflect evolving threats and operational requirements.

THE POWER OF LIVE-VIRTUAL INTEGRATION

An effective LVC training environment tightly integrates key communication and data systems across its live and simulated domains. Four critical components are coupled C2 Systems, live radio voice, tactical data messaging, simulated environment platforms, and full-motion video (FMV) feeds.

Coupled C2 systems

By connecting virtual and constructive simulations to operational C2 systems, training exercises can be seamlessly augmented with simulated flanking units, reinforcements, or opposing forces. This blurs the line between real and synthetic, enabling small-scale exercises to be expanded into complex, multi-domain operations—enhancing realism, decision-making, and mission readiness.

Live Radio and Voice Communications.

In a combined exercise, live troops must be able to talk over radios with virtual or remote units. This is achieved via radio gateways and/or software bridges. With a radio bridge, a simulated asset in another country can hear a Marine on a real radio net, and vice versa. This preserves the realism of radio comms, so that voice commands and readability are shared seamlessly across the LVC federation.

Tactical Data Links and Messaging.

Beyond voice, modern C2 requires digital message exchange (e.g., map positions, sensor tracks, fire commands). In LVC, these are carried over link protocols (such as Link 16, JREAP, or DIS). Middleware tools translate and route messages between live networks and simulators. For example, during the Bold Quest 2022 event, virtual units sent Link 16 surveillance tracks that were translated on the fly to feed live joint fires platforms. In practice, a simulated Unmanned Aerial Vehicle's (UAV) sensor imagery and track data can appear on a live unit's system just as if it were a real allied drone. This integration of tactical messaging enables collaborative targeting, situational awareness, and sensor-sharing across live and virtual participants.

Simulated Environment Platforms.

The “V” and “C” elements typically run on standardized simulators or constructive engines. Common simulation platforms (such as the Army’s OneSAF, the Navy’s Virtual Afloat trainers, or commercial solutions like Bohemia Interactive Simulations’ VBS4) generate the synthetic battlespace (PEOSTRI, 2025). These platforms ingest exercise scripts and broadcast entity behavior to participants. In the synthetic wrap approach, live events are enriched by these virtual scenarios. For example, a forward Joint Terminal Attack Controller (JTAC) might call in a strike on a live range and simultaneously see the effect of that strike in the constructive environment. By “wrapping” live maneuvers with virtual content, LVC makes large-scale and high-threat scenarios practicable.

Full-Motion Video (FMV).

Live video feeds from ISR assets (e.g., drones, reconnaissance planes, ground cameras) are often shared over the network to provide operators with a real-time view of the battlespace. In LVC, these FMV feeds can be real or synthetic. Such live or emulated FMV greatly enhances situational awareness, allowing commanders on either side of the exercise to view the action from remotely located platforms or simulation scenarios in real time.

Taken together, these LVC components create a unified training battlespace. Live troops communicate and text with simulated partners, view the same map and video feeds and respond as if participating in a single combined exercise.

BOLD QUEST 24 / ISLAND MARAUDER: A CASE STUDY IN LIVE-VIRTUAL SUCCESS

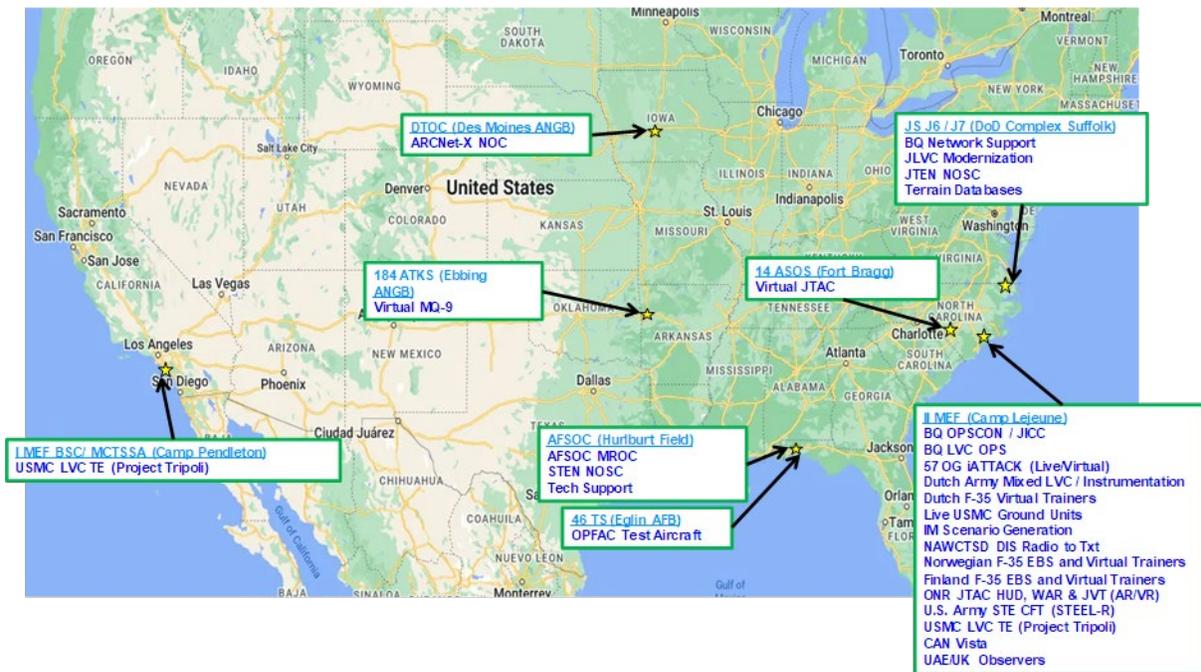


Figure 1: Locations of BQ 24 Participants

Bold Quest 24, the U.S. Joint Staff–sponsored Coalition Capability Demonstration and Assessment series, unfolded from October 7 to November 8, 2024, at Camp Lejeune, North Carolina. As a collaborative joint and multinational enterprise, Bold Quest provides a recurring cycle in which Nations, Services, and Programs pool resources to develop capabilities, demonstrate them under operationally representative conditions, and analyze performance for continuous improvement (Joint Chiefs of Staff, 2021). In 2024, more than 2,000 participants from U.S. Services and 20 partner nations converged on Camp Lejeune’s live training areas, simulation centers, and distributed nodes to execute an ambitious agenda. From Fires and Digitally Aided Close Air Support (DACAS) to Mode 5 Identification, Friend or Foe (IFF) and Friendly Force Tracking (FFT), the exercise integrated LVC elements to create a cohesive training environment. In coordination with BQ, the USMC Island Marauder successfully executed a unique live, virtual, and constructive (LVC) training opportunity. Of the U.S. services, the Marine Corps has specifically committed to leveraging the Joint Live, Virtual, and Constructive (JLVC) federation, which federates simulations at combatant

command (CCMD) levels, and to integrate live, virtual, and constructive domains via the JLVC High-Level Architecture (HLA)/ Distributed Interactive Simulation (DIS) federation (U.S. Marine Corps, 2025).

Distributed LVC Architecture

The backbone of Bold Quest's LVC environment incorporated multiple local and distributed sites linked over a high-bandwidth, federated mission network, as shown in Figure 1 (Department of Defense, 2014). On Camp Lejeune itself, the II Marine Expeditionary Force (II MEF) Battle Simulation Center (BSC), 2nd Air Naval Gunfire Liaison Company (2nd ANGLICO), 2nd Combat Engineer Battalion (2 CEB) building, and the Combat Town range—complete with surrounding training areas—hosted live maneuvers and local virtual operations. Beyond the base, networked nodes included the I MEF BSC (supported by 1st ANGLICO), the 184th Attack Squadron at Ebbing Air National Guard Base, the 14th Air Support Operations Squadron at Pope Army Airfield, and the German Air Force Simulation Control Center in Cologne, Germany. Each site contributed specific capabilities—virtual aircraft sorties, ground-truth sensing, adversary force modeling—and together, they demonstrated the feasibility of geographically dispersed, fully integrated coalition LVC training.

Scenario Threads and Operational Environment

Bold Quest 24's LVC scenario framework comprised of four interlocking threads:

1. **Coalition Intelligence, Surveillance, and Reconnaissance (CISR):** Simulated and organic ISR assets generated evolving target sets. Virtual MQ-9 Reaper feeds, simulated JSTARS tracks, and live ground spotters collaborated to locate, identify, and track Opposing Forces (OPFOR) from the fictional nations of Torbia and Donovia.
2. **Combined Operational Fires Experiment (COFx):** Serving as division-level headquarters, COFx planners received real-time battle rhythm updates, evaluated multiple courses of action, and directed both live and virtual fires.
3. **Ground Truth and Situational Awareness (G2SA):** Live sensor data—laser-designator points, Tactical Engagement Simulation System (TESS) hits (instrumented personnel and ground vehicles), and target track messages—fed into a common operating picture, ensuring that virtual models accurately reflected the live picture.
4. **Tactical Data Links (TDL):** MIL-SPEC message sets, voice-over-IP, and sensor point-of-interest messages traversed the network—initially via DIS 6 (IEEE 1278.1-1998), with a clear transition path toward NATO STANAG 4603 High-Level Architecture (HLA) compliance—binding all LVC assets into one synthetic battlespace.

This multi-threaded structure (figure 2) underpinned a complex scenario derived from the Operational Environment Data Integration Network (ODIN) doctrine in which Opposing Forces (OPFOR) advanced threateningly toward allied countries Framland, Arnland, and Torrike. Blue-force brigades and squadrons synchronized fires, logistics, and ISR to blunt the incursion, training in combined arms and multi-domain kill chains within a target-rich environment.

benefits. Soldiers were able to receive high-fidelity, real-time situational awareness stimulation, which is crucial for making informed decisions in dynamic environments. The ability to mark targets, share annotations, and communicate effectively with other units enhanced their operational efficiency and effectiveness (Johnston, Cannon-Bowers, & Salas, 1998). Overall, this initiative demonstrated the potential of advanced communication and simulation technologies to improve the capabilities of ground forces in complex scenarios. The OV-1 high-level operational concept graphic shown in Figure 3 depicts how six partner nations integrate live and virtual fire-capable platforms with ground forces to skillfully execute multidomain kills chains.

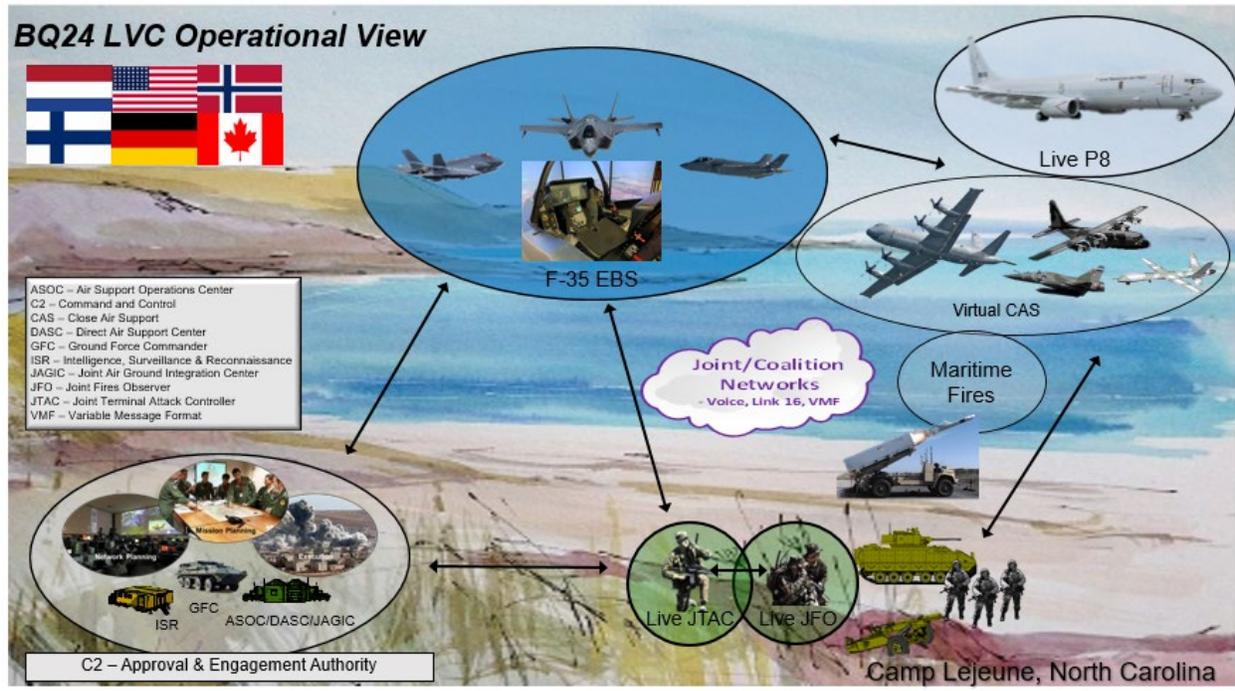


Figure 3: BQ 24 LVC OV-1 Diagram

Network and Interoperability Experiments

To support this level of integration, the RNLA SCL and its partners conducted several key experiments with network architectures and interoperability standards:

- **HLA Federation via Pitch DIS Adapter:** Federating Dutch systems (VBS4, VRForces, Mobile Combat Training Centre (MCTC), Steel Beast Pro) into a High-Level Architecture (HLA) federation, ported to the Bold Quest-Unclassified (BQ-U) network through a Pitch DIS Adapter.
- **UCATT HLA Federation Object Model (FOM):** Implementing and testing the UCATT FOM to standardize data exchange across multiple simulation tools (Cruiming, 2018).
- **ASTi LVC Radio Bridge:** Bridging URC 2000 and PRC-163A Combat Net Radios into the synthetic realm by converting CNR traffic to DIS.
- **VBS Radio over HLA:** Running Virtual Battlespace radio channels natively over HLA instead of legacy DIS.
- **Embedded JTAC Interactions:** Enabling JTACs to use ATAK, PRC-152A radios, and Battle Management Systems (BMS) for command and control, even when physically separated from simulation hardware.

Despite facing constraints of shipping and timing, the RNLA SCL achieved several significant milestones:

1. **Stable HLA Federation:** All Dutch simulation systems operated within a unified HLA federation, with robust DIS-to-HLA translation and minimal latency.

2. **Virtual FMV over CNR:** The first demonstration of VBS4 FMV streaming over Combat Net Radio to ATAK clients in the field, markedly enhancing tactical situational awareness.
3. **FPV Drone “Kills”:** Virtual first-person-view drone engagements on TESS-instrumented targets, controlled seamlessly from VBS4 using real-world controllers.
4. **Virtual Entity Injection:** Seamless pushing of simulated entity icons, threat markers, and waypoints into live ATAK situational displays via TrellisWare TSM IP radios.
5. **Network in the Sky (NITS):** A fully meshed Beyond Line-of-Sight network combining TSM radios and drone relay nodes, ensuring resilient, long-range connectivity.

Impact and Future Directions

By the end of Bold Quest 24, the Royal Netherlands Army’s synthetic wrap had enhanced live exercises with layered virtual realism and established a new standard for coalition interoperability. Transmitting simulated ISR FMV over live radios, integrating JTACs into virtual federations, and proving interoperability through NATO-aligned HLA standards demonstrated the potential for scalable, cost-effective, and tactically relevant coalition training.

Coalition operational interoperability standardization compels technology to evolve to enable platforms and supporting C2 systems to share information at speed and at scale. The ability to build skill and efficiency compels coalition partners to leverage integrated live and virtual environments to explore the tactical relevance of an increasingly connected battlespace. The interwoven nature of this near future illustrates the speed at which information is created and consumed such that the future warfighter must propagate knowledge to decisive action.

Bold Quest 24 built upon years of development in LVC environments, confirming its foundational purpose: to provide a venue where nations, services, and program offices can demonstrate and assess methods for developing and maintaining coalition warfighter skills in closing multinational, multi-domain kill chains under realistic conditions. The engagement of proficient partners—demonstrated by their investment of time, personnel, and technology—created a dynamic exercise environment in which significant gains occurred during execution.

THE FUTURE OF MILITARY TRAINING

By integrating live, virtual, and constructive elements into a cohesive training environment, military operations can be simulated with unprecedented realism and flexibility. This approach has several broader implications for future military operations.

Enhanced Realism and Preparedness: LVC training allows military personnel to experience realistic scenarios that closely mimic actual combat situations. This heightened realism ensures that soldiers are better equipped to face the unpredictability and challenges of real-world operations. By training in environments that replicate the complexities of modern warfare, including cyber threats and multi-domain coordination, military forces can develop the skills and adaptability needed to respond effectively to evolving threats.

Improved Interoperability: One of the key benefits of LVC training is its ability to enhance interoperability among coalition forces. By leveraging standardized protocols and technologies, such as NATO interoperability standards, partner nations can seamlessly integrate their simulation assets into a unified training environment. This collaboration fosters a sense of unity and cooperation, ensuring that coalition forces can operate effectively together during joint missions (Derleth, 2015).

Cost-Effective Training: Traditional training exercises can be logistically challenging and expensive. LVC training offers a cost-effective alternative by reducing the need for extensive physical resources and infrastructure. By utilizing virtual simulations and constructive inputs, military forces can conduct comprehensive training exercises without the high costs associated with live training. This approach allows for more frequent and diverse training opportunities, ultimately enhancing overall readiness. LVC provides cost avoidance at a ratio of ~100 to 1 for Live to LVC training (Park, 2023).

Technological Advancements: The integration of advanced technologies, including artificial intelligence, machine learning, and sophisticated communication systems, plays a crucial role in shaping the future of military training.

These technologies enable the creation of dynamic and adaptive training environments that can respond to participants' actions in real-time. Additionally, the development of more sophisticated simulation tools and environments will allow for the training of complex scenarios, including hybrid warfare and multi-domain operations. These advancements will ensure that military forces remain at the cutting edge of training and preparedness, and develop key skills in relation to parsing a variety of types of data streams

In effect, Bold Quest 24 validated the broader implications of integrating live and virtual environments. First, by enabling the pooling of scarce assets—virtual aircraft sorties, synthetic enemy formations, and advanced ISR—more coalition units could train together without leaving home bases. This dramatically reduced the logistical footprint compared to a purely live coalition exercise. Second, the event fostered interoperability: partnering nations practiced standard procedures and data exchanges in a realistic scenario, building the trust and shared understanding essential for wartime coalition operations. Third, the technological advances on display—HLA-based federations, state-of-the-art tactical data linked networks, high-throughput MANET radios, real-time FMV distribution, and adaptive adversaries—represent the cutting edge of simulation and networking, foreshadowing even more immersive and responsive training environments.

CONCLUSION

LVC training offers a superior and cost-effective approach to preparing military personnel for the complexities of modern warfare. Instead of relying solely on expensive live-fire exercises or static classroom instruction, LVC training weaves together live radio communications, digital message exchanges, and simulated environments—complete with full-motion video (FMV) and drone feeds—so that every participant, whether on the ground or behind a console, sees and interacts with the same operational picture. This seamless fusion of live and synthetic elements not only heightens immersion but also expands situational awareness, allowing warfighters to observe threats beyond their immediate surroundings and practice coordinated responses in a dynamic, multi-domain battlespace. This will be a vital set of skills for warfighters to develop going forward when there is a significant likelihood of increasing levels of technological data augmenting decision making in a real-life operation.

Cost-effectiveness is one of the most compelling advantages of LVC training. Traditional exercises require significant logistical support—moving troops, securing ranges, and expending costly munitions—while often limiting participants to a narrow set of scenarios. By contrast, virtual and constructive simulations reduce the need for physical resources: high-demand assets such as close-air-support sorties and unmanned aerial systems can be generated virtually and employed repeatedly without logistical overhead. At the same time, live elements (instrumented with systems like the Tactical Engagement Simulation System, or TESS) can interact with synthetic entities, preserving the realism of a live exercise while leveraging simulated threats and scenarios that would be prohibitively expensive or dangerous to replicate in the real world. As a result, training becomes more sustainable, allowing units to rehearse complex missions more frequently and at a fraction of the cost.

Beyond realism and cost savings, LVC training enhances collaboration across different units and services. Within a unified LVC federation—often built on High-Level Architecture (HLA) and linked with standardized data protocols—ground forces, air assets, and command posts all publish and subscribe to the same streams of information. This cross-thread cooperation enables joint fire execution within a synthetic environment: for example, a forward observer using an Android Tactical Assault Kit (ATAK) can mark targets on a shared digital map, cue virtual aircraft to simulate a close-air-support strike, and immediately see the results—whether manifested on a live range or in a constructive simulator. By rehearsing these integrated kill chains in peacetime, forces develop the communication skills, trust, and interoperability necessary to operate seamlessly in coalition operations.

Ultimately, LVC training represents a paradigm shift in military readiness. It empowers personnel to hone their skills, adapt to evolving threats, and achieve mission success more reliably than traditional methods alone. By making training more realistic, affordable, and collaborative, LVC environments are revolutionizing how armed forces prepare for the modern battlespace. As exercises like Bold Quest 24 demonstrate, integrated LVC events are the future of coalition training, offering cost-effective realism and accelerating interoperability by forcing diverse systems to work together and by identifying gaps before conflict. Looking ahead, continued advancements in simulation fidelity, secure networks, and data-centric command and control will only amplify the impact of LVC training, ensuring that coalition forces remain agile, responsive, and effective in the face of tomorrow's challenges.

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