Unmanned Ground Systems at the Tactical Edge: From Experimentation to Fielded Capability (Draft for Comments)

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Executive Summary

Unmanned ground systems (UGS) are approaching an inflection point in their development, driven by rapid advances in autonomy, the proliferation of commercial robotic platforms, and the evolving character of modern warfare. While unmanned aerial systems (UAS) have already transformed the battlefield through persistent surveillance and precision strike, ground systems have yet to achieve comparable scale or operational integration. However, recent developments across commercial industry, U.S. Army modernization efforts, and ongoing conflicts, most notably in Ukraine, indicate that UGS are poised to play a critical role in future maneuver operations.

The current UGS ecosystem is fragmented across multiple domains. Commercial industry is rapidly iterating on low-cost, adaptable platforms, often leveraging existing mobility solutions such as all-terrain vehicles to reduce cost and improve sustainment through established supply chains. At the same time, U.S. Army programs continue to pursue purpose-built systems designed to meet specific operational requirements, creating tension between bespoke military solutions and commercially derived alternatives. This divergence is further complicated by differing approaches to system architecture, with many vendors favoring vertically integrated solutions while operational units express a clear preference for interoperable systems that can integrate with existing mission command platforms.

Operational observations from Ukraine highlight both the potential and limitations of ground robotics in a contested environment. While UAS have achieved widespread adoption due to their relative affordability and ease of employment, UGS have been employed more selectively, often constrained by terrain, survivability, and cost. Nevertheless, emerging use cases, including logistics support under fire, persistent sensing, and distributed operations, demonstrate the unique advantages of ground platforms, particularly their ability to provide extended loiter, increased payload capacity, and sustained presence on the battlefield. These developments also underscore the reality that adversaries will adapt, employing electronic warfare, mines, and loitering munitions to counter robotic systems.

Experimental efforts provide critical insight into the current state of UGS technology, and the challenges associated with transitioning these systems into operational formations. A central finding of current Army experimentation is that the primary challenges associated with UGS are not solely technological, but systemic. Autonomy performance continues to improve, but its operational effectiveness is closely tied to user trust and risk tolerance. Software has emerged as a critical component of these systems, requiring continuous development, updates, and cybersecurity management, introducing a persistent funding

requirement that differs fundamentally from traditional hardware-centric acquisition models. At the same time, institutional preferences for multi-purpose platforms risk producing overly complex and costly systems, while mission-specific solutions introduce additional training and sustainment burdens.

Looking forward, the most significant operational advantages will not come from ground systems alone, but from their integration with other robotic capabilities. The future battlefield will be defined by the synergy between air and ground systems, where UAS provide reconnaissance, targeting, and communications, and UGS deliver persistence, payload capacity, and sustained presence. Together, these systems enable a distributed, resilient, and scalable approach to maneuver that enhances both survivability and lethality.

To realize this potential, the Army must address several critical challenges. These include standardizing control architectures, enforcing modular open system design principles, developing sustainable software funding models, clarifying key concepts such as “attritable” systems, and adapting doctrine, training, and force structure to effectively integrate human–machine teams. Additionally, the Army must carefully balance the adoption of commercial technologies with the need to ensure supply chain security and long-term sustainment.

Unmanned ground systems are no longer a future capability, they are an emerging reality. The question facing the Army is not whether to adopt these systems, but how to integrate them effectively into maneuver formations in a way that maximizes operational advantage while managing cost, complexity, and risk. The observations and analysis presented in this paper provide a framework for understanding the current state of UGS development and offer recommendations for their successful integration into the future force.

Introduction: The Emerging Role of Ground Robotics

The character of modern warfare is undergoing a fundamental shift driven by the rapid proliferation of unmanned systems, persistent sensing, and networked precision fires. Nowhere is this transformation more visible than in the widespread adoption of (UAS), which have become ubiquitous across recent conflicts. From small reconnaissance drones to loitering munitions, air platforms have reshaped how militaries observe, decide, and strike on the battlefield. In contrast, UGS have lagged behind in both adoption and operational impact, remaining largely confined to niche roles such as explosive ordnance disposal or limited logistics support.

This disparity is not due to a lack of potential, but rather the inherent complexity of operating on the ground. Unlike in the air, UGS must contend with highly variable terrain, obstacles, and mobility constraints that complicate autonomy and reduce reliability. At the same time, advances in sensing and targeting have made the battlefield increasingly transparent. Persistent surveillance from UAS, satellites, and networked sensors has significantly reduced the ability of forces to maneuver undetected. As a result, traditional approaches that rely on the survivability of manned platforms are becoming increasingly challenged, particularly in contested environments where detection can rapidly lead to engagement.

These conditions are driving a growing demand for capabilities that can operate with greater persistence, distribution, and reduced risk to human operators. UGS offer a unique opportunity to meet this demand. UGS can provide extended loiter, carry large payloads, and maintain a continuous physical presence in complex terrain. They have the potential to support a wide range of functions, including logistics under fire, reconnaissance, deception, and direct combat support. However, realizing this potential requires overcoming significant technological, organizational, and conceptual challenges.

A central issue is the fragmented nature of UGS development. Commercial industry is rapidly advancing robotic technologies, often prioritizing cost and speed of iteration through the use of commercially available platforms and components. In parallel, U.S. Army programs are pursuing purpose-built systems designed to meet specific requirements, often emphasizing survivability, integration, and scalability. Meanwhile, foreign forces, particularly those observed in ongoing conflicts such as Ukraine, are adapting available technologies in real time to meet immediate battlefield needs. These three domains: commercial innovation, institutional acquisition, and operational adaptation are evolving along different trajectories, creating gaps in integration, interoperability, and shared understanding.

This paper argues that UGS are not a niche capability, but a necessary component of future maneuver. However, their development and integration remain uneven and incomplete. By examining the current state of UGS across commercial industry, U.S. Army

programs, experimentation effort, and operational employment in Ukraine, this paper seeks to provide a comprehensive assessment of where these systems stand today and what challenges must be addressed to fully realize their potential.

The Global State of Unmanned Ground Systems

While multiple nations and industry partners are investing in robotic ground platforms for reconnaissance, logistics, and combat roles, these systems vary significantly in maturity, autonomy, and operational integration. Understanding the current global landscape is essential to identifying both the opportunities and limitations of these systems as they evolve from experimental capabilities into operational tools for the modern U.S. Army.

Categories of Unmanned Ground Systems

UGS can be broadly categorized based on their primary operational function, though many platforms are designed with modularity that allows them to support multiple mission sets. These categories provide a useful framework for understanding how UGS are currently being developed and employed across military and commercial applications.

While these categories provide a useful structure, the continued evolution of modular payloads and autonomy is increasingly blurring the lines between them, reinforcing the importance of flexible, mission-tailored approaches to UGS employment.

Reconnaissance systems are typically small, highly mobile platforms designed to provide forward sensing, surveillance, and situational awareness in complex or high-risk environments. These systems prioritize stealth, endurance, and sensor capability, enabling units to extend their observation beyond line-of-sight without exposing operators.

Figure 1. Ghost Robotics U.S. Air Force photo by SSgt Ryan Hayman, *"Don't go petting these dogs!"* August 5, 2022, DVIDS, VIRIN: 220805-F-NJ333-1092 (public domain).

Logistics and resupply systems focus on reducing the physical and operational burden on soldiers by transporting equipment, ammunition, and supplies. These platforms are often optimized for load-carrying capacity, range, and reliability, with an emphasis on following dismounted units or operating along pre-planned routes.

Figure 2. Small Multi-Purpose Squad Equipment Transport INC I, U.S. Army photo by SGT Chandler Coats, *"10th Mountain Division implements new drone tech during Combined Resolve 25-1,"* January 15, 2025, DVIDS, VIRIN: 250115-A-GR811-3137 (public domain).

Combat or armed systems integrate lethal or non-lethal payloads to provide direct fire support, security, or force protection. These systems introduce additional complexity related to rules of engagement, target identification, and control authority, often driving vendors toward more tightly integrated and controlled architectures.

Figure 3. The Milrem THeMIS unmanned ground system participates in the 2024 Army Expeditionary Warrior Experiment, January 29, 2024, Fort Moore, Georgia. U.S. Army photo by Camelia Streff, DVIDS, VIRIN: 240129-O-BN515-2145 (public domain).

Breaching and explosive systems are designed to operate in hazardous environments to clear obstacles, emplace effects, or conduct route clearance. These platforms prioritize durability, precision control, and the ability to operate in close proximity to threats such as mines, improvised explosive devices, or fortified positions.

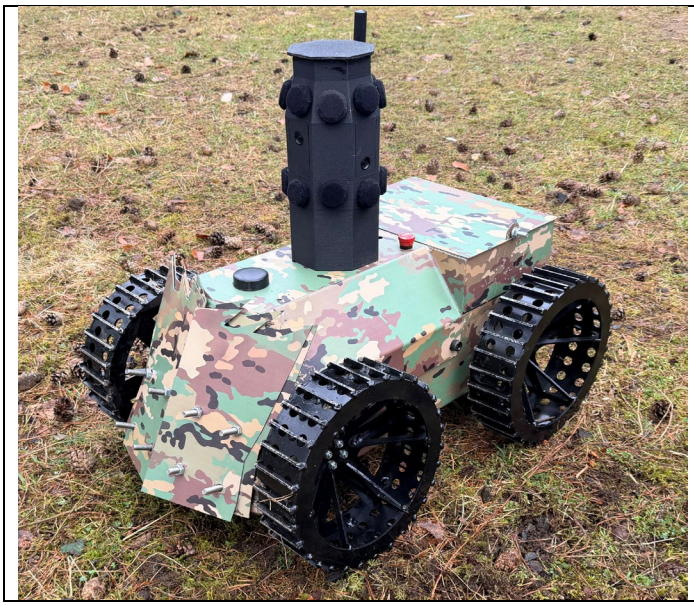

Figure 4. Gaard Tech Jaeger, Vilseck, Germany, March 11, 2026. Photo James Chaney.

Optionally manned systems represent a hybrid approach, allowing platforms to be operated either autonomously or with a human onboard. These systems offer flexibility in contested environments, enabling rapid repositioning, simplified transport, and mission adaptability while retaining the benefits of unmanned operation when risk to personnel is high.

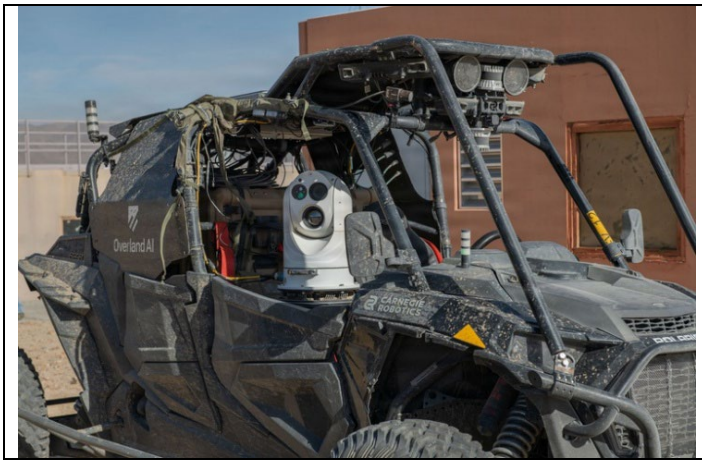

Figure 5. RACER Fleet Vehicle using a drive-by-wire Polaris RZR S4 1000 during testing in Texas, November 5, 2025. U.S. Army photo by Thomas Sakell, DVIDS, VIRIN: 251105-O-GT123-4213 (public domain).

Technology Maturity

The maturity of UGS varies significantly across platforms and is best understood through three key dimensions: autonomy, sensing, and communications, and control. While

progress has been made in each area, limitations in one often constrain the effectiveness of the others, highlighting the interdependent nature of UGS development.

Autonomy remains uneven across the current ecosystem. Most systems operate along a spectrum ranging from teleoperation, where the operator directly controls the platform, to supervised autonomy, where the system executes tasks with human oversight, and toward fully autonomous operation under limited conditions. While advances in edge computing and artificial intelligence have improved navigation and object detection, truly reliable autonomy in complex terrain remains a challenge, often requiring a balance between performance and acceptable operational risk.

Programs such as DARPA's RACER (Robotic Autonomy in Complex Environments with Resiliency), the U.S. Army's Robotic Combat Vehicle (RCV) efforts, and the Autonomous Navigation and Targeting initiatives under Army Futures Command were working to close the gap between current supervised autonomy and reliable, high-speed autonomous maneuver in complex terrain. Additional efforts, including DARPA's OFFSET (Offensive Swarm-Enabled Tactics) and Subterranean Challenge, as well as service-led autonomy experiments within Project Convergence, have further advanced perception, navigation, and multi-domain integration in contested and unstructured environments. These programs emphasize the ability to operate in conditions where obstacles, vegetation, and degraded communications challenge traditional autonomy approaches. By leveraging advances in machine learning, simulation, and edge computing, they aim to enable ground systems to operate at tactically relevant speeds with reduced human intervention. However, while these initiatives demonstrate significant progress in controlled and semi-structured environments, translating that performance into consistent, field-ready capability remains a challenge due to terrain variability, environmental complexity, and adversary interference. As a result, autonomy is advancing rapidly, but it has not yet achieved the level of robustness required for fully independent operation across the full range of military environments.

Figure 6. DARPA's Offensive Swarm-Enabled Tactics (OFFSET) experimentation at Joint Base Lewis-McChord, Washington, August 6, 2020. U.S. Navy photo, Naval Information Warfare Center Pacific, DVIDS, VIRIN: 200810-N-N1809-003 (public domain).

Figure 7. Robotic Combat Vehicle (Light), RCV(L), prototype during Soldier Experimentation at the National Training Center, Fort Irwin, California, September 30, 2023. U.S. Army photo by

Figure 8. U.S. Army Soldiers from the MCoE **E**xperimental Company demonstrate rapid medical evacuation using the Hunter WOLF litter-carrying vehicle during **Project Convergence Capstone 4** at the National Training Center, Fort Irwin, California, March 17, 2024. U.S.

	Savannah Baldwin, DVIDS, VIRIN: 230930-A-XP329-4721 (public domain).	Army photo by Sgt. Charlie Duke, DVIDS, VIRIN: 240317-A-UP538-1421 (public domain).

Sensing is becoming increasingly sophisticated, incorporating combinations of optical cameras, infrared systems, LIDAR, radar, and acoustic sensors to enable perception and navigation. These systems rely heavily on sensor fusion to compensate for the limitations of individual modalities, particularly in degraded environments such as low visibility, cluttered terrain, or contested electromagnetic conditions. However, sensor selection and configuration introduce trade-offs between detection capability, system cost, and signature management.

U.S. government efforts to advance sensing for unmanned ground systems are distributed across research, prototyping, and integration programs rather than centralized within a single initiative. Army SBIR efforts focused on perception for autonomous ground systems directly target key challenges such as off-road sensing, adverse weather performance, and long-range detection, while DARPA programs such as the Subterranean Challenge have significantly advanced multi-modal sensor fusion in degraded and GPS-denied environments. Additional efforts, including Assured Autonomy and long-standing Army Research Laboratory work on unattended ground sensors, address the reliability and persistence of sensing in operational conditions. At the same time, much of the rapid progress in sensing capability is being driven by the commercial sector, where advances in LiDAR, radar, and computer vision, originally developed for autonomous vehicles, are now being adapted for military applications. As a result, the state of sensing for ground autonomy is characterized not by a single dominant program, but by a convergence of government research and commercial innovation, with integration remaining the primary challenge to operational employment.

Communications remain one of the primary limiting factors for the effective employment of unmanned ground systems, particularly in contested and complex environments. U.S. Army efforts such as programs under CPE C2IN provide the foundational architecture for command and control, enabling platforms to connect with mission command systems and broader tactical networks. Experimentation efforts such as Project Convergence have further explored how unmanned systems can operate as part of a larger, networked force, sharing data across sensors, shooters, and autonomous platforms. At the same time, DARPA initiatives such as OFFSET have advanced concepts for distributed communications and coordination among robotic systems, emphasizing resilience in degraded and denied environments. Despite these efforts, communications for UGVs remain constrained by bandwidth limitations, terrain interference, and vulnerability to electronic warfare, all of which directly impact the ability to control platforms, transmit sensor data, and integrate into combined arms operations.

Much of the rapid advancement in UGV communications is being driven by the commercial sector, particularly through the development of mesh networking technologies that enable

decentralized, self-healing networks without reliance on fixed infrastructure. Systems from companies such as Persistent Systems and Silvus Technologies have demonstrated the ability to maintain connectivity across mobile formations, allowing UGVs to operate as nodes within a distributed network rather than as isolated platforms. Additional capabilities, including low Earth orbit satellite communications and emerging 5G-based solutions, offer increased bandwidth and extended range, but introduce tradeoffs in detectability, reliability, and dependence on external infrastructure. As a result, the evolution of UGV communications is increasingly defined by a balance between connectivity and survivability, with a growing emphasis on reducing communication requirements through greater onboard autonomy and edge computing. This shift reflects a broader recognition that in contested environments, the most effective systems will be those that can continue to operate even when communications are degraded or denied.

Control of UGS is emerging as a distinct and increasingly critical capability area, separate from communications and autonomy. Current systems are often fielded with proprietary control software and dedicated controllers, creating significant friction for units required to operate multiple platforms simultaneously. This fragmentation increases cognitive load, complicates training, and limits interoperability across formations. In response, the Army and broader DoW have begun emphasizing common control approaches that enable operators to manage multiple systems through a unified interface. Efforts such as DARPA's Squad X program have explored intuitive human–machine interfaces and mission command constructs that allow small units to employ robotic systems as extensions of the squad, rather than as standalone assets. Similarly, initiatives within the Maneuver Center of Excellence and DEVCOM Ground Vehicle Systems Center's 10x program were focused on rapid experimentation and integration of autonomous systems, including the development of common control frameworks that can support multiple platforms and payloads. These efforts align with broader Army objectives to integrate unmanned systems into existing mission command architectures, including potential interfaces through systems such as Android Team Awareness Kit (ATAK), reducing the need for platform-specific controllers.

Figure 9. Cpl. Tyler Coffie, a CBRN specialist with Charlie Company, 64th Brigade Support Battalion, 3rd Armored Brigade Combat Team, 4th Infantry Division, uses the **Android Team Awareness Kit (ATAK)** to locate simulated casualties during Ivy Sting 4 at Fort Carson, Colorado, February 3, 2026. U.S. Army photo by Pfc. Jacob Cruz, DVIDS, VIRIN: 260204-A-RE805-1026 (public domain).

Looking forward, control architectures must evolve beyond platform-specific inputs toward mission-based command of heterogeneous robotic teams. Rather than directing individual vehicles, future operators will need the ability to assign tasks such as “conduct reconnaissance,” “establish security,” or “conduct attack” across a mix of unmanned aerial and ground systems. This shift toward intent-based control is being explored through experimentation efforts such as Project Convergence and emerging autonomy frameworks that enable coordinated behavior across multiple domains. Achieving this vision will require not only advances in autonomy, but also standardized interfaces, shared data models, and trust in system performance. The integration of heterogeneous air-ground robotic teams represents a significant step forward, enabling complementary capabilities such as aerial sensing paired with ground-based persistence and payload delivery. However, this approach also introduces new challenges in synchronization, control authority, and human oversight. As a result, the future of UGS control will depend on the Army’s ability to transition from controlling individual systems to commanding integrated robotic formations, while maintaining simplicity and reliability at the point of employment.

Together, these factors illustrate that while UGS technology has advanced considerably, it has not yet reached a level of maturity that allows for consistent, scalable employment across all operational environments.

Key Limitations

Unmanned ground systems face several persistent limitations that constrain their operational effectiveness and scalability. These challenges are not isolated; they are interrelated and often compound one another, particularly in contested and complex environments.

Mobility vs Terrain

Mobility remains one of the most significant challenges for UGS. Unlike UAVs, ground platforms must physically traverse complex and unpredictable terrain, including

vegetation, urban obstacles, soft soil, and elevation changes. These conditions can slow movement, reduce reliability, or render routes impassable. As a result, mobility is not solely a function of vehicle design, but also of autonomy performance and route selection, both of which directly impact operational tempo.

Figure 10. RACER vehicle tows an M58 Mine Clearing Line Charge (MICLIC) during testing in Texas, October 29, 2025. U.S. DARPA photo by Thomas Sakell, DVIDS, VIRIN: 251029-O-GT123-6789 (public domain).

Autonomy Reliability

Autonomy continues to improve but remains inconsistent across environments. Systems that perform well in controlled or semi-structured conditions often struggle in cluttered, degraded, or dynamic terrain. Limitations in perception, decision-making, and obstacle classification can require frequent operator intervention, reducing the effectiveness of autonomous operation. This variability directly affects user trust and limits the ability to scale autonomous systems across formations.

Signature Management

UGS introduce unique signature challenges that can increase detectability on the battlefield. Active sensors such as LIDAR, as well as communications emissions and thermal outputs, can be detected by adversaries using night vision, electronic warfare, or other sensing technologies. Mitigation strategies such as sensor fusion and passive sensing can reduce signature but often come at the cost of reduced speed or performance, creating a tradeoff between survivability and capability.

Cost vs Scale

Cost remains a central constraint on the widespread adoption of UGS. High-end systems with advanced autonomy and sensor suites offer increased capability but are often too expensive to field at scale. Lower-cost systems enable greater distribution and attritability but may lack the performance, durability, or survivability required for certain missions.

Balancing cost, capability, and scalability is therefore a key challenge, particularly as the Army seeks to employ UGS as part of distributed and massed formations.

Commercial UGV Ecosystem

The commercial unmanned ground system ecosystem is rapidly evolving and increasingly influential in shaping the capabilities available to military users. Driven by cost, speed of iteration, and access to mature technologies from adjacent industries such as automotive autonomy and robotics, commercial vendors are developing a wide range of platforms that prioritize adaptability and scalability. Unlike traditional defense acquisition programs, which often focus on purpose-built systems, commercial approaches frequently leverage existing mobility platforms, modular components, and software-driven architectures to accelerate development and reduce cost. This dynamic has created a diverse and competitive landscape, where innovation is occurring at a pace that often outstrips formal military programs, while also introducing challenges related to integration, standardization, and long-term sustainment.

Commercial-First Design Trends

Commercial UGS development is characterized by design approaches that prioritize speed, affordability, and adaptability over traditional, purpose-built military solutions. One of the most visible trends is the use of commercially available mobility platforms, such as all-terrain vehicles and Polaris RZR systems, as the foundation for robotic platforms. By leveraging existing vehicle designs, vendors are able to reduce development timelines, take advantage of established supply chains, and simplify maintenance through widely available parts.

In addition to platform selection, commercial developers emphasize rapid prototyping and iterative design. Rather than pursuing long development cycles, vendors frequently field early versions of systems and refine them based on testing and user feedback. This approach accelerates innovation and allows for quicker adaptation to emerging requirements, particularly in areas such as autonomy, sensing, and payload integration.

Cost-driven design is a central feature of the commercial ecosystem. Vendors often make deliberate tradeoffs between performance and affordability to enable broader adoption and scalability. This includes selecting lower-cost components, simplifying system architectures, and focusing on modular designs that allow capabilities to be added or removed based on mission requirements. While this approach may limit performance in some areas, it aligns with the growing emphasis on distributed operations and the need to field systems at scale rather than in limited, high-cost quantities.

Advantages

The commercial UGS approach offers several distinct advantages that make it an attractive source of capability for military applications. One of the most significant is supply chain resilience. By leveraging commercially available platforms and components, vendors are able to draw from established manufacturing and distribution networks, reducing reliance on specialized or limited defense supply chains. This increases availability of parts, simplifies maintenance, and enhances the ability to sustain systems in both training and operational environments.

Cost efficiency is another key advantage. Commercial developers prioritize affordability by using off-the-shelf components, scalable production methods, and streamlined system designs. This enables the production of capable platforms at significantly lower cost than traditional defense systems, supporting the potential for wider distribution and attritable use. In parallel, rapid iteration allows vendors to quickly adapt designs based on user feedback and technological advancements. Short development cycles and continuous refinement enable systems to evolve at a pace that aligns more closely with operational needs, particularly in rapidly changing environments where requirements are still emerging.

Limitations

Despite the advantages of the commercial unmanned ground system ecosystem, several limitations constrain its direct application to military operations.

Survivability is one of the most significant limitations. Commercial platforms are typically not designed for contested environments and often lack the protection, redundancy, and hardening required to operate under fire, in electronic warfare conditions, or against adversary targeting systems. While this may be acceptable for certain mission sets or attritable concepts, it limits their effectiveness in high-threat environments without additional modification.

Standardization gaps also present a persistent challenge. The diversity of vendors and approaches has resulted in a fragmented landscape of hardware, software, and interfaces, with limited common standards across systems. This lack of standardization complicates interoperability, increases training requirements, and makes it difficult to integrate multiple platforms into a cohesive operational framework. Efforts to implement Modular Open Systems Architecture (MOSA) approaches can mitigate these issues but require deliberate enforcement and alignment across stakeholders.

Integration challenges further compound these limitations. Commercial systems are often developed independently of existing military networks, mission command systems, and doctrinal concepts, making it difficult to incorporate them into operational formations without additional integration work. This includes challenges related to communications compatibility, control interfaces, data formats, and cybersecurity requirements. As a result, while commercial platforms offer rapid capability development, significant effort is often required to transition these systems from standalone solutions into fully integrated components for military use.

Vendor Incentives

Vendor incentives for commercially based UGS often drive design decisions that can conflict with military preferences for interoperability and flexibility. Many companies pursue vertical integration, developing tightly coupled systems that combine mobility platforms, autonomy software, communications, and payloads into a single solution. This approach allows vendors to optimize performance, control system behavior, particularly for sensitive functions such as lethal payloads, and reduce integration complexity from their perspective. However, it can limit the ability to incorporate external components or adapt the system to evolving requirements.

This dynamic is closely tied to the development of proprietary ecosystems. Vendors frequently design systems with unique interfaces, data formats, and control architectures that restrict interoperability with other platforms. While this can create a more seamless user experience within a single system, it complicates efforts to integrate multiple vendors into a unified operational framework and runs counter to MOSA principles. As a result, units may be forced to operate multiple, incompatible systems, increasing cognitive load and training burden.

Software licensing models further reinforce these incentives. Unlike traditional hardware-centric systems, many commercial UGS rely on ongoing software development to maintain and improve autonomy, perception, and system functionality. Vendors often structure this as recurring licensing or support agreements, creating a continuous revenue stream but also introducing long-term cost considerations for the Army. This model can conflict with existing acquisition expectations and budgeting processes, which are typically oriented toward one-time procurement rather than sustained software investment. Together, these incentives shape the commercial landscape and present both opportunities and challenges for integrating UGS into military formations.

U.S. Army Programs and Requirements

Requirements Tensions

Platform requirements are shaped by a fundamental tension between the desire for a single, multi-purpose system and the operational reality that different missions demand different capabilities. While a unified platform can simplify training, sustainment, and procurement, attempting to satisfy reconnaissance, logistics, and combat roles within one system often results in increased complexity, higher cost, and degraded performance. Alternatively, fielding multiple specialized systems enables mission optimization but introduces additional burdens in training, maintenance, and integration across formations.

Lethality considerations create a second tension between combat capability and sustainment-focused roles. Armed platforms offer the potential to extend combat power and reduce risk to soldiers, but they introduce challenges related to rules of engagement, control authority, and system reliability. In contrast, logistics-focused systems provide immediate and measurable benefits by reducing soldier load and enabling sustainment in contested environments, though they may be perceived as less transformative than lethal capabilities. Balancing these priorities requires careful assessment of operational value, risk, and technological maturity.

Autonomy expectations continue to outpace operational reality, but this gap should not be interpreted as a failure of the technology itself. Requirements often assume high levels of autonomous performance across diverse environments, while current systems struggle to maintain reliability in complex terrain, degraded visibility, and contested electromagnetic conditions. This mismatch can lead to overestimation of system capability and, in some cases, a tendency to discount autonomy altogether when it does not meet idealized expectations. However, even limited or supervised autonomy can provide meaningful operational advantages by reducing operator burden, enabling persistent operations, and improving system performance in specific conditions. Bridging this divide will require aligning requirements with demonstrated performance, recognizing the incremental value of autonomy, and integrating these capabilities into formations in a deliberate and scalable manner.

Acquisition Friction

Requirements development introduces significant friction as UGS transition from rapid experimentation to broader adoption. While early efforts often demonstrate capability in focused scenarios, the process of expanding requirements to address additional missions, stakeholders, and conditions can create a disconnect between what was proven and what

is ultimately pursued. As requirements grow, systems are frequently burdened with additional features, performance thresholds, and integration demands that increase complexity, cost, and development time. This expansion can slow momentum, dilute originally demonstrated strengths, and discourage participation from commercial vendors who optimized their designs for speed, affordability, and specific use cases. Managing this tension requires discipline in requirements development and a willingness to prioritize operationally relevant capability over comprehensive but impractical solutions.

Prototyping efforts are often misaligned with the structure and expectations of enduring programs, creating friction in the transition from experimentation to operational capability. Rapid experimentation initiatives, including events such as xTech and other Army-led efforts, frequently leverage Other Transaction Authority (OTA) and bailments to accelerate development and engage non-traditional vendors. Similarly, Transformation in Contact (TiC) has introduced a pathway to place emerging capabilities directly into operational units for real-world evaluation and iterative refinement. These efforts are effective at demonstrating capability and informing requirements in relatively unconstrained environments. However, as systems mature, requirements often expand to address additional missions, integration demands, and stakeholder inputs, creating a gap between what was demonstrated and what is ultimately pursued. The path from successful prototype to scalable capability remains unclear, with limited mechanisms to transition systems without significant redesign or recompetition. This disconnect can result in innovative solutions failing to transition into operational use despite demonstrated utility, highlighting the need for closer alignment between experimentation, requirements development, and long-term adoption.

Funding models further complicate acquisition by reflecting a legacy focus on hardware procurement rather than software-driven capability. Traditional acquisition approaches emphasize one-time purchases of physical systems, while UGS increasingly rely on continuous software development for autonomy, perception, and cybersecurity. This creates a mismatch between how systems are funded and how they must be sustained over time, often leading to resistance against recurring costs or insufficient resourcing for long-term software support. Addressing this challenge will require adapting funding models to reflect the reality that modern robotic systems function as evolving software-enabled platforms rather than static hardware solutions.

Operational Lessons from Ukraine

Current Use of Ground Robotics

Unmanned ground systems are present on the modern battlefield, but their adoption remains limited compared to UAS. While UAS have proliferated rapidly due to their relative ease of employment and lower barriers to entry, UGS are still primarily employed in niche roles. Their use is growing, particularly in environments such as Ukraine, but they have not yet achieved the same level of mass adoption or tactical ubiquity.

Why UGV Adoption Lags UAS

Several factors explain this disparity. Ground systems must contend with terrain complexity that significantly constrains movement and reliability, unlike air platforms that can bypass obstacles. Cost dynamics also play a roll, UGS are often more expensive and less easily expendable than small drones, making widespread, attritable use more difficult. Additionally, their physical presence on the battlefield increases vulnerability to detection and destruction, particularly from mines, direct fire, and loitering munitions. These factors combine to slow adoption and limit employment primarily to specific mission sets where their advantages outweigh these constraints.

Emerging Use Cases

Despite these limitations, several use cases are emerging where UGS provide clear operational value. Logistics while in contact is one of the most promising applications, reducing risk to soldiers by enabling resupply in contested environments. Casualty evacuation is another, allowing units to recover wounded personnel without exposing additional forces. UGS are also being used for remote sensing, route reconnaissance, and deception, where their presence can draw enemy attention or provide persistent observation in areas too dangerous for manned systems. These roles emphasize persistence and physical interaction with the environment, capabilities that complement, rather than replace, UAS.

Adversary Adaptation

As with all battlefield innovations, the employment of UGS is driving adversary adaptation. Electronic warfare is increasingly used to disrupt communications and control links, while mines and obstacles are employed to channel or disable ground systems. Loitering munitions and direct fires provide additional means to target UGS once detected. These countermeasures reinforce a central reality that effectiveness of UGS will always be contested. As their use expands, so too will the development of counter-UGS tactics,

requiring continued adaptation in how these systems are designed, employed, and integrated into operations.

Unmanned Ground Systems: Ukraine in Focus

Unmanned Ground Systems in Ukraine: Case Studies in Robotic Assault and Robotic Evacuation

Here are two combat-uses of UGS in Ukraine, based on a mix of official statements, unit-released video reporting, and reputable international journalism. The two events were selected because they show how UGS can be used for direct combat action under drone-saturated conditions, and how UGS are increasingly used for logistics and casualty evacuation (CASEVAC) where manned vehicles and dismounted teams face prohibitive risk.

Event A (robotic assault / prisoner capture): On 9 July 2025, 3rd Separate Assault Brigade reported a successful assault in Kharkiv Oblast executed using only FPV drones and "kamikaze" ground robotic systems, resulting in Russian troops surrendering and the seizure of previously resilient enemy fortifications. The brigade attributed the action to its NC13 ground-robotics element ("DEUS EX MACHINA"). The exact date of the underlying assault (as distinct from the video release date) was not specified in the public reporting.

Figure 11. Captured Russian soldiers in the Kharkiv region. Summer 2025. Photo credits: 3rd Assault Brigade

Event B (robotic CASEVAC under mines and FPV attack): On 5 March 2026, 25th Separate Airborne Sicheslav Brigade and 68th Separate Jaeger Brigade conducted a casualty evacuation in the Pokrovsk sector using the "Bizon" ground robotic system. The

casualty had lost a foot to a mine; the evacuation route was described as heavily mined and under persistent enemy drone observation. During the exfiltration, a Russian FPV drone struck the UGS while it was halted and attempting to conceal; communications were briefly lost, but the casualty survived and ultimately reached friendly lines.

Figure 12. Ukrainian soldiers unload a Bizon ground robotic system following a casualty evacuation (CASEVAC) mission on the Pokrovsk front, during which the platform successfully transported a wounded soldier despite being struck by a Russian FPV drone. Source: 25th Separate Airborne Sicheslav Brigade (Ukraine) (combat footage, 2026).

Across both events, the dominant observed threats and countermeasures were mines, persistent FPV/loitering-munition attack, and communications disruption risk (including the broader electronic warfare environment), with air-ground teaming frequently used to compensate for UGS sensing and navigation limitations.

Robotic assault in Kharkiv Oblast with surrender and position seizure

Event name and date (public release): “Ground robots force Russian troops to surrender” (video/story released 9 July 2025).

Ukraine:

- Primary unit: 3rd Separate Assault Brigade.
- Sub-element identified: NC13 (ground robotic systems) / “DEUS EX MACHINA” (within the brigade’s assault structure).

Russia: Russian troops occupying field fortifications/dugouts in Kharkiv Oblast (no unit identification in the cited reporting).

UGS models used: The brigade and downstream reporting described the employment as ground robotic systems and kamikaze ground robotic systems, but did not publicly identify specific platform model names for the assault systems in the openly cited articles. (Unspecified.)

Mission type(s): Direct attack (robotic assault), bunker/dugout reduction, psychological coercion leading to surrender, exploitation/clearing and seizure of position.

Operational timeline and sequence (as reported):

1. Problem & setting: Enemy fortifications in Kharkiv Oblast had reportedly withstood multiple prior capture attempts by adjacent Ukrainian units, implying a hardened position and/or unfavorable approach conditions.
2. Remote strike and breach: The brigade reported striking the fortifications with FPV drones and "kamikaze" ground robotic systems.
3. Close approach by UGS: As another ground robot approached a damaged dugout/holdout, surviving Russian troops reportedly declared surrender to avoid detonation.
4. Custody sequence: The surviving Russians were escorted out of the danger area by drones to Ukrainian positions and taken prisoner in accordance with protocol, with Ukrainian infantry involvement described as absent from the assault itself (though custody necessarily implies some controlled handover).
5. Outcome claimed: The brigade stated it secured the cleared fortifications and adjacent forest belt and emphasized without infantry and without casualties. Independent verification of the first in history/first confirmed characterization was not provided in the cited reports and should be treated as a unit claim.

Tactical effects and outcomes:

- Immediate tactical effect: Enemy fortifications neutralized/cleared and prisoners taken under conditions described as unmanned assault.

- Operational implication (inference): The event illustrates a doctrinally familiar breach/clear/secure executed using remote systems: standoff strike then robotic close approach then exploitation and control of terrain. This inference is consistent with the reported sequence but cannot be fully validated absent the original unit video and after-action detail.

Adversary countermeasures observed (in reporting):

- This specific episode's public writeups emphasize Ukrainian success and do not detail Russian countermeasures during the action beyond the implicit presence of dugout fortifications and the risk of detonation. (Unspecified for the event.)

- Broader reporting on Ukrainian UGS use indicates the dominant threat to forward UGS is Russian FPV drones, including fiber-optic variants, and that operators often seek standoff distances on the order of kilometers to reduce drone risk.

Bizon UGS casualty evacuation under mine threat and FPV strike in the Pokrovsk sector

Event name and date: "Ground robotic system carrying wounded soldier survives FPV strike" (reported 5 March 2026).

Ukraine:

- 25th Separate Airborne Sicheslav Brigade (Pokrovsk front).
- 68th Separate Jaeger Brigade (adjacent unit supporting continuation of evacuation after the strike).

Russian:

- Russian FPV drone operators (strike on the UGS), plus persistent UAV presence described during the operation. No Russian unit identification in the cited accounts.

UGS model used: "Bizon" ground robotic system (also rendered "Bison" in some English-language reporting), described as having a protected capsule for casualty movement.

- Manufacturer attribution is not provided in the cited sources. (Unspecified.)

Mission type(s): Casualty evacuation (CASEVAC) under fire; movement through mined terrain; limited concealment/pausing under drone threat; coordination with adjacent unit for completion of evacuation.

Operational timeline and sequence (as reported):

1. Casualty-producing incident: The wounded soldier stepped on a mine while moving between points (~900 meters distance referenced), resulting in loss of a foot; comrades stabilized and moved him to a dugout.

2. Decision point: Command judged the route densely mined and under fire, making a conventional vehicle approach infeasible; evacuation was assessed as possible only on foot or by UGS. The unit chose UGS to reduce risk to personnel.

3. UGS insertion and loading: The Bizon platform moved at night along a field/road route, reached the casualty location, and the casualty was loaded into the protected capsule.
4. Drone-threat management: After covering roughly half the route, the team was warned that the sky was busy/dirty (heavy drone presence). Because nets and roadside constraints limited turning into cover, the UGS stopped on the road to conceal.
5. Adversary strike: While stationary, the platform was hit by a Russian FPV drone; communications were lost (reported in the account as a 10–15 minute period without contact).
6. Recovery of the casualty: The casualty later re-established contact, stated he had no new injuries, exited the capsule, and reached a nearby friendly position; personnel from the adjacent 68th Brigade completed further evacuation.
7. Scale/duration figures (as reported): Reported route length was ~24 km total (12 km each way) and total operation duration was reported as roughly 12 hours in one detailed account.

Tactical effects and outcomes:

- Primary effect: A casualty who could not be recovered by vehicle without compounding losses was evacuated despite enemy drone strike on the evacuation platform.
- Secondary effect: The incident provides direct evidence that CASEVAC UGS are being employed in conditions characterized by heavy mining and continuous drone presence, with partial survivability even after FPV impact.

Adversary countermeasures observed:

- Mines as mobility denial and casualty-producing threat.
- FPV drones as loitering munitions against UGS and the evacuated casualty.
- Persistent aerial surveillance/strike density shaping movement (stop/camouflage decision).

Follow-on operational detail (evidence of sustainment and recovery operations): Days later, the 25th Brigade publicized recovery of damaged UGS from the outskirts of Pokrovsk, explicitly noting there are routes where armored vehicles cannot go and that UGS are used for delivery and casualty evacuation but are expensive and frequently become expendable, motivating recovery missions through kill zones.

Implications for employment and force design

UGS are being pulled into the "kill zone" primarily by necessity, not novelty

Reporting from multiple Ukrainian units emphasizes that FPV drone prevalence makes traditional resupply and evacuation increasingly hazardous, driving a shift to machines, not people for frontline logistics and evacuation.

The Bizon CASEVAC case demonstrates the justification for UGS use was not convenience but the assessed infeasibility of vehicle-based extraction under mining and UAV threats.

Air-ground teaming is repeatedly described as the enabling architecture

Multiple sources describe a pattern where a UAV provides route reconnaissance, obstacle identification, and sometimes eyes for a ground robot that lacks robust onboard sensing, while the UGS does the physical work (carry, tow, evacuate, breach).

The July 2025 assault case similarly describes a combined FPV strike and ground "kamikaze" approach logic, suggesting that UGS effects are often inseparable from UAS-enabled sensing, targeting, and coordination in current practice.

The dominant counter-UGS threat is not small arms; it is drones and mines

In the Pokrovsk CASEVAC, the decisive threats were dense minefields (mobility denial and casualty creation) and FPV drones (precision loitering strike) rather than direct-fire engagement with the platform.

Ukrainian commentary on broader UGS employment similarly emphasizes that Russian FPV drones, particularly fiber-optic variants are a leading threat to forward-deployed ground robots operating 1–2 km from enemy positions. This implies that UGS survivability design and tactics must prioritize:

- Mine interaction (rollers, route proofing, recoverability)
- Low signature + rapid concealment + drone-aware movement discipline, more than traditional armor-vs-direct-fire tradeoffs (observed threat descriptions).

UGS impose a sustainment burden that becomes operationally visible at the tactical edge

The 25th Brigade's public discussion of recovering damaged UGS, because armored vehicles cannot reach some routes, highlights a reality often absent from robotics as

capability narratives: once robots become essential, robot recovery and repair become tactical missions competing with other combat tasks.

This is consistent with broader combat reporting that UGS are not cheap drones in attrition terms. Units describe them as expensive assets that frequently become expendable, motivating active recovery from the “grey zone” when feasible.

Experimentation: Bridging Innovation and Operational Integration

Experimentation has emerged as the Army’s primary mechanism for bridging the gap between rapidly evolving commercial technologies, formal requirements development, and real-world operational employment.

The Role of Experimentation in UGV Development

Experimentation plays a central role in reducing risk and accelerating the development of UGS by enabling the Army to evaluate emerging capabilities in realistic operational contexts before committing to formal programs. Through iterative testing and direct soldier involvement, experimentation supports discovery, allowing units and capability developers to better understand what technologies can achieve in practice. It also informs requirement refinement by identifying which capabilities are operationally relevant and which may be unnecessary or impractical. Equally important, experimentation provides a mechanism for incorporating soldier feedback early in the development process, ensuring that systems are aligned with how they will actually be employed in the field.

This approach is particularly critical for areas such as autonomy, human–machine teaming, and the development of concepts of employment, where traditional requirements are often insufficient to capture the complexity of real-world conditions. Unmanned systems do not operate in isolation, and their effectiveness depends on how they integrate with soldiers, formations, and other systems. As a result, experimentation has become a primary driver of both technical development and operational understanding. Increasingly, requirements are being informed by what is demonstrated through experimentation, rather than attempting to define capability in advance, reflecting a shift toward a more adaptive and evidence-based approach to modernization.

Evolution of Army Experimentation Efforts

Army experimentation with robotic systems has evolved significantly over time, reflecting broader changes in technology and operational priorities. Early efforts focused primarily on specialized applications, such as explosive ordnance disposal (EOD) systems and robotics initiatives associated with Future Combat Systems (FCS), where platforms were developed

and tested in relatively controlled environments. These efforts were largely platform-centric, emphasizing the performance of individual systems rather than their integration into operational formations.

Over time, the Army has shifted toward a more iterative and operationally driven approach to experimentation. This includes increased use of soldier touchpoints, rapid prototyping mechanisms, and direct integration of emerging technologies into training and operational units. Rather than evaluating systems in isolation, current experimentation efforts emphasize how capabilities perform within real-world conditions and alongside other systems. As a result, the Army has moved from platform-centric testing to iterative, operationally informed experimentation that prioritizes adaptability, integration, and feedback from the point of employment.

Current U.S. Army Experimentation

The Army's current experimentation system is composed of multiple complementary efforts designed to rapidly evaluate, refine, and integrate emerging technologies into operational formations. These initiatives collectively provide a continuous feedback loop between developers, requirements writers, and operational units, shaping the future of unmanned ground system employment.

Transformation in Contact (TiC)

Transformation in Contact (TiC) represents a shift toward embedding emerging capabilities directly within operational formations, including units such as the 101st Airborne Division and the 25th Infantry Division, to evaluate systems under mission-relevant conditions. Within these formations, soldiers are employing capabilities such as the Ground Optionally Autonomous Transport (GOAT) and a range of commercial unmanned ground and aerial systems to support reconnaissance, sustainment, and distributed operations. This approach enables immediate assessment of how these systems perform within existing formations, highlighting practical considerations such as operator burden, sustainment demands, and integration with mission command systems.

The value of TiC lies in its ability to expose capabilities to operational friction early, generating insights that are difficult to replicate in controlled environments. Feedback from units informs adjustments to autonomy performance, control methods, and system employment concepts, while also identifying gaps in doctrine, training, and organizational design. By placing real systems in the hands of operational units, TiC accelerates the transition from demonstration to application, providing a clearer understanding of how unmanned systems can be effectively integrated into maneuver formations.

In addition to informing capability development, TiC has the potential to significantly accelerate operational testing timelines by embedding evaluation within existing training and deployment cycles. When systems are assessed during combat training center rotations or other unit-level exercises, they are exposed to complex, multi-domain scenarios that more closely reflect operational conditions than discrete test events. This approach allows programs to collect relevant performance data, user feedback, and integration insights in parallel with unit training, reducing the need for separate, resource-intensive testing events. As a result, capabilities can progress more rapidly from experimentation to operational validation, compressing timelines and enabling earlier identification of both strengths and deficiencies within realistic mission contexts.

Project Convergence

Project Convergence serves as the Army's primary venue for large-scale experimentation focused on multi-domain integration, linking sensors, decision-makers, and shooters across the battlefield. The effort emphasizes the ability to rapidly collect, process, and disseminate data to enable faster and more accurate targeting decisions. Within this context, autonomy and networking are critical enablers, supporting the integration of manned and unmanned systems into a cohesive operational framework.

For UGS, Project Convergence provides a key environment to assess their role within broader kill chains and distributed operations. UGS are evaluated not only as standalone platforms, but as nodes within a larger network, contributing sensing, targeting, and sustainment capabilities. This includes integration with UAS to enable air-ground teaming, where UAS provide reconnaissance and targeting data that can be acted upon or sustained by ground systems. These experiments highlight both the potential and the challenges of incorporating UGS into multi-domain operations, particularly in areas such as data integration, network reliability, and coordinated autonomy across heterogeneous systems.

xTech and Non-Traditional Vendor Engagement

The xTech prize challenge provides a critical pathway for engaging non-traditional vendors and accessing rapidly evolving commercial technologies relevant to unmanned ground systems. By lowering barriers to entry and reducing the complexity typically associated with defense acquisition, xTech enables small businesses and commercial developers to present innovative solutions that may not otherwise enter military procurement. This approach expands the pool of potential contributors and introduces a wider range of design philosophies, particularly those focused on cost, modularity, and rapid development.

xTech Edge Strike: Ground in Focus

Role of Edge xTech Strike: Ground

The xTech program, administered by the Assistant Secretary of the Army (Acquisition, Logistics and Technology), serves as a facilitator of prize-based competitions designed to identify, mature, and accelerate innovative technologies from non-traditional vendors. By leveraging a competitive framework with low barriers to entry, xTech enables the Army to rapidly access commercial innovation and evaluate emerging capabilities outside the constraints of traditional acquisition processes. Within U.S. Army Europe and Africa, this model has been leveraged by the Global Tactical Edge Acquisition Directorate (G-TEAD), the Army's forward acquisition hub focused on rapidly translating urgent operational needs into interoperable, combat-ready capabilities. G-TEAD synchronizes efforts across the acquisition enterprise and works with allied partners to accelerate the delivery of capabilities aligned to priorities such as those associated with the European Deterrence Initiative and eastern flank operations.

The xTech|Edge Strike: Ground event represents a focused application of this approach, providing a structured environment to evaluate UGS technologies against operationally relevant problem sets. The competition was designed to identify solutions at a level of maturity suitable for near-term application, culminating in live demonstrations where selected vendors presented their systems to Army, joint, and allied stakeholders. By emphasizing capability validation over requirement generation, the event enabled rapid assessment of technical feasibility, operational utility, and scalability across a diverse set of approaches.

As part of the broader experimentation ecosystem, xTech Ground Strike functions as a bridge between commercial innovation and Army capability development. It provides a mechanism to rapidly screen emerging technologies, inform follow-on experimentation, and support alignment between operational needs and available solutions. In doing so, the event contributes to a more agile and responsive approach to modernization, particularly in areas such as unmanned ground systems where the pace of technological change continues to outstrip traditional acquisition timelines.

What xTech Reveals About the Market

Reality diverges from expectations when systems are placed in an operationally relevant environment. Capabilities that appear mature in controlled demonstrations often degrade when exposed to terrain complexity, user variability, and integration requirements. xTech highlights the gap between technical feasibility and operational reliability, reinforcing that performance must be evaluated in context rather than in isolation.

Behavior of vendors is shaped as much by incentives as by technology. When exposed to a competitive environment with defined problem sets, vendors tend to optimize for demonstrable performance within the event rather than long-term integration into Army formations. This reveals a structural mismatch between how industry delivers capability and how the Army ultimately needs to employ it, particularly in areas such as control architectures, interoperability, and sustainment.

Convergence across solutions is limited despite common problem sets. While multiple vendors address similar mission areas, their approaches to autonomy, control, and system architecture vary significantly, resulting in a lack of natural standardization. This suggests that interoperability will not emerge organically from the market and will instead require deliberate direction and enforcement from the Army.

Tradeoffs become more apparent when systems are evaluated side by side. xTech exposes the practical balance between cost, performance, autonomy, and survivability in a way that is difficult to capture through requirements alone. Rather than identifying a single "best" solution, the event highlights that each design reflects a set of prioritized compromises, reinforcing the need for mission-specific selection and integration rather than a universal platform approach.

Key Observations from xTech Ground Strike

Building on the broader experimentation framework and insights from the xTech Ground Strike event, the following observations capture recurring themes identified across participating systems and vendor approaches. These observations are not isolated to individual platforms but reflect consistent patterns in how UGS are currently being designed, integrated, and evaluated for emerging technology and systems. Organized by functional capability areas, they provide a structured view of the opportunities and challenges associated with transitioning these systems into operational formations.

The observations are grouped across the following key areas:

- Control
- Autonomy
- Sustainment
- Modularity
- Cost

Control architecture remains fragmented across systems, with most platforms relying on proprietary controllers and software tailored to individual vendors. This creates significant friction at the unit level, where operators must manage multiple interfaces to employ different systems. Units consistently demonstrated a preference for simplified control

approaches that integrate with existing mission command systems, such as ATAK, enabling a single interface to manage multiple platforms. In practice, many vendors are technically capable of integrating into these environments with relatively modest effort, suggesting that interoperability is often more a matter of design choice than technical limitation.

However, this approach introduces important considerations and risks. Integration through common applications can be constrained by bandwidth, latency, and data formatting limitations, particularly when attempting to control multiple systems or transmit high-fidelity sensor data. There are also challenges related to control authority, cybersecurity, and system reliability when abstracting control through a common interface not originally designed for platform-level command and control. As a result, while ATAK and similar tools offer a viable pathway toward common control, they may not fully replace the need for purpose-built control architectures, particularly for complex or time-sensitive operations.

The lack of common control frameworks continues to limit scalability and increase cognitive burden, particularly as formations begin to integrate both air and ground robotic systems. Future effectiveness will depend on transitioning from platform-specific control toward mission-based command, where operators assign tasks across heterogeneous systems rather than directly controlling individual platforms.

Autonomy capabilities demonstrated meaningful potential during the event, but their effectiveness was closely tied to operator familiarity and training. Vendors were permitted to provide limited instruction, after which soldiers were expected to operate the systems without contractor intervention. This exposed gaps in usability and understanding, as systems that performed well during vendor-led demonstrations were more difficult to employ effectively under independent operation. In many cases, performance issues were not solely the result of autonomy limitations, but of insufficient training and user proficiency, highlighting that even advanced autonomous systems remain dependent on well-trained operators.

At the same time, autonomy provided measurable benefits even at lower levels of maturity, particularly in navigation, obstacle avoidance, and workload reduction. Systems capable of assisting with basic movement and task execution reduced operator burden and improved consistency when properly employed. The key challenge is not the absence of capability but aligning expectations with demonstrated performance and recognizing that autonomy does not eliminate the need for training. Effective integration will require a balanced approach in which autonomy enhances human decision-making while training ensures operators understand both the capabilities and limitations of the systems they employ.

Sustainment approaches vary widely across systems, with some platforms designed for soldier-level maintenance and others requiring significant vendor support. Systems built on commercial platforms benefit from established supply chains and readily available parts, simplifying maintenance and improving availability. However, more complex or proprietary systems introduce additional sustainment challenges, particularly in deployed environments.

Software sustainment represents an emerging and often underappreciated requirement, particularly as some vendors approach UGS as software companies with a mobility platform attached. For these vendors, the core value lies in autonomy stacks, perception algorithms, and control software, which are often delivered through licensing models rather than one-time purchases. This creates a dependency on continuous updates for performance improvements, cybersecurity, and feature development, requiring ongoing support and funding. While this model enables rapid capability evolution, it introduces long-term cost considerations and potential restrictions tied to licensing, access, and system modification. As a result, the shift toward software-dependent systems challenges traditional sustainment models and requires new approaches to lifecycle management that account for both hardware and continuously evolving software components.

Modularity is a key enabler for flexibility and adaptability, but is unevenly implemented across systems. Platforms that expose interfaces protocols and MOSA are better positioned to integrate diverse payloads, communications systems, and autonomy stacks. This allows for mission-specific configuration and the ability to incorporate best-of-breed components.

In contrast, vertically integrated systems limit interoperability and reduce flexibility, even when they offer optimized performance within a single platform. The lack of consistent modular standards across vendors highlights the need for deliberate architectural guidance to enable scalable integration across formations.

Cost challenges in the UGS market are driven less by individual platform price points and more by the absence of clear pathways to scale. Many systems remain in low-rate prototyping or limited production, where unit costs are inherently higher due to a lack of manufacturing efficiency and stable demand. Without transition to larger production runs, vendors are unable to reduce costs through economies of scale, limiting the Army's ability to field these systems in meaningful quantities.

This dynamic is compounded by uncertainty in long-term demand signals. Without clear commitment through mechanisms such as the Future Years Defense Program (FYDP), commercial vendors and their investors face increased risk when allocating resources

toward production capacity, workforce expansion, and supply chain development. As a result, companies may hesitate to invest beyond prototype-level capability, slowing maturation and increasing per-unit cost. Bridging this gap will require not only identifying promising technologies, but also providing clearer signals of sustained demand to enable industry to scale production and reduce costs over time.

Experimentation: Putting it all Together

Taken together, current experimentation efforts indicate that the challenge with UGS is no longer identifying viable technology, but integrating that capability into operational formations at scale. Across TiC, Project Convergence, xTech, and many other pockets of experimentation, a consistent pattern emerges. Useful capability exists today, but it is uneven in maturity, fragmented across vendors and programs, and difficult to integrate within existing architectures and concepts of employment. Experimentation is revealing that the primary barriers are not platform performance alone, but friction in control, communications, sustainment, training, and transition pathways. At the same time, these efforts demonstrate that requirements are increasingly being informed by observed performance and soldier feedback rather than predefined assumptions, highlighting a shift toward a more adaptive approach to capability development. Ultimately, success will depend less on selecting a single system and more on developing the frameworks, architectures, and institutional processes needed to employ a diverse set of robotic systems in a coordinated and operationally relevant manner.

What This Means for the Future of UGVs

The collective insights from commercial development, Army programs, operational observations, and experimentation efforts indicate that the future of unmanned ground systems will be defined less by individual platforms and more by how they are integrated, scaled, and employed within formations. UGVs are transitioning from experimental capabilities to operational tools, but their effectiveness will depend on resolving persistent challenges in control, communications, sustainment, and training, while aligning requirements with demonstrated performance. Rather than pursuing a single, universal solution, the Army will need to adopt a flexible, mission-driven approach that leverages a diverse set of systems, supported by common architectures and clear pathways to scale.

The Platform Fallacy

The pursuit of a single UGS capable of performing across too many mission sets is both impractical and counterproductive. Efforts to consolidate reconnaissance, logistics, and combat functions into a single platform often results in increased complexity, higher cost,

and reduced effectiveness in any one role. These “all-in-one” solutions tend to accumulate requirements over time, leading to systems that are difficult to field, sustain, and scale.

Operational observations and experimentation efforts consistently demonstrate that different missions demand different capabilities, tradeoffs, and levels of performance. Rather than a universal solution, effective employment of UGVs will require a family of systems tailored to specific mission requirements. Within this approach, commonality should not be forced at the platform level but enabled through standardization of key components and interfaces. Interchangeable parts such as common tire sizes, batteries, fasteners, and other repair-critical components can significantly reduce sustainment burden, simplify logistics, and improve field-level maintainability across diverse systems. Coupled with modular architectures and shared integration frameworks, this approach allows the Army to balance diversity in capability with practicality in sustainment, enabling scalable and operationally relevant use of UGS.

Software is the Center of Gravity

Software is increasingly the center of gravity for UGS, with autonomy, perception, and control algorithms driving the majority of operational value. While hardware provides the physical platform, it is the software stack that enables navigation, object detection, decision-making, and integration with other systems. As a result, two platforms with similar physical characteristics can deliver vastly different levels of capability depending on the maturity and performance of their software.

This shift fundamentally changes how these systems must be funded and sustained. Unlike traditional platforms, where capability is largely fixed at the point of fielding, software-driven systems require continuous updates to improve performance, address vulnerabilities, and adapt to evolving operational needs. This creates a requirement for persistent funding and long-term support models, often in the form of licensing, maintenance agreements, or ongoing development contracts. Recognizing software as the primary driver of capability is essential to ensuring that UGS remain effective, relevant, and adaptable over time.

Integration is the Real Problem

The primary challenge facing UGS is not hardware or autonomy in isolation, but the integration of these components into a coherent system-of-systems. Individual platforms and autonomy stacks have demonstrated sufficient capability to provide operational value. However, their effectiveness is often limited by the difficulty of integrating them with communications networks, control interfaces, mission command systems, and other

robotic platforms. This fragmentation creates friction at the unit level, where systems must be operated, sustained, and synchronized within a broader operational framework.

A key aspect of this challenge is the limited ability to decouple autonomy from the underlying platform. In many cases, vendors deliver tightly integrated solutions where autonomy software, mobility systems, and control architectures are bundled together, restricting flexibility and interoperability. However, the ability to apply one vendor's autonomy stack to another vendor's platform represents a significant opportunity to accelerate capability development and enable best-of-breed solutions. Achieving this will require standard interfaces, open architectures, and deliberate enforcement of interoperability across programs. Ultimately, success will depend on shifting focus from optimizing individual systems to enabling seamless integration across a diverse ecosystem of platforms, sensors, and software.

Force Design and Organizational Integration

UGS present a growing challenge not only in technology and integration, but in force design. While experimentation has demonstrated the potential utility of UGS across reconnaissance, logistics, and combat functions, there is currently no widely adopted organizational structure within maneuver formations to absorb and employ these systems at scale. As a result, UGS are often treated as add-on capabilities rather than integral components of units, leading to unclear ownership, inconsistent employment, and increased burden on already constrained personnel.

This lack of defined structure creates ambiguity in roles and responsibilities, including who operates the systems, who maintains them, and how they are integrated into existing command and control frameworks. In many cases, UGS are managed at the small-unit level without dedicated personnel, increasing cognitive load and reducing effectiveness. At the same time, centralizing these capabilities risks isolating them from the formations they are intended to support. The absence of a clear force design solution also complicates training, sustainment, and career development, as there is no established pathway for building expertise in robotic systems within maneuver units.

Addressing this challenge will require deliberate consideration of how unmanned systems are organized, manned, and integrated into formations. This may include the development of dedicated robotic elements, integration within existing platoons or companies, or hybrid approaches that balance specialization with operational flexibility. Ultimately, the successful adoption of UGS will depend not only on the maturity of the technology, but on the Army's ability to design formations that can effectively incorporate and sustain these capabilities as part of routine operations.

Attritable does not mean Disposable

The term “attritable” is frequently used in discussions of unmanned systems but remains inconsistently defined and often misunderstood. Attritable systems are not disposable. Rather, they are designed to be affordable enough to accept a higher level of risk in employment without incurring unacceptable operational or financial loss. This distinction is critical, as treating attritable systems as expendable can lead to poor design decisions, reduced capability, and ineffective employment concepts. While some systems are intentionally designed to be disposable, such as breaching platforms or explosive-laden systems that function similarly to mobile mines, these represent a specific subset of capabilities and should not define the broader category of attritable systems.

Properly understood, attritability reflects a balance between cost, capability, and survivability. These systems must still deliver meaningful operational value, maintain sufficient reliability, and be supportable within the force. Repairability is a key component of this concept. Units must be able to recover and restore systems in the field through dedicated training, access to common replacement parts, and the ability to address both hardware and software faults. This includes operating through degraded modes, such as transitioning from autonomous operation to remote control when sensing or autonomy functions fail. Redefining attritable in this context shifts the focus from expendability to resilience and scalability, enabling commanders to employ unmanned systems more aggressively while preserving combat effectiveness and sustaining capability over time.

The Human Dimension

The integration of UGS fundamentally changes the demands placed on leaders and soldiers, particularly in terms of cognitive load and decision-making. Operators are increasingly required to manage multiple systems simultaneously, often across different control interfaces and levels of autonomy, while still executing traditional mission tasks. This added complexity can quickly overwhelm individuals if not properly managed, especially when systems require continuous attention for control, monitoring, and troubleshooting. As formations incorporate both air and ground systems, the challenge is no longer just operating a platform, but orchestrating a network of capabilities in real time.

Trust in autonomy is a critical factor influencing how these systems are employed. When autonomy performs reliably, it can reduce workload and enable more effective use of robotic systems. However, inconsistent performance, particularly in complex or degraded environments, can lead to hesitation, overreliance on manual control, or underutilization of available capabilities. Building trust requires not only improvements in system reliability, but also transparency in how systems operate and fail, allowing users to understand limitations and make informed decisions.

Training implications are equally significant. Effective employment of UGS requires more than basic operator familiarity; it demands a deeper understanding of system behavior, limitations, and degraded modes of operation. This includes the ability to transition

between autonomous and manual control, troubleshoot issues in the field, and integrate systems into mission execution. Without dedicated training and repetition, even capable systems may underperform in operational use.

For leaders, the introduction of unmanned systems adds a new dimension to decision-making. Leaders must determine how to allocate robotic assets, balance risk between manned and unmanned elements, and integrate these capabilities into existing tactics and formations. This requires not only technical understanding, but also the development of new mental models for employing human-machine teams. Ultimately, the success of UGS integration will depend as much on the ability of soldiers and leaders to adapt as it does on the maturity of the technology itself.

The Enemy Gets a Vote

The employment of UGS cannot be viewed in isolation, as every capability introduced on the battlefield will generate a corresponding countermeasure. Observations from Ukraine demonstrate that the rapid proliferation of unmanned systems, particularly UAS, has been met with equally rapid adaptation in electronic warfare, camouflage, deception, and targeted destruction. As ground systems become more prevalent, they can be expected to follow a similar trajectory, becoming priority targets for loitering munitions, mines, and electronic attack.

UGS introduce unique vulnerabilities that adversaries can exploit. Their reliance on communications links, predictable mobility patterns, and physical interaction with terrain make them susceptible to detection and targeting in ways that differ from UAS. Additionally, autonomy systems can be degraded or deceived through environmental manipulation, obscurants, or deliberate interference. These dynamics reinforce that unmanned systems do not eliminate risk, but redistribute it, often in ways that require new mitigation strategies.

The implication is clear: the effectiveness of UGS will depend not only on their inherent capability, but on the ability to operate in a contested and adaptive environment. Survivability, deception, redundancy, and the ability to operate in degraded conditions must be considered from the outset. As demonstrated in Ukraine, technological advantage is temporary, and the widespread adoption of unmanned systems will inevitably lead to the development of counter-UGS tactics and technologies.

Conclusion

UGS are approaching an inflection point in their development and employment. The technology has progressed beyond experimentation alone, with demonstrated capability

across reconnaissance, logistics, and combat functions. Observations from commercial development, operational use in Ukraine, and Army experimentation efforts such as xTech Ground Strike, Transformation in Contact, and Project Convergence all indicate that these systems are no longer conceptual. However, their effectiveness remains uneven, and their integration into maneuver formations is still in its early stages.

The central challenge is no longer whether the technology works, but how it is integrated into the force. As this paper has demonstrated, the primary barriers are not hardware limitations or the absence of autonomy, but friction in control architectures, communications, sustainment models, training, and organizational design. These challenges are compounded by misaligned requirements, unclear transition pathways from prototyping to scale, and the absence of consistent standards for interoperability. Without addressing these issues, the Army risks fielding capable systems that cannot be effectively employed in a consistent manner.

Experimentation has provided a clear signal on the path forward. Across multiple efforts, a consistent pattern has emerged: useful capability exists, but it must be integrated, scaled, and employed within a broader system-of-systems. The future of UGS will not be defined by a single platform, but by a family of systems operating within a distributed, networked framework. This includes the integration of air and ground robotic systems into a cohesive system, where sensing, decision-making, and action are shared across platforms to create combined effects.

At the same time, institutional adaptation must keep pace with technological advancement. Leaders must shift from controlling individual systems to commanding effects across formations, while units must be structured and trained to operate, maintain, and repair these systems without reliance on external support. Concepts such as attritability must be clearly defined, and sustainment approaches must account for both hardware and software as integral components of capability.

Success will require deliberate choices: prioritizing interoperability over platform optimization, scalability over perfection, and operational relevance over theoretical capability. Those organizations that adapt fastest will gain a decisive advantage in the evolving character of warfare.

Implications for Army Modernization

The integration of UGS presents implications across all elements of DOTMLPF-P. While technology has advanced rapidly, institutional adaptation has lagged, creating gaps between available capability and operational employment. Addressing these gaps will require coordinated changes across doctrine, force structure, training, and policy to enable effective integration of robotic systems into maneuver formations.

Recommendations

Doctrine

Current doctrine does not adequately address the employment of unmanned ground systems within maneuver formations, particularly in conjunction with unmanned aerial systems. Doctrine must evolve to incorporate human–machine teaming, distributed robotic operations, and air-ground integration, with an emphasis on mission-based command rather than platform-level control.

Codify UGS as a core maneuver enabler, not a niche capability

- Integrate UGS into maneuver doctrine alongside fires, protection, and sustainment
- Treat robotic systems as part of combined arms, not an adjunct capability

Develop doctrine for air-ground robotic teaming

- Define task organization and coordination between aerial and ground systems

Shift from platform control to mission-based command of robotic systems

- Incorporate command constructs such as: Conduct reconnaissance, Establish security, and Conduct attack

Incorporate degraded operations into all UGS employment concepts

- Require doctrine to address: loss of communications, degraded autonomy, transition to manual control
- Normalize operation under partial system failure

Establish doctrine for distributed robotic operations

- Enable employment of multiple UGS across formations rather than centralized control
- Define how robotic systems support dispersed maneuver and sustainment

Integrate UGS into sustainment doctrine

- Formalize roles for UGS in: resupply under contact, casualty evacuation, and forward logistics nodes
- Include sustainment-specific CONOPS for robotic systems

Develop doctrine for human-machine teaming at echelon

- Squad: task-level employment of 1–2 systems
- Platoon/company: coordinated employment across multiple systems
- Higher echelons: integration into sensor-to-shooter networks

Address control architecture in doctrine

- Establish requirement for: common control interfaces where feasible and integration with mission command systems (ATAK)
- Recognize limitations and risks of single-interface control

Incorporate counter-UGS considerations into doctrine

- Assume adversary adaptation: EW, mines, and loitering munitions
- Develop TTPs for: survivability, deception, and redundancy

Move away from "one system" solutions in planning

- Explicitly state that UGS employment requires a **family of capabilities**
- Align doctrine with mission-specific capability selection

Organization

There is no standardized force structure to absorb unmanned ground systems at scale. Units require clearly defined roles and responsibilities for operating, maintaining, and employing these systems. This may include dedicated robotic elements or integration within existing formations but must balance specialization with operational flexibility.

Establish a defined organizational construct for UGS within maneuver formations

- Eliminate ad hoc employment at the squad/platoon level without structure
- Clearly assign ownership, employment, and sustainment responsibility

Adopt a hybrid approach: embedded capability + specialized support elements

- Embed small numbers of UGS within squads/platoons for immediate use
- Create higher-echelon robotic elements (company/battalion level) for: massing effects, sustainment support, and specialized capabilities

Create dedicated robotic sections or platoons within BCT formations

Define clear roles within units

- Operator: employs system during mission
- Maintainer: responsible for repair and sustainment (hardware + software)
- Autonomy supervisor: manages system behavior and degraded modes
- Avoid overloading a single soldier with all roles

Prevent "additional duty" failure model

- Do not assign UGS responsibilities as collateral duties
- Ensure dedicated personnel or clearly defined responsibilities within units

Enable task-organized robotic formations

- Allow commanders to allocate UGS dynamically across companies and platoons
- Support mission-specific grouping of robotic assets

Integrate UGS into existing command structures

- Avoid creating isolated "robot units" disconnected from maneuver
- Ensure UGS are directly tied to supported units and missions

Establish maintenance and recovery structure within formations

- Forward repair capability
- Recovery teams for disabled systems
- Enable repair at lowest possible echelon

Design for interoperability across units and systems

- Organizational structure must support: multiple vendors and mixed platform types
- Avoid unit structures tied to a single system or vendor

Account for scale from the outset

- Design organizations assuming dozens (not single digits) of UGS per formation
- Ensure structure can scale without exponential increase in personnel burden

Align organization with air-ground robotic teaming concepts

- Ensure coordination between UAS operators and UGS operators
- Consider combined robotic elements for integrated employment

Training

Training must extend beyond basic operation to include system integration, degraded operations, and troubleshooting of both hardware and software. Units must be trained to operate systems without contractor support and to employ autonomy effectively, including transitioning between autonomous and manual modes.

Train soldiers to operate UGS without contractor support

- Require operator proficiency after limited new-equipment training

Establish separate training tracks for operators, leaders, and maintainers

- Operator training: startup, mission execution, payload employment, degraded modes
- Leader training: task organization, mission command, risk management, air-ground teaming
- Maintainer training: recovery, hardware repair, software troubleshooting, updates, reconfiguration

Make human-machine teaming a recurring training objective

- Integrate UGS into squad, platoon, and company training events
- Train leaders to employ UGS alongside dismounted soldiers, manned platforms, and UAS

Incorporate UGS into combat training center rotations and major exercises

- Use rotations to generate operationally relevant data on usability, integration friction, and sustainment burden
- Reduce dependence on stand-alone demonstration events

Train to mission command, not just platform control

- Shift from “how to drive the robot” to “how to assign tasks and manage effects”
- Build proficiency in commanding heterogeneous air-ground robotic teams

Require troubleshooting and field expedient repair training

- Train soldiers to diagnose common faults in power systems, sensors, comms links, and software interfaces
- Include recovery of disabled systems under tactical conditions

Standardize core tasks across vendors where possible

- Common tasks should include launch, movement, payload swap, route execution, recovery, and emergency shutdown
- Reduce retraining burden when units receive different platforms

Build trust through repetition, not assumption

- Require repeated use in realistic terrain, weather, and mission conditions
- Treat trust in autonomy as an outcome of training and demonstrated reliability

Create a certification pathway for UGS employment

- Establish progressive qualification standards for units and individuals
- Link certification to operational employment, not just classroom completion

Integrate software sustainment into training

- Train units to manage updates, licenses, version control, and software-dependent configuration changes
- Ensure units understand how software changes can affect performance and interoperability

Train for counter-UGS environments

Include EW, deception, terrain masking, mines, and signature management in training scenarios

Ensure units understand that adversaries will actively target robotic systems and their control links

Materiel

Materiel solutions should prioritize modularity, interoperability, and sustainment over platform-specific optimization. This includes enforcing open architectures, enabling cross-platform integration, and standardizing key components such as batteries, tires, and repair parts to reduce logistical burden.

Enforce Modular Open Systems Architecture (MOSA) as a requirement, not a preference

- Mandate open interface control documents (ICDs) for autonomy stacks, communications, payloads, and control interfaces
- Enable integration of best-of-breed components across vendors

Decouple autonomy software from the physical platform

- Require architectures that allow one vendor's autonomy stack to operate on another vendor's vehicle
- Avoid vendor lock through tightly integrated, proprietary solutions

Standardize control interfaces where operationally feasible

- Enable integration with common systems (ATAK) for basic control and situational awareness
- Define thresholds where dedicated control systems are required (latency-sensitive or lethal applications)

Prioritize interoperability over platform optimization

- Accept minor performance tradeoffs to enable cross-system integration
- Design systems to operate within a broader ecosystem, not as standalone solutions

Standardize key sustainment components across platforms

- Common batteries, tires, connectors, fasteners, and repair kits
- Reduce logistical burden and simplify field-level maintenance

Design for field-level repair and recovery
- Require systems to be repairable at the lowest echelon possible
- Include onboard diagnostics and modular component replacement
- Enable rapid recovery of disabled systems under operational conditions

Plan for degraded operations as a design requirement
- Systems must operate under intermittent or denied communications, degraded sensing, and partial system failure
- Include fallback modes (teleoperation, waypoint navigation)

Reduce communication dependency through edge processing
- Prioritize onboard autonomy and decision-making
- Minimize reliance on continuous high-bandwidth links

Incorporate signature management into design
- Address detectability of LIDAR, communications emissions, and thermal signatures
- Provide selectable operating modes (low-signature vs high-performance)

Enable rapid payload interchangeability
- Standardize mounting, power, and data interfaces
- Allow units to swap sensors, communications packages, and mission-specific payloads
- Support mission-driven configurations

Leverage commercial mobility platforms where appropriate
- Use commercial vehicles (ATV-class platforms) to reduce cost and improve parts availability
- Focus military investment on autonomy, integration, and payloads rather than bespoke chassis

Design systems for scalability and production
- Avoid low-rate, prototype-only solutions that cannot transition to mass production
- Ensure designs are manufacturable at scale

Align materiel solutions with software-centric lifecycle models
- Treat software as a primary capability driver
- Plan for continuous updates, cybersecurity, and performance improvements

Support heterogeneous system integration
- Ensure compatibility across UGS, UAS, and mission command systems
- Enable air-ground robotic teaming through shared data and control frameworks

Avoid “one platform” requirements creep
- Design materiel solutions for specific mission sets
- Enable a family of systems rather than forcing a universal platform

Leadership

Leaders must adapt to managing human–machine teams and integrating robotic systems into tactical decision-making. This includes understanding system capabilities and limitations, managing increased cognitive load, and employing unmanned systems to reduce risk while maintaining mission effectiveness.

Adopt mission command for human–machine teams

- Shift from just using platforms to assigning effects ("recon," "screen," "resupply," "attack")
- Define commander's intent for elements with UGVs and allow decentralized execution

Balance risk between manned and unmanned assets

- Deliberately use UGS to reduce risk to soldiers where appropriate
- Accept calculated loss of attritable systems to achieve mission advantage

Manage cognitive load at echelon

- Limit the number of systems directly controlled at the lowest level
- Aggregate control at platoon/company level when employing multiple systems
- Avoid over-tasking leaders with platform management

Build calibrated trust in autonomy

- Train leaders on where autonomy is reliable and where it is not
- Require confirmation behaviors for critical actions (navigation in complex terrain, target engagement)
- Encourage use of autonomy for workload reduction, not blind reliance

Enforce simplicity in employment

- Prefer fewer, well-integrated systems over many disconnected ones
- Standardize TTPs for common tasks (launch, route, recovery, payload use)

Integrate air–ground robotic teaming into planning

- Pair UAS (sensor/relay) with UGS (persistence/effects) in every scheme of maneuver
- Plan for handoffs between UAV sensing and UGV action

Plan for degraded operations by default

- Assume intermittent comms, sensor loss, and partial system failure
- Establish pre-briefed contingencies and fallback modes (waypoint execution, teleop)

Demand interoperability and resist vendor lock

- Prioritize systems that integrate with common control and data frameworks
- Challenge proposals that require proprietary ecosystems for basic employment

Develop leaders who can command systems-of-systems

- Train leaders to synchronize sensors, networks, UAS, and UGS as a cohesive system
- Emphasize decision-making with distributed, partially autonomous assets

Set realistic expectations for capability

- Avoid overpromising autonomy performance
- Employ systems within demonstrated limits while driving incremental improvement

Create a culture that values repair and recovery

- Emphasize recovery of disabled systems when tactically feasible
- Treat maintenance and software updates as operational tasks, not rear-area functions

Personnel

The integration of UGS will require new skill sets within formations, including operators, maintainers, and autonomy specialists. Career pathways and personnel models must evolve to build and retain expertise in robotic systems while avoiding over-specialization that limits flexibility.

Define distinct roles for UGS within formations

- **Operator:** executes missions, manages payloads and modes
- **Maintainer:** conducts recovery, hardware repair, and software updates
- **Autonomy/Systems Supervisor:** manages autonomy settings, monitors behavior, handles degraded modes
- Avoid collapsing all roles onto a single soldier

Create a foundational UGS skill identifier (ASI/SQI) across MOSs

- Establish baseline qualifications for operators and leaders
- Enable cross-MOS employment without creating excessive specialization

Develop advanced career tracks for robotics and autonomy

- Build expertise in autonomy integration, systems-of-systems employment, and software-enabled capabilities
- Provide progression from operator to leader

Avoid over-specialization that isolates capability

- Do not centralize all expertise in small, disconnected teams
- Ensure knowledge is distributed across maneuver formations

Include software competency as a core skill set

- Train personnel to manage updates and version control, configuration management, and basic troubleshooting of autonomy and control software

Incorporate UGS responsibilities into existing MOS structures where possible

- Infantry: employment and integration at squad/platoon level
- Maintenance MOS: hardware and system repair
- Signal/cyber: communications and network integration
- Avoid creating entirely new MOSs unless required

Plan for increased personnel demand at scale

- As UGS numbers grow, ensure personnel models scale accordingly
- Avoid assuming “one operator per many systems” without validation

Integrate UAS and UGS personnel where appropriate

- Enable cross-training between UAV and UGV operators

Facilities

Facilities must support the storage, maintenance, and testing of unmanned systems, including requirements for charging infrastructure, software updates, and integration testing. Training environments must also be adapted to incorporate robotic systems into realistic scenarios.

Establish dedicated UGS support spaces within unit motor pools
- Integrate unmanned systems alongside existing vehicle fleets
- Provide covered work areas for maintenance, diagnostics, and software updates

Develop charging and power infrastructure at echelon
- Support battery charging, swapping, and storage
- Plan for high-demand power requirements during sustained operations

Enable field-level maintenance and repair capability
- Equip facilities with tools and parts for component replacement, sensor calibration, and software diagnostics

Incorporate software support infrastructure
- Enable units to manage software sustainment without external support

Adapt training facilities to include UGS employment
- Modify ranges and maneuver areas to support autonomous navigation, air-ground robotic teaming, and degraded communications scenarios

Plan for forward and austere facility requirements
- Design mobile or expeditionary support packages for charging, repair, and system updates
- Enable sustained operations in contested or distributed environments

Account for scalability in facility design
- Plan for growth from small numbers of systems to large-scale fielding
- Avoid facilities that only support limited prototype quantities

Incorporate signature management considerations
- Reduce visibility of charging, storage, and maintenance areas where possible
- Consider dispersion and concealment in forward environments

Policy

Policy must adapt to address autonomy, control authority, software licensing, and sustainment models. This includes clarifying definitions such as “attritable,” establishing guidance for human oversight, and aligning acquisition and funding approaches with software-driven capabilities.

Define “attritable” in policy and align it to funding and employment
- Distinguish clearly between attritable (recoverable, repairable, risk-tolerant) and disposable (one-time use systems such as breaching or explosive platforms)
- Tie definitions to procurement quantities, sustainment expectations, replaceability, and risk acceptance

Establish policy for software sustainment and licensing
- Require programs to plan for recurring software updates, cybersecurity patches, and autonomy improvements
- Address risks of vendor-controlled licensing (access, modification, long-term cost)

Mandate Modular Open Systems Architecture (MOSA) compliance
- Require open interfaces for autonomy, communications, and payload integration
- Prevent vendor lock and enable cross-platform interoperability

Enable cross-vendor integration as a policy requirement

- Require systems to support third-party autonomy integration and common control interfaces where feasible
- Treat interoperability as a threshold requirement, not a goal

Align acquisition policy with experimentation outcomes

- Reduce requirements expansion that invalidates proven prototypes

Provide clear demand signals to industry

- Use FYDP and other mechanisms to signal intent for production scale and long-term sustainment
- Reduce investment risk for commercial vendors

Establish policy for operation in degraded environments

- Require systems to function under limited communications and degraded autonomy
- Include fallback modes (teleoperation) as a requirement

Define control authority and human oversight requirements

- Clarify levels of autonomy allowed for navigation, targeting, and engagement (where applicable)
- Ensure consistent guidance across programs

Incorporate cybersecurity requirements early

- Require secure communications, software integrity, and update mechanisms
- Address risks associated with commercial and foreign-developed components

Address supply chain and foreign vendor considerations

- Balance rapid capability adoption with long-term security risks
- Establish guidelines for use of foreign components and systems

Update sustainment policy to reflect repair and recovery requirements

- Require systems to be repairable at the lowest echelon
- Support policies for parts commonality and field-level maintenance

Align policy with force design and personnel realities

- Ensure policies support defined organizational structures, training requirements, and personnel roles for operation and maintenance

Incorporate counter-UGS considerations into policy

- Assume adversary adaptation and require survivability considerations
- Address signature management, redundancy, and resilience

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