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Exploring military UAV innovation strategies: Theoretical perspectives and international case studies

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Abstract

This study aims to examine two distinct innovation pathways: the "state-led" model and the "civilian-driven" model. By comparing these pathways, this comparative analysis verifies that both models have their own applicable conditions. The study primarily focuses on US military unmanned aerial vehicles (UAVs) and drones in the Russo-Ukrainian war. The selected cases represent two innovation models. (i) State-led model: exemplified by the US military small UAV development programs; and (ii) civilian-driven model: exemplified by Ukraine during the Russia–Ukraine war (2022–2025). This paper proposes that the anticipated mode of conflict may shape a state's distinct technological and organisational innovation pathways. The study translates its core findings into the following hypotheses for future empirical testing. A decentralised and civilian-driven innovation model can be superior under specific strategic conditions, such as prolonged attrition, compared to the traditional state-led mode; and diminishing returns of innovation: the initial tactical advantage of any military innovation diminishes rapidly as the adversary adapts. The study finds that there is no universally optimal model of military innovation. While it remains to be checked whether the "civilian-driven model" can be fully replicated during peacetime, the underlying principle holds true. In the face of the unpredictability of modern warfare, sustained advantage lies in the institutional capacity to iterate faster than the enemy can adapt.

Keywords:

asymmetric warfare, military innovation, unmanned aerial vehicle (UAV), Russia–Ukraine War, defence innovation

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Introduction

Military innovation has long been regarded as a symbol of progress that renders previous modes of warfare obsolete. Traditional theories identify support from military leaders and national strategy as the primary drivers of innovation (Posen, 1984, p. 22), and two representative examples of such innovation are the Dowding System and the Triad. Such successful innovations often prompt emulation by other states, a phenomenon that scholars call "innovation diffusion" (Farrell and Terriff, 2002, p. 5). However, rapid advances in civilian commercial technologies and the spontaneous mobilisation of civil society have challenged the primacy of national strategy. The Russia–Ukraine war has demonstrated a paradigm shift, as spontaneous forces emerging from society have also become a model for innovation.

Accordingly, this study examines two distinct innovation pathways: (1) the "state-led" model (using the historical US military approach as a reference) and (2) the "civilian-driven" model (centred on Ukrainian battlefield experiences). By comparing innovation pathways, this comparative analysis shows that both models have their own applicable conditions, and that maintaining a sustained battlefield advantage relies heavily on a nation's institutional capacity to iterate faster than its adversary can adapt.

Literature review and theoretical framework

To examine the transformations brought about by unmanned aerial vehicle (UAV) technology, this study first defines the concept of military innovation and establishes the academic context that provides a foundation for subsequent case analysis.

The meaning of military innovation

Military innovation was initially defined as a fundamental change in the "operational methods" within military organisations. In his seminal work, *The sources of military doctrine*, Posen (1984, p. 22) argued that when a nation's military develops new preferences in strategic thinking, organisational structure, or operational methods, this constitutes military innovation. Over time, different academic schools have proposed varying perspectives, but the widespread consensus is that while innovation may succeed or fail, the critical criterion is whether it produces effective change.

In most accounts, innovation plays a decisive role in achieving victory by significantly enhancing military effectiveness (Jungdahl and Macdonald, 2014, p. 469). However, not all innovation has positive implications. Historians Millett and Murray (2010, p. 469) observed that during peacetime innovation, "wrong choices and irrelevant investments will occur and are difficult to correct." Naval War College professor Kuo (2022, pp. 48–87) notes that under pressure from expanding security commitments and shrinking resources, military leaders tend to place excessive hope in military innovation, which leads to wishful thinking and hasty development that produces "harmful innovation." Kuo (2022) illustrates this with the case of British and German armoured forces in World War II. While both implemented mechanisation, and Britain developed earlier with larger mechanised forces, the British misallocated resources and adopted the overly optimistic strategy that "armored forces alone could replace infantry and artillery functions." This neglected the transition time required for paradigm shift following innovation, thereby increasing the risks of employing innovation on the battlefield. By contrast, Germany remained a semi-modern, semi-motorised army that heavily relied on marching, horses, and railways for movement. Unlike the British adoption of radical pure tank formations, the Germans retained a combined-arms approach. When the two forces clashed in North Africa (1941–1942), British armoured brigades, lacking supporting arms, were annihilated; only after restoring infantry support did they gradually reverse their disadvantage. Kuo (2022) therefore argues that when national security commitments exceed military capacity, excessive pursuit of progress often produces harmful innovation.

Theoretical schools of military innovation

Theories of military innovation have primarily examined the factors that drive it. From the perspective of military organisational culture, Rosen (1991, p. 21) argues that military innovation often originates in questioning the existing methods of warfare. He emphasises that innovation encompasses how military organisations adapt to political demands and wartime requirements. This can be seen, for example, in the development of the US submarines and strategic bombers as well as the evolution of British tanks. Rosen also highlights that inter-service competition can facilitate development. However, with advances in technology and changes in battlefield tactics, historians have also proposed revised perspectives on the origins of military innovation, with distinct explanatory perspectives.

For example, Posen (1984) argues that military innovation is primarily driven by external threats and shifts in the international environment. Because military organisations tend towards bureaucratic inertia, Posen (1984) contends that civilian intervention is often necessary to overcome internal resistance and initiate doctrinal change, particularly when political leaders respond to pressing strategic imperatives. Rosen (1988, pp. 134–168), by contrast, locates the impetus for innovation within the military itself. He argues that successful innovation typically arises from senior officers who construct new promotion pathways for younger officers championing emerging operational concepts, thereby reshaping organisational culture from within.

Huntington (1961, pp. 80–85) argues, however, that military innovation involves close interaction between national politics and organisational culture through long-term historical evolution. His famous book, *The common defense: strategic programs in national politics*, discusses military innovation as fundamentally a gradual shift in resource allocation and power structures. The integration of deeply rooted civilian expertise within the US Army, Navy, and Air Force cultures facilitates innovation.

Contemporary scholars Horowitz and Pindyck (2022) synthesise the common ground and divergences across scholarly research; they argue that military innovation should be viewed as a three-stage process comprising invention, incubation, and implementation. Although the boundaries between the stages remain fluid, innovation is influenced by five major categories of factors throughout this process: national strategy and service tactics; organisational culture; operational environment and battlefield conditions; macro-social factors (mobilisation capacity and economy); and technological pursuit (Horowitz and Pindyck, 2022, p. 1). Military innovation is thus a dynamic process involving numerous factors. It may involve transforming organisational structure, culture, and strategy. Farrell and Terriff (2002, p. 5) point out that successful innovations attract imitation, thereby leading to their diffusion. To analyse systematically the process and context of innovation, the following research methodology is established based on the variables identified by the aforementioned scholars (see Table 1).

Table 1. Variables identified by scholars as drivers of military innovation.

Scholars	Perspective	Variables related with military innovation				
		National strategy & service tactics	Culture	Operational environment	Macro-social factors	Technology pursuit
Posen (1984)	Driven by external threats in the international environment, military innovation requires strong intervention from civilian leaders to overcome the military's bureaucratic resistance to change.	V	V	V		
Rosen (1988 and 1991)	Military innovation is a spontaneous process driven internally by senior generals, organisational learning, and new promotion pathways, rejecting the need for civilian intervention.		V	V		
Huntington (1961)	Innovation is closely linked to culture and national politics; cultures resistant to change may stifle innovation.	V	V			V
Horowitz and Pindyck (2022)	Innovation is divided into three stages: invention, incubation, and implementation; innovation may be emulated.	V	V	V	V	V
Kuo (2022)	"Harmful innovation" is possible when, under resource constraints, leaders hastily pursue innovation, producing wishful outcomes.	V	V	V	V	V

Source: Compiled by the author.

Selection of case studies

This study seeks to verify the applicability of traditional innovation theories in contemporary contexts and identify areas for theoretical refinement. It primarily focuses on the evolutionary trajectory and continuous technological advances of the US military UAVs as well as the Russo-Ukrainian war, which has brought global attention to the strategic significance of drone technology. The selected cases represent the following two innovation models:

State-led model: Exemplified by the US military small UAV development programs (1990s–2010s), representing top-down planning constrained by traditional military–industrial systems.

Civilian-driven model: Exemplified by Ukraine during the Russia-Ukraine war (2022–2025), focusing on modification and rapid iteration of commercial drones, representing a bottom-up, highly flexible innovation model.

This paper proposes that the anticipated mode of conflict may shape a state's distinct technological and organisational innovation pathways, and this proposition is examined through the two cases mentioned below.

Early drone development and evolution in the United States

From early-target drone missions to support for military reconnaissance and strike operations, the trajectory of UAV development illustrates a gradual process of innovation, from initial invention to integration with service-level tactics. The US military's UAV development history provides a quintessential case of the state-led model of military innovation. This model validates the theories of Posen (1984) and Rosen (1991), which hold that military innovation often originates from national strategic requirements.

National strategy and service tactics

According to Blom's (2010, p. 29) historical analysis of the US Army UAVs, the US Army's maneuver tactics were forced to evolve within the strategic context of the Korean War and nuclear deterrence. The US Army reorganised its forces into the "Pentomic Division," designed for dispersed deployment in a checkerboard pattern to avoid becoming a concentrated target for enemy's tactical nuclear weapons. To support this highly decentralised strategic structure, the "Reorganization Objective Army Divisions" (ROAD) plan, approved in 1961, elevated aviation units from the "company" level to the "battalion" level. Under this new architecture, drone sections were formally integrated into the aviation general support company's organisational structure.

During the global war on terror, specifically in the conflicts in Afghanistan and Iraq, the US military relied heavily on the synergy between special operations forces and precision airstrikes. This strategic demand catalysed the exponential growth in the development and deployment of UAVs, such as the Predator and Global Hawk. The persistent surveillance and real-time imagery provided by these drones significantly shortened the sensor-to-shooter kill chain, which aligned perfectly with the strategic requirement of conducting real-time strikes against high-value targets (Blom, 2010, pp. 121–122).

Organisational culture

Innovation within the US military does not, however, proceed uniformly; rather, it is heavily shaped by distinct service cultures and budgetary considerations. Massive and overly rigid bureaucratic structures often resist change, whereas more flexible and adaptive service cultures create better conditions for fostering innovation. For instance, in addition to establishing a laboratory to develop drone tactics as early as in the 1960s (Office of the Secretary of Defense, 2005), the US Marine Corps (2020, p. 2) proposed in its "Force design 2030" report to reduce the number of traditional infantry battalions while increasing the deployment of long-range precision strike capabilities and UAVs. This pivotal shift demonstrates how the internal organisation of these diverse service cultures heavily influence funding allocation and the willingness to embrace organisational change, which aligns with Quinn's (1980, pp. 65–84) thesis that organisational culture evolves incrementally. This dynamic is clearly reflected in the Department of Defense's fiscal year 2025 (FY 2025) budget request, which revealed a significant divergence in UAV development pathways across different military branches. These budgetary and strategic variations confirm that organisational culture serves as the one of the determinants of technological choices during the innovation process.

Operational environment

The US innovation model achieved significant success in the operational environments of the Gulf War and the war on terror. During the Gulf War, the employment of UAVs was profoundly influenced by Warden's (1995, p. 40) "five rings theory," which prioritised the paralysis of enemy leadership and critical systems' infrastructure. To operationalise this strategy, commanders required persistent and precise intelligence to identify, map, and monitor the vulnerabilities within these critical nodes. Under this guidance, UAVs were assigned specific intelligence, surveillance, and reconnaissance roles dedicated to finding and tracking these exact strategic targets.

Subsequently, Deptula's (2001, p. 5) "effects-based operations" further propelled UAVs towards strike-centric roles. This theory emphasised striking "critical nodes," and it directly contributed to the weaponisation of the MQ-1 Predator with Hellfire missiles (US Air Force, 2025). Such environments are typically far from the US mainland; once hostilities escalate into a war of attrition, they entail extremely high logistical costs. In recent years, owing to the reduced deployment of ground forces (i.e. in peacetime or low-intensity operational environments), US military weapons development has gradually shifted towards "high-tech" and "stealth" capabilities. This shift in the direction of development, driven by changes in the operational environment, has made the US drone systems excessively expensive and complex, which means they are now considered less suitable for high-intensity "attrition warfare" environments.

Macro social factors

Macro factors primarily encompass supply chain resilience, industrial infrastructure, and production capacity. In the case of the United States, the cost of weapons manufacturing depends on the domestic industrial environment. If industrial production capacity undergoes significant changes, it can easily lead to soaring costs (Jones and Palmer, 2024, pp. 5–12). Although the US innovation model also relies on the participation of private enterprises, the level of urgency does not match that of the war in Ukraine, which sometimes creates a mismatch between commercial objectives and military requirements. This may result in products that do not fully meet the actual performance demands of the battlefield, and the cycle from product development to actual battlefield validation is relatively long (Government Accountability Office [GAO], 2025). However, the US strict procurement regulations and procedures play a critical role in this environment, effectively preventing corruption (Department of Defense & National Aeronautics and Space Administration, General Services Administration, 2019).

The pursuit of technology

While the US drone technology is undoubtedly labelled as highly advanced, its continuous pursuit of technological sophistication has yielded diminishing marginal utility while simultaneously escalating the risks of prolonged deployment cycles and budget overruns. In the development of innovative systems, internal components and platforms frequently fail to integrate seamlessly, which leads to prohibitively high proportions of system failure or outright program cancellations. This aligns with the theory of Kuo (2022, pp. 48–87), which posits that, under pressure from emerging threats, military services often over-demand technological sophistication or rush deployment schedules by adopting a strategy of "concurrent development and production." The military also frequently expects the development of low-budget systems that possess "interoperability and commonality" across different services while remaining capable of executing multi-mission profiles (Blom, 2010, p. 127). An excessive focus on maximising quality, while simultaneously minimising costs, ultimately tends to result in failure. A case in point is the US Army's (2019) Aquila UAV program in the 1980s; the development team concurrently developed multiple components, including data links and sensors, only to find that integrating these separately tested parts into a single, specification-compliant airframe was exceedingly difficult, a process that ultimately forced severe compromises in the overall performance (Blom, 2010, pp. 67–68).

The challenge of US drone innovation

The development of UAVs in the United States has faced numerous obstacles, including persistent skepticism and formidable technical hurdles that have posed significant challenges to innovation. These challenges and their underlying causes can be fundamentally categorised into the following two dimensions: (i) institutional resistance, and (ii) budgetary constraints.

Institutional resistance and inter-service bureaucratic in-fighting

Military organisations frequently exhibit resistance to new technologies, at times even actively stifling innovative advancements. Huntington (1961) also noted that the US strategy was rarely purely rational, but rather the complex result of interactions among the President, the Congress, the Joint Chiefs of Staff, and various defence departments. This injects commercial and political factors into what would otherwise be pure military innovation. Furthermore, such resistance is often driven by institutional anxieties over budget reallocations and the fear of career obsolescence. For instance, certain factions within the US Air Force (2025) have historically opposed the development of unmanned reconnaissance aircraft, citing concerns that UAVs would jeopardise funding for manned aviation and potentially threaten the professional livelihoods of pilots. In an earlier era, the US army and air forces similarly mounted fierce opposition against devolving the control of light observation aircraft to ground artillery units, a move aimed at safeguarding its newly acquired independent status and preventing mission redundancy (Blom 2010, pp. 14, 46–47). Internal institutional resistance naturally disincentivises the wholesale adoption of unproven technologies.

Budgetary constraints and the prohibitive cost of mission payloads

Rigid structural budget constraints frequently derail the trajectory of military innovation by restricting the long-term vision of military leaders. As Kuo (2022) argues, the institutional stress generated by such financial pressures often leads to harmful and ineffective innovation cycles. Numerous highly promising innovation projects were terminated prematurely due to funding depletion, even after substantial resources were already invested.

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Although innovative technologies, such as UAVs, are frequently lauded for their "low-cost" economic advantage, practical development reveals that the cost of engineering complex mission payloads (such as advanced sensors and data links) often dwarfs the cost of the aerial platform itself. During the Cold War era, the vast majority of failed UAV innovation initiatives—including the US Army's SD series and the Navy's drone anti-submarine helicopter program—stumbled before reaching actual deployment, unable to transition beyond the testing phase because of exorbitant research and development (R&D) costs and severe budget overruns (Blom, 2010, pp. 14, 54–55).

How the war in Ukraine is rewriting us drone strategy

The US Air Force tends to pursue systems with stealth capabilities, high survivability, and artificial intelligence (AI) autonomy. These platforms typically feature advanced sensors and data links, which enable UAVs to conduct long-range stealth strike missions alongside bombers. In the FY 2025 budget, the Air Force vigorously promoted the collaborative combat aircraft program, with projected investment of nearly $9 billion in R&D funding over 5 years (US Department of Defense, 2024, pp. 5–20). While unit costs for these systems aimed to be lower than manned fighters, they still reached tens of millions of dollars. This investment pattern reflects the Air Force's attempt to leverage technological superiority into service tactics. Naval investment, meanwhile, has concentrated on large systems integrable with carrier strike groups, such as the MQ-25 Stingray unmanned tanker. Owing to demanding performance requirements for carrier operations and high survivability standards, unit costs are extremely high. Given that carriers and submarines already consume the vast majority of service budgets, the room for further innovation is inherently limited.

Compared to the US Air Force and Navy, the Army's culture has demonstrated significant transformation in recent years. Inspired by the Russia–Ukraine war, the US Army canceled its previously prioritised Future Attack Reconnaissance Aircraft program in 2024, acknowledging that expensive manned reconnaissance aircraft are unlikely to survive modern air defence threats (US Army Public Affairs, 2024). In its place, the Army fully supports the Department of Defense's (2024) replicator initiative. Informed by the lessons learned from the Russia–Ukraine war, this initiative directs resources towards procuring thousands of small UAVs and loitering munitions, such as the switchblade series.

The Russia–Ukraine drone war

National strategy and service tactics

Ukraine's current military innovation stems from national strategic requirements and high-level leadership support; however, hampered by insufficient resources and internal factional resistance, the military personnel and institutional reforms led by successive Ukrainian leaders are inextricably linked to the growing urgency of the situation. Ukraine's military modernisation has evolved through three distinct waves, each driven by the shifting strategic necessity to move from the Soviet-era legacies towards the standards of North Atlantic Treaty Organization (NATO). The first followed the 2014 Russian seizure of Crimea and the start of fighting in Donbas (Sauser, 2026, p. 133). This was a reconstitution wave aimed at restoring the armed forces to a standard level. The second wave led from 2016 to 2021 and aligned the armed forces of Ukraine with NATO capability targets. It rebuilt staff structures and a strategic defence bulletin. During this stage, Ukraine introduced Turkish Bayraktar TB2 drones and integrated NATO's concepts of maneuver warfare. They also signed a conscription plan to address long-standing manpower shortages. However, these innovations had to coexist with aging Soviet equipment and a rigid bureaucracy, creating a force that displayed both remarkable agility and significant dysfunctioning when the full-scale invasion that began in 2022.

The third wave began on February 24, 2022, and focused on the wartime adaptation the country's capabilities. Faced with a severe shortage of artillery shells caused by delays in the US military aid, Ukraine's national strategy was forced to compromise with reality, explicitly treating drones as substitutes for conventional ammunition (Gady and Kofman, 2024, p. 19). Driven by wartime urgency, Ukraine's national strategy broke away from the state monopoly on the traditional defence industry, instead establishing an independent parallel budget and significantly streamlining cumbersome military procurement regulations (Sauser, 2026, p. 134). In June 2024, Ukraine implemented an unprecedented organisational transformation (Sauser, 2026, p. 132). Under the direct support of President Zelenskyy, Mykhailo Fedorov, Ukraine's Minister of Digital Transformation, launched the "Drone Army" initiative (Sauser, 2026, p. 134). The official establishment of an independent "unmanned systems forces" not only addressed operational needs but also standardised training across the country's fifteen drone schools, preparing for a protracted war (Sauser, 2026, pp. 132–133).

Organisational culture

Drawing lessons from the conflict in the East, the leadership culture of the Ukrainian armed forces gradually shifted from the Soviet model to the Western-promoted concept of "mission command." Originating from Prussia (US Army, 2019), this approach to command and control uses commander's intent to empower and encourage subordinate decision-making and initiative appropriate to the situation (Townsend *et al.*, 2019). It is the only approach to command and control that provides sufficiently flexible and rapid decision-making to exploit operational initiative when fighting a near-peer adversary. It later became a core leadership concept for NATO and the US military, serving as the optimal means of adaptation in situations where superiors struggle to grasp the full picture. This approach delegates decision-making and execution responsibilities to the grassroots level, enabling non-commissioned officers (NCOs) and junior lieutenants to respond autonomously when facing an invasion. By adopting the NATO-style command principles, Ukraine decisively moved away from the less effective Soviet approach. In the Soviet model, NCOs were merely mouthpieces between officers and soldiers, whereas after the reform, Ukraine granted grassroots NCOs actual decision-making power for execution and tactical autonomy (Sanders, 2023).

Operational environment

At the tactical level, evolving battlefield conditions have continuously driven doctrines and operational shifts. Following Russia's victory at Avdiivka, Ukraine transitioned to defensive operations while simultaneously confronting severe artillery shortages. Ukraine therefore treated drones as substitutes for conventional ammunition and delegated small UAVs to platoon and company-level units, directly connecting them to artillery fire control and command nodes (Bondar, 2025), gradually developing "drone wall" tactics (Kunertova, 2024, p. 12; Molloy, 2024, p. 24). The development of the drone wall also extended beyond aerial systems; Ukraine increasingly integrated uncrewed ground vehicles for critical logistics, ammunition resupply, and medical evacuations, effectively establishing an approximately 30-km attrition belt along the frontline to systematically target

Russian forces (Watling, 2025, pp. 5–6). Ukrainian forces achieved higher kill ratios with first-person view drones compared to Russian forces, demonstrating drones' tactical innovation advantages against armoured vehicles (Kirichenko, 2025).

However, such tactical advantages were often short-lived; once these innovations demonstrated success, Russian forces rapidly adapted, deploying countermeasures that triggered a continuous cycle of tactical action and reaction. Specifically, Russian adaptation included mirroring Ukrainian UAV tactics and systematically targeting Ukrainian electronic warfare (EW) positions, radar, and UAV pilots (Watling, 2025, pp. 4–6). By using combined strikes of artillery, multiple launch rocket systems, and glide bombs to push Ukrainian operators further from the forward line of their own troops, Russian forces aim to reduce the range and density of Ukraine's intelligence, surveillance, and reconnaissance coverage (Watling, 2025, pp. 4–5). These actions sought to neutralise the tactical edge initially provided by Ukrainian military innovation.

To overcome the fragility of relying predominantly on drones, high-performing Ukrainian units are conceptualising a new battlefield geometry and redefining the environment into a "contested zone," a "middle battle area," and the "deep" (Watling 2025, pp. 6–7). Within this framework, they pioneered a systematic seven-phase combined arms concept that demonstrated the capability to reduce assault casualty proportions. Collectively, these examples illustrate the highly iterative nature of battlefield innovation.

Macro social

One reason Ukrainian drones have become battlefield mainstays is civilian support. Their low cost and ease of manufacture enable many Ukrainian civilian workshops to produce them. Even before 2022, volunteers collected thousands of civilian quadcopters for military reconnaissance (Bilousova *et al.*, 2024, p. 16; Braunerhjelm and Brychko, 2025). Additionally, the volunteer-organised defence tech for Ukraine gained international endorsement and received global donations, enabling it to catalyse the annual production capacity to 4.5 million drones within 3 years while continuously improving technology (Bilousova *et al.*, 2024, p. 27; Miroshnichenko, 2025, p. 44). Coupled with software development startups, such as Swarmer (dedicated to drone swarm automation technology enabling semi-autonomous control of drone groups), the resilience of small drones in this resource-intensive war has increased dramatically (Bilousova *et al.*, 2024, p. 35; Kunertova, 2024, p. 12).

Through the Brave1 platform, the Ukrainian military and government directly connect and coordinate military R&D centres with private technology companies, while centrally managing procurement and logistics networks to ensure that new technologies are truly integrated into the military system (Sauser, 2026, p. 133). Ukraine's wartime national strategy has shifted to that of a "regulatory facilitator and resource matchmaker" that enables social resources to be mobilised for national security. This also enables private startups to quickly grasp frontline needs and participate in the development of unmanned systems and related technologies (Sauser, 2026, p. 134). Ultimately, this deep integration of civilian innovation, military application, and state coordination serves as a modern, technological manifestation of Clausewitz's (1984, p. 89) "remarkable trinity" (the people, the military, and the government). Ukraine's approach vividly demonstrates how blurring the lines between civil society and the defence sector effectively channels a nation's entire socio-economic resources into a unified war effort.

The Pursuit of technology

Ukraine's weapon modifications do not prioritise exquisite technological development; instead, they emphasise abundant supplies and readily available, immediately usable equipment. This approach is affected by the enormous consumption proportions in the ongoing war of attrition. According to an analysis of the Center for Strategic and International Studies (CSIS), both sides are deploying tens of thousands of small and medium UAVs on monthly basis along the contact line (Allen *et al.*, 2025, pp. 2–5). At the same time, Russia's Shahed series of loitering munitions forces Ukraine to expend substantial and expensive air defence resources (Eslami, 2022, p. 513). Given limited resources, simple and sustainable weapons have proven highly effective. For instance, rather than relying solely on advanced soft-kill systems, erecting physical drone-interception nets near bases has become a low-cost yet effective countermeasure used by both countries. To maximise the impact of these available systems, Ukrainian forces have even developed a dedicated drone service branch to continuously adjust employment strategies on the front lines. Mounting losses on both sides have prompted the development of these pragmatic countermeasures that emphasise cost-effectiveness as the central priority driving drone evolution (Kukkola, 2025, p. 37).

This need for practical and rapid adaptation also extends into the fierce electromagnetic measure–countermeasure competition defining the operational environment. Pervasive Russian EW systems have forced continuous tactical adaptations, as drones must survive intense signal jamming to remain effective on the battlefield. In response, Ukrainian operators have innovated rapidly by shifting to analog video transmissions, employing AI-assisted terminal guidance, and even deploying fibreoptic-controlled drones to completely evade EW interference (Sauser, 2026, p. 138).

Ultimately, in this prolonged war of attrition, the pursuit of technology no longer focuses on widening the technological gap with the adversary. Rather, it is about leveraging readily accessible materials to find pragmatic ways to neutralise the enemy's advantages. This reality reinforces the idea that true military advantage currently stems from resilient production scales and rapid iteration rather than purely from advanced technological superiority.

The challenge of Ukraine drone innovation

Behind Ukraine's demonstration of civilian unity, however, corruption scandals have emerged between some companies and government officials. Ukraine's National Anti-Corruption Bureau reports that multiple Ukrainian government officials are involved in corruption cases. Local officials and National Guard members allegedly inflated prices significantly during the procurement of military drones and electronic jamming systems, receiving kickbacks of up to 30% of the contract value (Hunder, 2025). Beyond corruption and bureaucratic hurdles, the Ukrainian drone model also faces severe operational constraints that expose the hidden costs of such innovation. While the first-person view platforms are inexpensive, sustaining them requires complex logistical networks for microprocessors and batteries. The battlefield is also plagued by intense Russian EW, causing 60–70% of Ukrainian drones to fail before reaching their targets. Human capital presents another bottleneck, as operator training programs experience washout proportions of up to 60% because of extreme cognitive demands (Sauser, 2026, pp. 138–139).

This heavy reliance on a decentralised civilian-driven network also creates profound command and control challenges. While civilian volunteers have compensated for initial shortfalls, regular military professionals often view these decentralised units as difficult to control, which hampers large-scale operational coordination and risks the "primitivisation" of military tactics (Käihkö and Honig, 2025, p. 30). Ultimately, the dependence on rigid military specifications and bureaucratic processes constitutes the greatest obstacle to rapid product iteration. A significant gap persists between strategic technology transfer and actual procurement. Absent of an existential crisis—and the willingness to tolerate both decentralised operational chaos and high combat attrition—fully replicating the agile Ukrainian model remains highly impractical for states maintaining a conventional "steady-progress" defence posture.

The lessons learned from those two cases

Analysing these two case studies echoes the theoretical frameworks of Horowitz and Pindyck (2022) and sheds light on the historical trajectory of military UAV innovation in the United States and its subsequent diffusion effects during the Russia–Ukraine war. Although the United States historically endured several counterproductive innovations, the hard-won lessons from these setbacks ultimately laid the groundwork for its subsequent technological successes. The United States has also leveraged contemporary insights from the Ukrainian theater to refine its own defence procurement and production workflows. Conversely, Ukraine's civilian-driven military innovation paradigm would have been virtually unsustainable without the influx of global financial and material assistance. While both innovation trajectories are deeply rooted in their respective geopolitical and temporal contexts, they collectively demonstrate that the willingness and determination to overcome adversity serve as the ultimate catalysts for military innovation.

From surgical strikes to a war of attrition

The divergence between the state-led model and the civilian-driven model is fundamentally shaped by their underlying military strategies. The US military primarily focuses on precision surgical strikes aimed at rapidly paralysing adversaries within a short timeframe. In contrast, Ukraine is embroiled in a protracted war of attrition. The characteristics of their respective innovation trajectories thus differ profoundly. The crucial takeaway here is that successful military innovation necessitates local knowledge and context-specific adaptation to the operational environment. Because every strategic and geographic landscape is unique, nations must cultivate their own optimal paradigms rather than rigidly replicating these two specific cases. This dynamic closely echoes Posen's (1984) observation that military innovation stems from the interaction between national strategy, military culture, and organisational structure, often originating in a critical reevaluation of the existing warfare methods. Ultimately, true innovation is a deliberate transformation driven by the necessity to address and rectify the existing strategic vulnerabilities and operational pain points.

UAV innovation and diminishing marginal utility

The diffusion of military innovation not only influences other nations but also actively shapes the tactical evolution of adversaries. The initial military advantage generated by the original innovation is thus subjected to diminishing marginal utility as the enemy adapts and develops countermeasures. This dynamic is vividly illustrated in the Russo-Ukrainian war. In the case of Ukraine, beyond the aid provided by allied nations, the initial success of its drone industry stemmed from a strategic transition from mere technological innovation to prioritising scale and efficiency. Driven by government initiatives and grassroots civilian mobilisation, over 400 decentralised drone workshops emerged in Kyiv, its surrounding suburbs, and cities near the front lines (Bilousova *et al.*, 2024, p. 42; Kunertova, 2024, p. 14). Crucially, this distributed industrial cluster served as a highly effective model of asymmetric defence, mitigating the risk of Russian missiles crippling critical military–industrial facilities in a single strike and granting Ukraine a significant early tactical edge.

However, exemplifying the law of diminishing returns, Russia swiftly recalibrated its own strategy to counter Ukraine's decentralised advantage. Experiencing the direct impact of this innovation diffusion, Russia established a dedicated unmanned systems forces to centralise and optimise its drone warfare capabilities (McDermott, 2025). Learning from early setbacks, Russian forces heavily focused on scaling up production and achieving near-seamless reconnaissance–strike integration (Kukkola, 2025, p. 52; Samus, 2024, p. 30). For example, systems such as the Orlan-10 ("Sea Eagle") and Albatross series drones are now systematically deployed for constant reconnaissance and electronic relay (Royal United Services Institute, 2025). Once these frontline systems identify a target, rear-positioned Lancet suicide drones and missiles are launched in tandem to neutralise Ukrainian HIMARS and related critical infrastructure, thereby effectively degrading Ukraine's initial asymmetric advantage. The dominant weapons on the battlefield have thus undergone profound qualitative and quantitative transformations (Bendett, 2024, p. 290; Samus, 2024, p. 20). Ultimately, this dynamic underscores a critical lesson: in a landscape defined by rapid technological diffusion, reciprocal tactical adaptation, and the inevitable diminishing utility of new technologies, building and maintaining the resilience of a nation's scalable industrial ecosystem has become the decisive factor for sustained victory.

Advantages of flexible procurement mechanisms

The success of the US case relies on advanced technology and a supportive national strategy, but the required budget may be unaffordable. The Ukraine model features procurement reforms that have lowered entry barriers, effectively integrating private enterprises into the defence industry. Ukraine created an independent parallel budget within defence spending and substantially simplified cumbersome procurement rules, establishing a commercial-first defence market. Prior to 2021, only the Ministry of Defense handled military procurement. After 2021, efforts to revitalise military industry began but remained ineffective until 2023, when autonomous procurement programs were introduced, expanding in late 2024 to drone-procurement platforms. Although grassroots factories still complain about procedural complexity, these streamlined electronic procurement procedures, with procurement authority delegated to independent military unit levels, are faster and more responsive, better meeting frontline operational demands. Ukraine's experience thus demonstrates that problem identification led by frontline personnel produces faster, more practical solutions, as frontline needs are fed back directly to factories, enabling Ukrainian units to communicate directly with engineers rather than relying on bureaucratic demand forecasting while expanding the range of potential suppliers.

Policy recommendations

Sustaining the defence innovation ecosystem

Although domestic defence technology start-ups have demonstrated meaningful technical capabilities, they remain heavily dependent upon government procurement contracts for revenue. This single funding source makes the industry extremely vulnerable; once defence budgets are frozen or delayed, the entire supply chain stalls. It is therefore recommended to maintain consistent, long-term investment to prevent disruptions in the technological chain. By focusing on technologies that align with the specific geographical and strategic landscape, the resulting asymmetric solutions can remain highly competitive in the long term.

Regulatory and procurement mechanism reform

To establish civilian participation in national defence, similar to the Ukrainian model, defence establishments should experiment with flexible procurement mechanisms. This approach would allow operational military units to allocate specific budget percentages directly to the procurement of certified domestic products. By meeting government-identified requirements, procurement orders with R&D subsidy characteristics would enable manufacturers to invest in continuous innovation while receiving corresponding compensation.

Because unmanned systems involve multiple ministries, coordination should also be directed by a centralised, inter-ministerial authority. This would facilitate the formulation of national-level development plans, avoid resource dispersion, and unify command over cross-domain issues such as drone force training and industrial support. Lowering the procurement threshold and simplifying administrative processes can substantially shorten the cycle from tactical requirement submission to actual equipment deployment, thereby reducing the defence industry's vulnerability to single-year budget constraints. Simultaneously, the government must establish standardised certification and testing platforms to ensure that grassroots-procured systems meet required operational standards. While peacetime conditions preclude the real-time battlefield data feedback seen in Ukraine, routine operational training and exercise data retain high value for continuous product iteration.

Supply chain resilience and wartime backup networks

Domestically rooted supply chains become the ultimate defensive shield should hostilities occur. State capital or entities such as the National Development Fund should therefore provide dedicated subsidies for core components that domestic manufacturers cannot yet mass-produce autonomously. This financial support would help manufacturers overcome the barriers of high initial capital expenditure and long payback periods. Ultimately, this strategy would serve not only to stimulate industrial development but also to guarantee a minimum capability for domestic production and maintenance when international supply chains are inevitably disrupted during wartime.

Conclusions

By comparing the paths of drone innovation in the United States and Ukraine, this study reveals that military innovation should adopt strategies appropriate to the situation and urgency. This study translates its core findings into the following hypotheses for future empirical testing:

- Hypothesis 1: A decentralised and civilian-driven innovation model can be superior in some circumstances to the traditional state-led model.

- Hypothesis 2: The initial tactical advantage of any military innovation diminishes rapidly with the adversary's adaptations; sustaining advantage therefore depends less on the sophistication of any single platform than on the tempo, cost, and decision-level at which iteration occurs. The two cases represent contrasting institutional solutions to this requirement. The US model pursues long-cycle, high-cost iteration centralised within the defence–industrial complex, optimised for limited high-intensity contingencies. The Ukrainian model, meanwhile, compresses iteration to weeks through decentralised civilian–military integration, optimised for protracted attrition.

By comparing the drone innovation pathways of the United States and Ukraine, this study finds that there is no universally optimal model of military innovation. While it remains to be seen whether the civilian-driven model can be fully replicated during peacetime, the underlying principle holds true: as Clausewitz (1984, p. 89) observed, war is never a unilateral action but always the collision of two living forces. What proves decisive is the alignment between a nation's innovation paradigm and the adaptation curve of its adversary. In the face of the unpredictability of modern warfare, sustained advantage lies in the institutional capacity to iterate faster than the enemy can adapt.

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