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DIFFUSION OF INNOVATION IN THE RUSSIA-UKRAINE WAR: A PORTRAIT OF MODERN WARFARE EVOLUTION

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Abstrak
Penelitian ini bertujuan untuk menganalisis adopsi teknologi senjata dalam konflik Rusia-Ukraina, khususnya berfokus pada drone, Starlink, dan sistem berbasis AI, sebagai cerminan evolusi peperangan modern. Menggunakan Teori Difusi Inovasi Everett Rogers, penelitian ini menyelidiki bagaimana karakteristik inovasi—keunggulan relatif, kompatibilitas, kompleksitas, *trialability*, dan *observabilitas*—memengaruhi penyebaran teknologi dalam sistem militer kedua belah pihak. Pendekatan kualitatif diterapkan melalui analisis dokumen sekunder, termasuk laporan akademik, artikel jurnal, dan berita media, dengan triangulasi untuk memastikan validitas data. Temuan utama menunjukkan bahwa dinamika adopsi teknologi didorong oleh kebutuhan taktis yang mendesak dan struktur organisasi yang adaptif. Baik Ukraina maupun Rusia menunjukkan siklus inovasi yang cepat melalui adaptasi dan emulasi taktik lawan. Kesimpulan dari penelitian ini adalah bahwa keberhasilan adopsi teknologi militer di medan perang modern sangat bergantung pada persepsi terhadap karakteristik inovasi tersebut, serta kemampuan adaptasi dalam konteks konflik yang dinamis.

Abstract
This research aims to analyze the adoption of weapon technology in the Russia-Ukraine conflict, specifically focusing on drones, Starlink, and AI-based systems, as a reflection of the evolution of modern warfare. Utilizing Everett Rogers' Diffusion of Innovations Theory, this study investigates how innovation characteristics—relative advantage, compatibility, complexity, trialability, and observability—influence the spread of technology within military systems of both sides. A qualitative approach is applied through the analysis of secondary documents, including academic reports, journal articles, and media news, with triangulation employed to ensure data validity. The main findings indicate that technology adoption dynamics are driven by urgent tactical needs and adaptive organizational structures. Both Ukraine and Russia demonstrate rapid innovation cycles through adaptation and emulation of opponent tactics. The conclusion of this research is that the successful adoption of military technology on the modern battlefield heavily relies on the perception of these innovation characteristics, as well as the capacity for adaptation within a dynamic conflict context.

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INTRODUCTION

Technological developments have fundamentally altered the landscape of modern warfare. Advances in information technology, automation and cyber operations have expanded the dimensions of conflict from physical combat to the digital realm. 21st century warfare no longer relies solely on conventional forces, but also on the ability of states to adopt and integrate technological innovations quickly and effectively. Major conflicts around the world have become testing grounds for new technologies, where the dynamics of combat drive rapid cycles of innovation. In this context, the Russia-Ukraine war, which began with the annexation of Crimea in 2014 and escalated sharply in 2022, stands out as a unique laboratory for understanding how technological innovations are adopted by militaries and developed in real conflict situations.

The Russia-Ukraine conflict, rooted in historical tensions and post-Cold War geopolitical rivalries, has evolved from localized fighting in eastern Ukraine to a full-scale war with global implications (Kang, 2020). The annexation of Crimea in 2014, followed by Russia's support of separatist groups in Donetsk and Luhansk, created a hybrid conflict pattern that blends military operations, cyberattacks and disinformation campaigns (Kyrydon & Troyan, 2022). The massive invasion in February 2022 accelerated this escalation, attracting the involvement of international actors and changing the dynamics of global security. The war not only changed the geopolitical map of Europe but also triggered a global energy and food crisis, deepening polarization among western powers (Tampubolon, 2022). Diplomatic efforts and economic sanctions applied by the international community have so far not been able to stop the conflict, leaving an uncertain future for regional stability.

The impact of technological development on warfare, especially in the context of the Russia-Ukraine conflict, has garnered significant scholarly attention. For instance, Oleksandr Sotula (2024) focuses on the international legal implications of advanced technologies like artificial intelligence (AI) and cyber warfare, highlighting the challenges they pose to existing legal frameworks. Dehegani Ayoub and Maizi Lynda (2024) examine how the digital military revolution is transforming warfare, analyzing the strategic effects of smart weapons, drones, and AI, while also identifying new vulnerabilities that arise from these technologies. Additionally, Marina Favaro and Heather Williams (2023) discuss how new technologies can influence the escalation of conflicts, arguing that despite Russia's advanced capabilities, its reliance on nuclear deterrence indicates a continued dependence on traditional military strategies. Together, these works illustrate that while new technologies are reshaping tactics and expanding the scope of conflict, their influence on fundamental strategic doctrines and the dynamics of escalation is complex and multifaceted.

The research to be discussed in this paper will present a new perspective compared to previous literature, specifically on the Russia-Ukraine war as an arena of military technology evolution, by applying the Diffusion of Innovation Theory to analyze how weapon technologies were adopted by both sides, focusing on their innovation characteristics. Different from Oleksandr Sotula's analysis highlighting the international legal implications of advanced technologies, Dehegani Ayoub & Maizi Lynda's approach examining the impact of the digital military revolution and operational limitations, and Marina Favaro & Heather Williams' paper discussing the risk of nuclear escalation due to modern technology, this study emphasizes the dynamics of innovation diffusion in military systems. By analyzing the various factors that influence technology adoption, it raises a key question: What technologies are Russia and Ukraine using on the battlefield, and why are they choosing them? This research offers novelty by integrating the Diffusion of Innovations framework to explain the process of selecting and adopting specific technologies. This approach not only complements the analysis of technology from a legal, strategic and conflict escalation dynamics perspective, but also broadens the understanding of how and why certain innovations are adopted in complex geopolitical contexts. As such, this research makes a significant and original contribution to the study of international relations, particularly in understanding the interaction between technological innovation, military decisions, and global political dynamics.

ANALYSIS FRAMEWORK

This research uses the Diffusion of Innovation Theory as an analytical framework to understand how new weapons technologies were adopted by both sides in the Russia-Ukraine war, as well as why they were chosen. This theory, popularized by Everett Rogers, explains the process of spreading new ideas, technologies or practices in a social system, including why and how quickly adoption occurs. In the context of the Russia-Ukraine conflict, this theory is relevant for analyzing how technologies such as automation systems, cyber operations, and data-driven platforms, can affect the success or barriers to adoption. The framework focuses on five innovation characteristics that are key reasons for technology adoption: relative advantage, compatibility, complexity, trialability and observability. By applying this framework, this research aims to provide insights into the dynamics of technological innovation and its implications that are useful for the study of global defense strategy in an international relations perspective.

The Diffusion of Innovation Theory: Basic Concepts

The Diffusion of Innovations theory, developed by Everett M. Rogers, provides a powerful framework for understanding how new ideas, practices, and objects spread through social systems. Diffusion is defined as the process by which an innovation is communicated through specific channels over time among members of a social system (Rogers, 1983). Meanwhile, Innovations are ideas, practices, or objects that are perceived as new by individuals or other units of adoption (Rogers, 2003). Rogers goes on to identify five key characteristics of innovations, perceived by individuals, that help explain why some innovations are adopted more quickly than others based on the five characteristics of relative advantage, compatibility, complexity, trialability, and observability. In this regard Rogers states that "innovations perceived to have greater relative advantage, compatibility, trialability, observability, and lower complexity will be adopted more rapidly than other innovations (Rogers, 1983, p. 233).

In this paper, the main focus is on two important issues related to the dynamics of innovation in the Russia-Ukraine conflict. First, we will discuss the various forms of innovation that emerged and were implemented during the conflict process. These include the use of the latest military technologies, such as combat drones, artificial intelligence, satellite-based communication systems, and the development of electronic warfare systems. These innovations not only reflect cutting-edge technological developments, but also show how the modern battlefield has become a live arena for technological diffusion and testing. Second, we will focus our analysis on the characteristics of innovations based on Everett M. Rogers' Diffusion of Innovations theory. Through the five main characteristics of relative advantage, compatibility, complexity, trialability, and observability. We will evaluate these technologies through the five characteristics of innovation to explain why certain innovations are adopted more quickly and effectively than others. With this approach, this paper aims to provide an in-depth understanding of the logic of innovation adoption in armed conflict situations and how innovation characteristics play a role in the process.

This theory is particularly relevant for the Russia-Ukraine war as the conflict is characterized by rapid innovation cycles, with both sides racing to adopt new technologies to gain a strategic advantage. For example, the use of data-driven technologies for battlefield analysis or cyber operations to disrupt the opponent's infrastructure shows how innovations spread in military systems. However, successful adoption depends not only on the technology itself, but also on military actors' perceptions of the innovation's characteristics. Therefore, this research focuses on five innovation characteristics as the main reasons why a particular technology is selected and adopted.

Innovation Characteristics As Reasons For Adoption

Relative Advantage

Relative advantage is the degree to which an innovation is considered better than the practice or technology it replaces (Rogers, 1983, p. 15). According to Rogers, this superiority can be measured through dimensions such as economic benefits, operational efficiency, convenience, satisfaction, or social prestige (Rogers, 1983, pp. 214–215). Users' subjective perceptions of superiority are more important than objective superiority, as these perceptions drive adoption decisions. Incentives, such as subsidies or logistical support, can increase perceptions of relative advantage, thereby accelerating diffusion (Rogers, 1983, pp. 219–223). Innovations that offer tangible benefits, such as cost savings or increased status, tend to be adopted more quickly. Relative advantage is a key driver because it motivates individuals or organizations to switch from old solutions to new innovations, reducing uncertainty and increasing the attractiveness of innovations in social systems (Rogers, 1983, pp. 217–218).

Compatibility

Compatibility refers to the extent to which an innovation is perceived as consistent with the values, past experiences, and needs of potential adopters (Rogers, 1983, p. 15). Rogers identified three aspects: alignment with values and beliefs, pre-existing ideas, and the specific needs of users (Rogers, 1983, pp. 223–226). Innovations that conform to cultural norms, social systems, or established practices tend to be adopted more quickly because they reduce resistance. Conversely, non-conformity can lead to rejection, as in the case of the boiling water campaign in Peru that went against local values. Conformity facilitates the integration of innovations into existing contexts, reducing psychological and practical barriers. This characteristic is particularly important in rigid social systems, where major changes are often resisted, thus accelerating the adoption process through alignment with user needs (Rogers, 1983, pp. 1–5).

Complexity

Complexity is the perceived degree of difficulty in understanding or using an innovation (Rogers, 1983, p. 230). Innovations that are perceived as complex or requiring new skills tend to be adopted more slowly because they increase uncertainty and require additional effort from users. Rogers emphasizes that complexity has a negative relationship with adoption rates, so simple and intuitive innovations are more easily accepted. To overcome complexity, training, documentation, or design simplification is often required. Perceptions of complexity vary between individuals or groups, depending on their experience and expertise. This characteristic affects the speed of diffusion because it determines how easily users can integrate the innovation into their routines, making it a key factor in successful adoption across different social systems (Rogers, 1983, pp. 230–231).

Trialability

Trialability is the degree to which an innovation can be tested on a limited scale before full adoption. Innovations that allow small-scale experimentation reduce risk and uncertainty, thereby increasing users' confidence to adopt. According to Rogers, trialability is especially important for early adopters, who are often more risk-taking but still need early validation. Trials allow users to evaluate the effectiveness and benefits of innovations without a major commitment, reducing potential downsides. This characteristic supports diffusion by providing empirical evidence of the innovation's performance, which can reassure other users in the social system. Innovations with high trialability tend to spread faster because they minimize barriers to adoption (Rogers, 1983, p. 231).

Observability

Observability is the degree to which the results of an innovation are visible to others. Innovations with clear and measurable outcomes, such as increased efficiency or tangible success, encourage interpersonal communication within social networks, thereby accelerating diffusion. Rogers emphasized that observability influences the perception of innovation success, triggering discussion and validation among potential users. When innovation outcomes are easily observable, such as in public demonstrations or success reports, innovations become more attractive. Observability reinforces network effects, where early adopters share their experiences, encouraging further adoption. These characteristics are particularly important in social systems where communication between members plays a large role in the diffusion process, increasing the attractiveness of the innovation (Rogers, 1983, p. 232).

A Framework for Analyzing Military Technology Adoption in Conflict

To understand the dynamics of military technology adoption in the context of modern armed conflict, this research employs the Diffusion of Innovations Theory, originally formulated by Everett M. Rogers. This theory offers a conceptual lens to analyze how new technologies spread, particularly within institutional systems such as the military. Rogers defines diffusion as the process by which an innovation is communicated over time among members of a social system (Rogers, 1983). He emphasizes that the perception of newness, along with the specific characteristics attributed to an innovation, plays a central role in determining the speed and success of its adoption.

In the context of military organizations, especially during conflict, the decision to adopt a technology is rarely based solely on its technical capabilities. Instead, it is shaped by how the innovation is perceived relative to existing systems, operational demands, institutional culture, and the broader strategic environment. Rogers emphasizes that an innovation's success in diffusing through a social system is significantly influenced by five core perceived attributes: relative advantage, compatibility, complexity, trialability, and observability (Rogers, 1983, p. 233).

Relative advantage refers to the extent to which an innovation is perceived as superior to the technology or practice it seeks to replace. This superiority may be framed in terms of efficiency, effectiveness, cost savings, or even symbolic prestige. Importantly, it is not the objective value of the innovation that matters most, but rather how its advantages are perceived by potential adopters within their specific social and organizational context (Rogers, 1983, pp. 219–223). In military settings, such perceptions can be shaped by strategic priorities, combat urgency, or the influence of allied actors.

Compatibility denotes the degree to which an innovation aligns with existing values, prior experiences, and current operational needs. Technologies that are consistent with established doctrines, tactical procedures, or communication systems are more likely to be accepted and integrated quickly. Conversely, when a new technology challenges deeply embedded norms or necessitates significant changes in military training and behavior, its adoption may face institutional resistance (Rogers, 1983, pp. 1–5).

Complexity pertains to how difficult an innovation is to understand, implement, or utilize. Rogers suggests that innovations perceived as overly complicated will likely experience slower diffusion (Rogers, 1983, pp. 230–231). In the high-pressure context of armed conflict, where time and resources are constrained, technologies that require minimal training and can be quickly deployed tend to be favored. Thus, the perception of usability becomes a critical determinant of an innovation's practical appeal.

Trialability refers to the extent to which an innovation can be experimented with on a limited basis before full-scale implementation (Rogers, 1983, p. 231). This characteristic is particularly important in conflict situations where uncertainty and risk are elevated. The ability to test a technology in specific units or controlled environments allows decision-makers to assess its reliability and relevance before committing to widespread adoption. Trialability serves as a risk mitigation mechanism and often enhances institutional confidence in the innovation.

Observability is the degree to which the results or benefits of an innovation are visible and communicable within a social system

(Rogers, 1983, p. 232). In the military domain, observable outcomes such as successful tactical applications, increased survivability, or strategic gains can lead to broader institutional validation. When the effects of an innovation are clearly demonstrated in one setting, they can influence adoption decisions elsewhere through imitation, shared learning, and internal communication channels.

Together, these five characteristics offer a robust framework to explore the adoption of military technologies within complex and dynamic conflict environments. Rather than treating military innovation as a purely technical process, this framework situates it within a sociological perspective that considers perceptions, organizational behaviors, and the broader geopolitical context. By focusing on the interplay between these innovation characteristics and institutional settings, this study aims to contribute to a more nuanced understanding of how and why certain technologies are adopted in wartime, and how their diffusion reflects broader patterns in international relations and strategic behavior.

RESEARCH METHOD

This research uses a qualitative approach to analyze the adoption of weapons technology in the Russia-Ukraine conflict through the lens of Everett Rogers' Diffusion of Innovation Theory. The qualitative approach was chosen for its ability to explore the complex dynamics of technology adoption in the context of armed conflict, which involves the interaction of social, military organizational, and geopolitical factors. The research focuses on technologies such as drones (common, Shahed, fiber-optic, thermite), Starlink, and AI-based systems, adopted by Ukraine and Russia from the escalation of the conflict in 2014 to 2025.

Data was collected through secondary document analysis, including academic reports, journal articles, media news, and official sources such as relevant government and international organization reports. These documents were selected based on relevance to military technology and conflict development, with a time span of 2014-2025 to capture the evolution of the technology. Document analysis was conducted to identify the type of technology, its history of use, and factors influencing adoption based on Rogers' five characteristics of innovation: relative advantage, suitability, complexity, trialability, and observability.

Data analysis was conducted using a thematic approach, categorizing findings based on innovation characteristics and adoption dynamics on both sides. The research also considered the differences between decentralized military systems in Ukraine and centralized in Russia to understand how organizational structure affects technology diffusion. Data validity was strengthened through triangulation, comparing sources from academic, media and official report perspectives to minimize bias. Research limitations include reliance on secondary sources and limited data potential due to information sensitivity. This approach is expected to provide an understanding of how technology diffuses in conflict situations and the implications for global defense strategy.

RESULT AND DISCUSSION

Contextual Background of the Conflict for Technology Adoption

The Russia-Ukraine conflict is one of the most complex conflicts of the 21st century, rooted in the long history of relations between the two countries dating back to the Russian Empire and the Soviet Union. Ukraine, which became independent in 1991 after the collapse of the Soviet Union, has close cultural and ethnic ties with Russia, but tensions have arisen due to Ukraine's aspirations to move closer to the West, particularly the European Union and NATO (Brunk & Hakimi, 2022). The conflict encompasses political, territorial, and national identity dimensions, culminating in key events in 2014 and 2022, with significant developments through 2025.

In February 2014, Russia annexed Crimea after a controversial referendum denounced as illegal by Ukraine, the US, the EU and the UN. The annexation was preceded by pro-Russian riots in Crimea and followed by a conflict in the Donbas, where Russian-backed separatist groups controlled parts of Donetsk and Luhansk regions. The war in Donbas (2014-2022) involved a combination of Russian hybrid tactics, including unmarked troops, disinformation and military support for separatists (Makio & Fuccille, 2023). Ceasefire efforts through the Minsk II Agreement (2015) failed due to repeated violations, leaving 7% of Ukrainian territory under temporary occupation in 2019. This conflict caused more than 14,000 civilian casualties between 2014 and 2021, particularly in 2014-2015, with significant infrastructure damage in Donbas (International Crisis Group, 2022).

On February 24, 2022, Russia launched a full-scale invasion of Ukraine, marking the largest escalation since World War II. The invasion was preceded by a buildup of 190,000 Russian troops on the border in 2021, under the pretext of a "special military operation" to "demilitarize and denazify" Ukraine, a claim dismissed as propaganda (D'Anieri, 2023). Russia annexed Donetsk, Luhansk, Kherson and Zaporizhzhia in September 2022, an act considered internationally illegal. The invasion led to the largest refugee crisis in Europe since World War II, with nearly 7 million refugees as of February 2025 (The UN Refugee Agency, 2025). Russian attacks on civilian infrastructure, such as the Zaporizhzhia power plant, posed a nuclear threat and major damage that resulted in the suspension of operations of some of its reactors (World Nuclear Association, 2025).

Until 2025, the Russia-Ukraine war dragged on without a significant breakthrough. Russia controls about 20% of Ukraine, more than 4,000 km² by 2024, with control of the Donbas and parts of the east (Center for Preventive Action, 2025). Ukraine, supported by the West, continues to fight back through counter-attacks such as "Operation Spider's Web" in June 2025, which successfully destroyed 41 Russian aircraft, causing billions of dollars in losses (Mazhulin et al., 2025). Nevertheless, the frontline remained stagnant, with both sides suffering heavy losses. Peace efforts, including several rounds of talks in Istanbul until 2025 failed to reach an agreement as military escalations during negotiations still occurred, such as the three-day Russian drone attack in May 2025 (Atalan & Jensen, 2025). Russia remains diplomatically isolated, with Western sanctions costing the Russian economy hundreds of billions of dollars (Temnycky, 2025). As of the writing of this paper, a peaceful outcome has yet to be achieved, with Russia relying on allies such as North Korea and Iran, while Ukraine faces the uncertainty of US aid under Trump (Choi & Gale, 2025). These conflicts continue to complicate global geopolitical dynamics, with no clear peaceful solution on the horizon.

Technological Innovation and Weapons Employed

The Russia-Ukraine conflict, which began with the annexation of Crimea in 2014 and escalated dramatically with a full-scale invasion in 2022, has become an important arena for the development and adoption of advanced weapons technologies, making it an ideal case study to apply Everett Rogers' Diffusion of Innovation Theory. In the context of this conflict, Ukraine with its Western-backed decentralized approach and

Russia with its centralized command have adopted various new weapon technologies, such as (common) drones, Shahed drones, fiber-optic drones, thermite drones, starlink, and artificial intelligence (AI)-based systems. This research analyzes the deployment of these technologies in the military systems of both sides, focusing on the classification of technologies, the history of their use.

Drones (General)

One prominent technology is drones, or unmanned aerial vehicles (UAVs), which cover a wide range of platforms, from small commercial models to advanced military systems, used for reconnaissance, precision strikes and artillery setting. Ukraine began utilizing commercial drones like the DJI Mavic as early as 2014 in Donbas, with units like Aerorozvidka modifying drones for military use (Pettyjohn, 2024). By 2022, drones became the backbone of Ukraine's defense, with the "Army of Drones" initiative collecting 1,400 UAVs in three months through donations, accelerating technology deployment through training and collaboration with local startups (The Presidential Office of Ukraine, 2022). In June 2025, Ukraine launched "Operation Spider's Web," using long-range drones to attack Russian air bases, destroying 20-41 strategic aircraft such as Tu-95MS and Tu-22M3, demonstrating tactical necessity-driven technology diffusion (Allison, 2025). Russia, initially lagging behind, used drones like the Orlan-10 for reconnaissance and as decoys to expose Ukrainian air defense systems (Kunertova, 2023). From 2022, Russia increased its commercial and military use of drones, learning from Ukrainian tactics, with technology dissemination accelerated through internal communication channels and the importation of Shahed drone technology from Iran.

Shahed Drones

The Shahed , or Shahed-136 (called Geran-2 in Russia), is a low-cost kamikaze drone from Iran, designed for long-range attacks with an explosive payload of up to 45 kg (Eslami, 2022). Russia began importing the Shahed in July 2022, with the first strike on Odesa in September 2022 (Military Watch Magazine Editorial Staff, 2022). In 2023, Russia began construction of the Shahed-136 (known as Geran-2 in Russia) kamikaze drone production facility in Yelabuga, Republic of Tatarstan, in cooperation with Iran. This facility is part of Russia's strategy to increase its capacity to produce low-cost but effective weapons in the Ukraine conflict

(Chivers, 2025). By 2025 Russia aims to produce 6,000 units (Ilyushina, 2025). This reflects a "drone saturation" approach, which aims to overwhelm Ukraine's air defense systems with an overwhelming number of drone strikes, thus draining defense resources and creating opportunities for other strikes (Jensen & Atalan, 2025).

Ukraine, while not using Shahed-136 kamikaze drones like Russia, has shown an innovative response to the threat of Russian drone attacks by developing advanced defense systems, such as the Zvook acoustic sensor that aids early detection of enemy drones so they can be tracked and destroyed. These systems are designed to counter Russia's strategy focused on "drone saturation," which aims to overwhelm Ukraine's air defenses with large numbers of drones (Kushnikov, 2014). This is evidenced by ukrina's success in the June 9, 2025 raid that managed to shoot down more than 400 drones (The Kyiv Independent, 2025). The diffusion of Shahed in Russia occurred through international cooperation with Iran, with deployment accelerated through training and domestic production, while Ukraine adopted counter-drone technology as a reactive response, demonstrating a two-way diffusion dynamic.

Fiber-Optic Drones

Fiber-optic drones, which use fiber-optic cables for data transmission and are immune to electronic jamming, are becoming an important innovation, although they are limited in range (about 10 km) due to the cable load. Russia is pioneering this technology, with units like Rubikon using them in 2022 to attack Ukrainian logistics lines. The development of fiber drones until 2025 recorded an increase where the range of these drones was up to 50 km. The deployment of this technology in Russia occurred through tactical training and collaboration with tech startups (Hambling, 2025). Ukraine began developing fiber-optic drone technology in 2024 in response to Russian jamming. Despite Russia being an early innovator in the use of fiber-optic drones, Ukraine adopted this technology selectively (Farrell, 2025). This development reflects the different approaches in military systems and the dynamics of technological innovation between the two countries.

Thermite Drones

Thermite drones, are modified drones that use thermite payloads as the main weapon. Thermite is utilized because it can generate extreme heat, used for precision strikes. Ukraine utilized these drones in 2024 to attack Russian positions in Donbas, with this technology spreading through collaboration with local startups and small units on the frontlines (Lendon, 2024). Russia is also reportedly using thermite in their dromne on the frontline of defense (Altman, 2024). Both sides adopted these technologies through local innovation and emulation of opponent tactics, with deployment driven by training and industry collaboration, reflecting a competitive diffusion cycle.

Starlink

Starlink, a SpaceX satellite system, has been Ukraine's communications backbone since 2022, supporting military operations, reconnaissance, and drone control despite telecommunications infrastructure damage from the Russian invasion. With hundreds of satellite constellations in low orbit, Starlink is resistant to most jamming and interference (Abels, 2024). Russia responded with cyberattacks, destroying shortwave repeaters and using electronic warfare systems to disrupt Ukrainian communications. On the other hand, Russia utilized illegally obtained black market Starlink terminals in the occupied territories to improve the coordination and precision of their artillery and drone attacks, thus reducing Ukraine's technological advantage on the battlefield (Friel, 2024).

AI-Based Systems

AI-based systems, such as those used for data analysis, target guidance and autonomous navigation, became an important pillar in this conflict. Ukraine started using AI through startups like Zvook. The Zvook system, with a range of 10kmn can detect air threats using AI for voice analysis (Matviienko et al., 2025). Russia uses AI for terminal guidance on Shahed drones, improving accuracy with satellite modules and antennas of Chinese origin (Dmytriieva, 2025). Ukraine leads as an AI innovator through local technology ecosystems, while Russia adopts through global collaborations, suggesting diffusion influenced by different social systems.

The dynamics of technology adoption in this conflict show a very fast innovation cycle, driven by battlefield needs. Ukraine leveraged organizational flexibility and Western support to become an early innovator, spreading technology through training, collaboration with startups, and international aid. Russia, although initially slow, accelerated adoption through emulation of opponent tactics, technology importation (such as the Shahed from Iran), and domestic development. This two-way diffusion, where both sides learn from the opponent's successes and failures, creates a dynamic technology race. This conflict confirms that technology adoption depends not only on the innovation itself, but also on the ability of military organizations to spread knowledge and adapt in different social systems. In the context of adaptation, we will next describe the characteristics of each technology based on the five characteristics of innovation: relative advantage, suitability, complexity, trialability, and observability.

Analysis of Innovation Characteristics

Drones (General)

The widespread use of commercial drones by Ukrainian forces exemplifies their relative advantage in modern warfare, offering crucial low-cost reconnaissance and rapid adaptability compared to traditional, more expensive military assets. For instance, units like Aerorozvidka began modifying commercial drones such as the DJI Mavic for military use as early as 2014 in Donbas (Pettyjohn, 2024), demonstrating their immediate utility. This rapid adaptation highlights their high compatibility with dynamic battlefield needs, particularly for real-time intelligence and improvised strike capabilities. By 2022, drones quickly became the backbone of Ukraine's defense (Samus, 2025).

Furthermore, the relatively low complexity of these commercial drones allows for quick training of operators, facilitating widespread and rapid deployment across various units. Their intuitive piloting also supports efficient tactical adaptation on the frontlines. The trialability of these low-cost systems, enabling widespread experimentation in diverse combat scenarios with minimal risk, allowed for rapid iteration of operational doctrines. Their clear observability in early, successful operations such as Ukraine's "Operation Spider's Web" in June 2025, which reportedly destroyed 20-41 Russian strategic aircraft (Allison, 2025) vividly demonstrated their immediate effectiveness. This tangible proof of utility significantly encouraged mass adoption, exemplified by Ukraine's "Army of Drones" initiative, which rapidly mobilized 1,400 UAVs through donations within just three months (The Presidential Office of Ukraine, 2022). Meanwhile, Russia, which was initially lagging in drone deployment, gradually increased its use of unmanned systems, including the Orlan-10 for reconnaissance (Kunertova, 2023). This development was, in part, a response to observed Ukrainian tactics, from which Russia appeared to draw operational lessons.

Shahed Drones

Russia's adoption of Shahed drones is primarily driven by their relative advantage as a low-cost kamikaze weapon designed for long-range attacks with an explosive payload of up to 45 kg (Eslami, 2022). These drones offer a cost-effective method to strike distant targets and overwhelm defenses. Their high compatibility with Russia's "drone saturation" strategy is evident, as they are specifically deployed in overwhelming numbers to deplete Ukraine's air defense resources and create opportunities for other attacks (Jensen & Atalan, 2025).

The simple complexity of Shahed drones facilitates their mass production and rapid deployment, a key factor in Russia's strategy to increase its overall strike capacity. Russia's strategic move to commence domestic production in Yelabuga in 2023, in cooperation with Iran (Chivers, 2025), underscores this. The trialability of these drones has been repeatedly proven in actual attacks, demonstrating their effectiveness, with the first reported strike on Odesa occurring as early as September 2022 (Military Watch Magazine Editorial Staff, 2022).

Finally, the clear observability of Shahed drones' destructive impact on Ukrainian infrastructure, such as power grids and civilian facilities, validated their operational effectiveness, driving Russia's commitment to large-scale domestic production targeting 6,000 units by 2025 (Ilyushina, 2025). These visible results, amplified through battlefield reports and media, reinforced Russia's "drone saturation" strategy, accelerating adoption and production (Jensen & Atalan, 2025). At the same time, Ukraine's counter-responses, including the development of AI-based acoustic detection systems like Zvook, have emerged as reactive innovations driven by similarly observable battlefield needs (Czerny, 2024). These countermeasures illustrate how observable outcomes not only accelerate adoption but also generate adaptive diffusion on both sides.

Fiber-Optic Drones

Fiber-optic drones are adopted by both Russia and Ukraine primarily for their relative advantage in maintaining immunity to electronic jamming, a crucial capability on the modern battlefield where electronic warfare is pervasive (Frąckiewicz, 2025)

While their compatibility for reconnaissance missions or precision strikes is currently limited by distance due to the cable load, their secure communication link provides a distinct operational benefit in contested electromagnetic environments.

Despite their inherently higher complexity compared to standard drones owing to the challenges of managing and deploying the fiber-optic cable their trialability was swiftly proven in early strikes. Russia, for instance, pioneered this technology with units like Rubikon reportedly using them in 2022 to attack Ukrainian logistics lines (Hambling, 2025). The clear observability of these drones successfully avoiding signal interference showcased their significant potential, directly prompting further development for an increased range of up to 50 km by 2025 (Hambling, 2025). Ukraine, in turn, began developing its own fiber-optic drone technology in 2024 (Farrell, 2025) as a direct, reactive response to Russia's jamming threat, demonstrating a competitive diffusion cycle driven by observable success.

Thermite Drone

The relative advantage of Thermite drones for both Ukraine and Russia lies in their unique ability to generate extreme heat for precision strikes on specific targets, enabling the destruction of hardened enemy positions or ammunition depots more effectively than conventional explosives. Their high compatibility with the tactical objective of neutralizing specific, high-value targets makes them a highly effective and ideal choice on the battlefield.

The complexity of Thermite drones is notably low, primarily involving the simple modification of standard drones to carry thermite payloads, making their development and deployment relatively accessible for both state and non-state actors. This inherent simplicity facilitates rapid integration. Their rapid frontline trialability, particularly through collaboration with local startups and small units, quickly allows for tactical validation, as seen in Ukraine's utilization of these drones in 2024 to attack Russian positions in Donbas (Lendon, 2024).

Finally, the clear observability of Thermite drones effectively destroying targets in combat scenarios significantly encourages their rapid adoption and the emulation of tactics between both sides. According to open-source reporting, the use of thermite payloads has resulted in the destruction of multiple Russian ammunition depots, as well as fires that rendered several armored vehicles inoperable during 2024 assaults by the Ukrainian army in Eastern Ukraine (Sánchez, 2024). Moreover, legal experts have raised concerns over the incendiary nature of thermite in dense combat zones, particularly due to its potential to cause uncontrollable fires and structural collapse when deployed against urban or industrial infrastructure (Coble & Hernandez, 2024). Russia also reportedly employed thermite-equipped drones on the frontline since September 2024 (Altman, 2024). These tangible and observable impacts reinforce the operational effectiveness of thermite drones, prompting accelerated diffusion.

Starlink

Starlink's rapid adoption by Ukraine is primarily due to its relative advantage as a distributed, highly interference-resistant military communications backbone, offering unparalleled connectivity even after traditional telecommunications infrastructure was damaged by the Russian invasion. Its hundreds of satellite constellations in low orbit make it uniquely resilient to most jamming and interference attempts (Abels, 2024). This robust capability highlights its high compatibility with the urgent and critical communication needs on dynamic battlefields.

Despite being a sophisticated system-wide technology, Starlink exhibits remarkably low complexity for end-users, facilitating rapid deployment and operational integration by frontline personnel. Its trialability has been extensively proven through its continuous support of Ukrainian field operations since 2022, unequivocally demonstrating its effectiveness in real-world combat scenarios. The clear observability of Starlink maintaining stable and reliable communications despite persistent Russian cyberattacks and electronic warfare efforts has strongly encouraged its widespread use. This effectiveness was so evident that even Russia reportedly resorted to illegally obtaining and utilizing black market Starlink terminals in occupied territories to improve its own coordination and precision (Friel, 2024). This further underscores the observed utility of the system and helps explain its broad diffusion across the battlefield.

AI-based Systems (Zvook, etc.)

AI-based systems, such as those developed by Ukrainian startups, have been crucial due to their relative advantage in rapid data analysis and early aerial threat detection, particularly against "drone saturation" tactics. For instance, Ukraine's Zvook system, a grassroots acoustic air defense initiative, uses AI for voice analysis to detect air threats with a 10km range (Matviienko et al., 2025). This highlights their high compatibility with the urgent needs for wide-area surveillance and precise target guidance in a complex, fast-moving conflict environment.

While their complexity can be high in terms of development, requiring sophisticated machine learning models, these systems are designed for efficient operation by end-users. Their trialability has been demonstrated through continuous field-testing, proving their accuracy and efficacy. For example, Zvook's acoustic sensors, developed by a startup, are deployed across Ukraine, processing ambient sounds to identify threats and sending fused data to mobile firing teams in real-time (Militarnyi, 2024; UNITED24 Media, 2025). This ability to integrate and process massive amounts of data from diverse sources (drones, satellites, social media) for rapid decision-making has been crucial (CNAS, 2025).

The observability of AI-based systems in enhancing situational awareness and strike accuracy has become a central driver of their rapid adoption and continued innovation in Ukraine's military strategy. A clear example of this occurred on June 9, 2025, when Ukrainian forces successfully neutralized 479 incoming Russian aerial threats. Of these, 292 were physically shot down, while 187 were disrupted through electronic warfare, demonstrating the operational effectiveness of AI-enhanced air defense systems in countering large-scale saturation attacks (The Kyiv Independent, 2025). Among these systems, Zvook stands out for its use of AI-powered acoustic threat detection, which enables real-time identification and localization of hostile drones. Its integration into frontline operations provides direct tactical benefits by supporting rapid interception decisions and coordinating with mobile firing teams. At the same time, Russia is also incorporating AI into its offensive capabilities, particularly in the terminal guidance of Shahed drones, using satellite modules and antennas of Chinese origin to improve targeting precision (Dmytriieva, 2025; Ukrainska Pravda, 2025). This parallel adoption, driven by observable tactical advantages on both sides, highlights the transformative role of AI in modern warfare and illustrates the accelerating pace of its diffusion across competing military forces.

CONCLUSION

The Russia-Ukraine conflict has emerged as a crucial case study for understanding the dynamics of military technology adoption in modern warfare. Rapid advancements in information technology, automation, and cyber operations have transformed the nature of conflict, emphasizing the importance of a state's ability to integrate innovations quickly and effectively. This research adopts Everett M. Rogers' Diffusion of Innovations Theory as its primary analytical lens, offering a distinct perspective from previous studies that focused on international legal implications, the impact of the digital military revolution, or the risks of nuclear escalation.

By focusing on five innovation characteristics—relative advantage, compatibility, complexity, trialability, and observability—this research has elucidated how and why specific technologies were adopted by both Russia and Ukraine. Relative advantage drove the adoption of systems that enhance precision and efficiency, such as real-time reconnaissance technology. Compatibility with existing doctrines and systems accelerated integration, like technologies aligned with NATO standards for Ukraine or hierarchical control systems for Russia. Low complexity facilitated rapid adoption under combat pressure, encouraging the use of user-friendly technologies. Trialability allowed for small-scale testing, reducing risk and building confidence before widespread implementation. Finally, the observability of clear and measurable results spurred adoption through social influence and demonstrated success on the battlefield.

By analyzing military innovation not merely as a technical process but as a sociological phenomenon influenced by perceptions and operational contexts, this research provides a more nuanced understanding of technological choices in wartime. The significant contribution of this study lies in its application of the Diffusion of Innovations framework to explain the selection and adoption processes of specific technologies, enriching the study of international relations and geopolitical dynamics. Ultimately, the Russia-Ukraine conflict reaffirms that while technology reshapes tactics and expands the domain of conflict, its successful adoption heavily depends on how these innovations are perceived and integrated within complex military ecosystems.

While the above findings provide significant insights, this study has limitations.

Reliance on secondary sources may lead to incomplete information, especially due to the sensitive nature of the Russia-Ukraine conflict. Limited access to primary data, such as interviews with military actors or internal documents, hinders a first-hand perspective on the technology adoption process. Furthermore, the focus on specific technologies, such as drones and AI-based systems, potentially overlooks other less documented or emerging innovations. To overcome these limitations, future research could integrate primary data through interviews or field observations and extend the analysis to a wide range of military technologies. This approach will provide a more holistic understanding of the dynamics of innovation diffusion in armed conflict, thus enriching contributions to the study of international relations and global defense strategy.

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