The Evolution and Future of Mobile Artillery
Technological Advances, History and Future of Artillery Warfare

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This article explores the evolution of mobile artillery, from oxen-drawn cannons and camel-mounted swivel guns to today's self-propelled, precision-guided systems. It highlights how battlefield mobility, rapid fire-and-move tactics, and integration with digital command networks have made mobile artillery indispensable in modern warfare. Drawing lessons from recent conflicts like the Russia–Ukraine war and the Azerbaijan–Armenia clashes, this article analyses how mobile artillery—augmented by unmanned aerial vehicles (UAVs), smart munitions and autonomous logistics—has adapted to fast-paced, multi-domain operations. The study underscores mobile artillery's unique role as a survivable, flexible and cost-effective firepower solution amid evolving threats and terrain-driven challenges.

Keywords: *Mobile Artillery, Self-Propelled Howitzers (SPH), Precision-Guided Munitions (PGM), Network-Centric Warfare, Shoot-and-Scoot Tactics, Artillery Modernisation, Smart Munitions, Autonomous Fire Control Systems, Multi-Domain Operations (MDO), Loitering Munitions Integration, Russia–Ukraine Conflict, Azerbaijan–Armenia War, AI-Enabled Artillery Systems, Rocket Artillery (MLRS), Hybrid Propulsion Artillery Platforms*

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ISSN 0976-1004 (print); 2583-7567 (online)

Journal of Defence Studies, Vol. 19, No. 4, October-December 2025, pp. 25–49

Introduction

Throughout military history, artillery has served as the defining arm of decisive warfare—shaping battles not merely through brute force, but through its ability to project power across terrain and time. From the towering siege cannons of the middle ages to the agile, digitally controlled systems of today, artillery has evolved alongside doctrines, technologies, and the character of war itself. At its core, this transformation reflects a relentless pursuit of three battlefield imperatives: mobility, precision and responsiveness.

Early mobile innovations—from China's 'Huo Che' rocket carts to Tipu Sultan's iron-cased rockets—highlighted the strategic value of artillery that could move and strike rapidly. In the industrial era, Napoleon's reforms and World War mechanisation brought about towed and self-propelled guns that could keep pace with manoeuvre warfare. But it is in the modern age—shaped by digitisation, unmanned systems and multi-domain warfare—that artillery has truly been reimagined.

Today's self-propelled artillery and rocket systems are not just platforms for indirect fire, they are smart, networked assets capable of autonomous operation, real-time target coordination, and precision strikes with minimal collateral damage. Whether deployed in the plains of Ukraine, the mountains of Ladakh, or the deserts of the Middle East, modern artillery must adapt to varied terrains, evolving threats and increasing demands for rapid, flexible response.

This article chronicles the evolution of mobile artillery, from its earliest forms to the sophisticated, integrated systems of the 21st century. It examines technological breakthroughs, strategic shifts, and the role of major militaries in shaping the doctrine of mobile firepower. As warfare becomes faster, smarter, and more contested, the story of artillery's transformation is not just one of innovation, it is a story of survival and strategic relevance in the age of precision and complexity.

The Evolution of Mobile Artillery: From Siege Engines to Mechanised Power

Before self-propelled artillery, the evolution of firepower passed through key phases—from immobile siege cannons to more agile towed systems. Massive early guns, prominent in the late middle ages, were effective against fortifications but logistically cumbersome, requiring teams, animals and complex set-ups that limited battlefield agility.[1]

China's Song dynasty introduced mobile innovations like the 'Huo Che' rocket launcher and early bombards, emphasising the value of mobility alongside firepower.[2] The Mughal empire institutionalised artillery under Akbar, notably fielding Zamburaks—camel-mounted swivel guns that enabled rapid re-deployment in rugged terrain, offering a tactical advantage during sieges and manoeuvres.[3] In southern India, Tipu Sultan's iron-cased rockets, especially at Pollilur (1780), added lethal mobility and influenced Britain's Congreve rockets.[4]

At the Battle of Plassey (1757), Robert Clive's use of oxen-drawn artillery outmaneuvered Nawab forces, underscoring the rising importance of mobile firepower in doctrine.[5] Towed artillery, gaining prominence in the 18th and 19th centuries, bridged the gap between siege and mechanized systems—used extensively in both the World Wars and are valuable even today where cost, terrain, or logistics limit self-propelled platforms.

Napoleon's reforms through the Gribeauval System and Grand Battery strategy further institutionalised mobility and massed fire coordination, setting the stage for mechanised artillery's role in modern combined-arms warfare.[6]

The Shift in World War I: Mobility Becomes Imperative

World War I's trench warfare exposed the limitations of static, horse-drawn artillery, which often lagged behind infantry, leading to operational failures. British artillery, moving at a walking pace, struggled during rapid manoeuvres, highlighting the need for mobility.[7]

The introduction of tanks in 1916—combining firepower, armour and terrain-crossing capability—inspired the concept of self-propelled artillery (SPA). Early adaptations like the British Mark IV with mounted guns, France's Schneider CA1, and Germany's A7V marked the birth of mobile artillery platforms, enabling fire support to move in sync with advancing forces.[8]

The war underscored that artillery needed to be mobile, survivable and integrated within fast-paced operations.[9] This lesson shaped inter-war military thinking, despite constrained budgets and pacifist sentiments.

During the inter-war years, Britain developed the Birch Gun (1925), one of the first SPAs, though it was eventually shelved due to doctrinal uncertainty.[10] Germany, evading Versailles restrictions, developed the Sturmgeschütz III (StuG III), initially for infantry support but later evolving into an effective tank destroyer central to blitzkrieg tactics.[11] In the Soviet

Union, early SPA experiments like the SU-12 and SU-76 laid the groundwork for World War II-scale production.[12]

The US, slower to adopt SPA concepts, experimented with T3 and T4 Gun Motor Carriages, which paved the way for platforms like the M7 Priest. The 1919 Westervelt Board also emphasised mobility in future artillery doctrine.[13]

Meanwhile, the emergence of battlefield radio transformed fire coordination. Real-time communication enabled accurate, responsive targeting by mobile units—turning artillery from a static arm into a dynamic, integrated force. These developments laid the foundation for the highly mobile, combined-arms artillery doctrine of World War II.[14]

World War II: The Rise of Mechanized Artillery

World War II firmly established SPA as an essential part of mechanized warfare. Rapid, combined-arms offensives demanded artillery that could keep pace with tanks and infantry.[15]

Britain: From Bishop to Sexton

Britain's early SPA, the Bishop (based on the Valentine tank), was limited by design flaws. Learning quickly, engineers developed the Sexton, a 25-pounder gun mounted on a Canadian Ram tank chassis. It proved effective in North Africa and Europe, enhancing indirect fire capabilities with increased mobility.[16]

The United States: M7 Priest and Beyond

The M7 Priest, mounting a 105mm howitzer on an M3 chassis, became the workhorse of American and British artillery units.[17] It was complemented by the M12 (155mm) for heavy fire and the M8 Scott for light support. The introduction of Fire Direction Centres (FDCs) allowed dynamic targeting and rapid coordination.[18]

Germany: Mobile Synergy with Blitzkrieg

Germany excelled in integrating SPA into blitzkrieg tactics. Platforms like the Wespe (105mm) and Hummel (150mm) provided powerful, mobile fire support. The versatile StuG III became a battlefield staple due to its low cost and multipurpose functionality. Despite economic constraints, these systems exemplified how mobile artillery could maximise battlefield synergy.[19]

Soviet Strategy: Deep Battle and Mass Production

The Red Army relied on mass-produced SPAs like the SU-76 and the powerful SU-152/ISU-152. Designed to neutralise German armour, the latter earned the nickname 'Zveroboy' (Beast Slayer). Soviet Deep Battle Doctrine integrated SPAs into large-scale offensives, reinforcing artillery's central role in breakthrough operations.[20]

Other Nations

France: Though under occupation, it developed the AMX 105mm platform that would influence post-war designs.

Italy: The Semovente 75/18 offered mobile support across diverse battlefields.

Japan: Vehicles like the Type 1 Ho-Ni I and Type 4 Ho-Ro provided mobile artillery but suffered due to limited industrial capacity.

Doctrinal Impact

The success of SPAs during World War II prompted a doctrinal shift. Artillery was no longer relegated to static roles; it became a fluid component of mechanized warfare. Advances in mobility, protection and firepower set the stage for Cold War developments and beyond.[21]

Conclusion

From oxen-drawn cannons and camel-mounted guns to tank-chassis self-propelled platforms, artillery has continuously adapted to the demands of mobility and modern warfare. The development of towed artillery served as a crucial bridge, providing greater flexibility and battlefield adaptability before the full mechanisation of artillery systems. Each conflict, from medieval sieges to World War II, added layers of complexity and innovation. The evolution of mobile artillery was driven not only by technological ingenuity, but also by strategic necessity, ensuring artillery remains a decisive force on future battlefields.

Strategic Shifts: The Cold War's Influence on Mobile Artillery Development (1947–1991)

The Cold War era fundamentally reshaped artillery doctrine, driven by the strategic need for mobile firepower capable of supporting armoured thrusts and deterring nuclear escalation. Both the North Atlantic Treaty Organization

(NATO) and the Warsaw Pact prioritised self-propelled artillery (SPA) systems that could deliver rapid, sustained fire support while keeping pace with mechanized units.[22]

The US adopted the M109 Paladin in 1963 as a modular 155mm SPA optimised for manoeuvre warfare, later upgraded with digital fire control and precision-guided munitions. It became NATO's standard artillery platform, reflecting Western emphasis on interoperability and precision coordination.[23]

In contrast, Soviet doctrine centred on massed fires and operational depth. Systems like the 2S3 Akatsiya and 2S5 Giatsint were designed to accompany tank offensives and deliver overwhelming barrages, forming a key component of the USSR's 'deep battle' strategy. The 2S19 Msta marked the USSR's move towards modernised SPAs with improved automation and range.[24]

Tactical nuclear artillery also emerged during this period, with platforms like the US M65 'Atomic Annie' and nuclear-capable Soviet SPHs serving as battlefield deterrents. However, the shift to missile-based deterrence gradually rendered nuclear artillery obsolete.

West Germany's PzH 155-1, aligned with NATO standards, underscored the strategic push for standardised, network-compatible platforms across allied forces—preparing for rapid, integrated response to Soviet aggression.[25]

Overall, the Cold War accelerated the transition from static to highly mobile, survivable artillery. It established divergent yet complementary doctrines—NATO prioritising precision and flexibility, and the USSR favouring volume and momentum—all of which laid the technological and strategic foundation for 21st-century artillery warfare.[26]

Modern Era (Post-1991): Advancements in Mobile Artillery

The end of the Cold War and the rise of asymmetric warfare transformed artillery doctrines, shifting from massed barrages to rapid, precision-guided engagements. This transition emphasised mobility, automation and network-centric warfare, particularly in urban and expeditionary operations.[27]

Shifting Doctrines

Military doctrines post-1991 witnessed a decisive shift from sheer volume-based firepower to precision-centric, technology-enabled artillery engagements. This transformation was driven by battlefield lessons and evolving threats across a range of conflicts.[28]

Gulf War (1991): The US-led coalition's integration of artillery with airpower, GPS-guided munitions, and real-time coordination demonstrated how artillery could serve as a force multiplier in manoeuvre warfare. It validated the utility of networked fire control and precision over massed barrages.[29]

Chechnya and Georgia (1990s–2008): Russia's experience in Chechnya exposed the vulnerabilities of conventional artillery in urban environments, while the Georgia war emphasised the need for rapid integration of electronic warfare (EW), drones and fire control. These shaped Russia's modernisation of systems like the 2S19 Msta and led to the deployment of UAV-linked SPAs and MLRS in later conflicts.[30]

Azerbaijan–Armenia Conflict (2020): Azerbaijan's use of loitering munitions (e.g., Israeli Harop drones), along with precise artillery and rocket strikes guided by UAV reconnaissance, marked a doctrinal leap.[31] This conflict underscored how drone-artillery integration could achieve decisive results against entrenched adversaries, leading to global reassessments of artillery tactics and C4ISR coordination.[32]

Ukraine Conflict (2014–present): Russia's combined use of UAVs, electronic warfare and long-range rocket artillery, including the Tornado-S and 2S7M Malka, demonstrated the effectiveness of digitised artillery networks in modern warfare.[33] In response, Ukraine leveraged US-supplied HIMARS and Excalibur rounds for high-value precision strikes, setting a new benchmark for mobile, rapid-strike capability.[34]

These conflicts collectively redefined artillery doctrine by validating the importance of:

- Real-time intelligence and sensor-to-shooter links.
- Artillery survivability through mobility and shoot-and-scoot tactics.[35]
- Precision-guided munitions in reducing collateral damage.
- Integration of UAVs and EW with traditional artillery units.[36]

This evolution in doctrine forms the basis for the comparative analysis presented in Tables 1 and 2—one for *Self-Propelled Artillery Systems* and another for *Rocket Artillery Platforms*[37]—highlighting the capabilities and roles of modern artillery assets across major militaries.

Table 1 Advances in Self-Propelled Artillery[38]

System	Country of origin	Weight (tonnes)	Caliber (mm)	Rate of fire (rpm)	Range (km)	Mobility Type	Special features
M109A7 Paladin	USA	35	155	4	30–40	Tracked	Digital fire control, Excalibur GPS-guided rounds
PzH 2000	Germany	55	155	10–13	30–40	Tracked	MRSI, automated loading, advanced FCS
2S19 Msta	Russia	42	152	6–8	24.7	Tracked	UAV targeting integration
2S7M Malka	Russia	46.5	203	1–2	37.4	Tracked	Long-range heavy gun, limited rate of fire
PLZ-05	China	35	155	8–10	35–50	Tracked	Networked operations, rapid targeting
PLZ-52	China	43	155	8–10	50+	Tracked	Extended range, advanced digitisation
ATMOS	Israel	22	155	4–6	30–40	Wheeled	Highly mobile, air-transportable
CAESAR	France	18	155	6	42	Wheeled	Modular, lightweight, highly deployable
K9 Vajra	South Korea (India)	47	155	6–8	40+	Tracked	Customised for Indian terrain, auto loader
MGS 105 mm	India	18	105	6	18	Wheeled	Lightweight, Indian designed
MGS 155 mm	India	28	155	6	40+	Wheeled	Heavy wheeled artillery, digital integration

Table 2 Rocket Artillery Modernisation[39]

System	Country	Calibre (mm)	Range (km)	Guidance system	Fire control system	Types of munition	CEP (m)
HIMARS	USA	227	Up to 300	GPS/INS	Automated C4ISR	HE, sub-munitions, unitary, ATACMS	<10 (Excalibur/ ATACMS)
BM-30 Smerch	Russia	300	70–90	Inertial	Semi-automated	HE, sub-munitions, thermobaric	150–200
Tornado-S	Russia	300	120+	GLONASS/ INS	Modern digital	HE, cluster, thermobaric, guided	30–50
PHL-03	China	300	~150	GPS/INS	Digital with BeiDou	HE, cluster, incendiary	100+
PHL-16	China	370	280–500	BeiDou/ GPS/INS	Integrated C4ISR	HE, guided, cluster	30–50
Pinaka Mk-I/ Mk-II	India	214	40–75	GPS/INS	Computerised Indigenous	HE, cluster, precision-guided (Mk-II)	60–80 (Mk-II)
Fateh-110	Iran	610	~300	INS/GPS	Digital FCS	HE, cluster, penetration, unitary	30–50
Fatah-1	Pakistan	300	~150	INS/GPS	Pakistani digital FCS	HE, cluster, GPS-guided, fragmentation	30–50
Fatah-2[40]	Pakistan	400	~400	INS/GPS	Pakistani advanced FCS	HE, cluster, precision-guided, penetration	20–30

Networked, Precision-centric Operations

By the 2010s, artillery had fully transitioned into a digital-era battlefield asset, shaped by lessons from conflicts like the Gulf War, Kargil, and the

Azerbaijan–Armenia war. No longer operating in isolation, modern artillery units became integral components of real-time, multi-domain command networks.[41]

Digitally integrated into C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance) systems, artillery platforms began receiving real-time targeting inputs from forward observers, UAVs, radar systems and electronic warfare assets.[42] This allowed for sensor-to-shooter cycles measured in seconds, not minutes, enabling immediate and highly accurate fire missions.[43]

Precision-guided munitions like Russia's Krasnopol, India's Laser-Guided Ammunition (LGM), and the US Excalibur GPS rounds significantly reduced circular error probabilities (CEP), allowing surgical strikes even in complex terrain or urban environments. These munitions minimised collateral damage while maximising operational effect—especially crucial in asymmetric and high-density conflicts.

The use of AI-assisted fire control systems, loitering drones and automated target acquisition systems accelerated artillery responsiveness. Real-world combat, such as the Ukraine conflict, validated the need for shoot-and-scoot tactics, aided by rapid sensor coordination and battlefield digitisation.

This convergence of mobility, precision and network connectivity transformed post-1991 mobile artillery into a flexible, survivable and decisive firepower instrument. Whether through automated self-propelled systems or long-range MLRS platforms, the modern artillery doctrine now emphasises digital coordination, smart munitions and integrated ISR as central to combat success.[44]

Future Possibilities and Research in Self-Propelled Artillery

The post-2020 era has ushered in a transformative period for SPA, shaped by the rapid advancements in artificial intelligence (AI), autonomous systems, precision weaponry, hybrid propulsion and multi-domain operations (MDOs).[45] The Russia–Ukraine War has particularly reinforced the necessity of SPA modernisation, demonstrating the vulnerabilities of static artillery and the advantages of highly mobile, precision-strike systems.[46] A parallel can be drawn to the 2020 Nagorno-Karabakh War between Azerbaijan and Armenia, where Azerbaijan's effective use of drones and networked artillery played a decisive role in neutralising Armenian defences, highlighting a seismic shift in battlefield dominance through precision and mobility.[47]

As modern warfare becomes increasingly network-centric, data-driven and technology-integrated, SPAs are evolving to meet the demands of future battlefields. The next-generation SPAs will be capable of rapid relocation, high-precision targeting, and seamless integration with cyber and electronic warfare operations, ensuring their continued dominance on the battlefield.[48]

The Evolution of Self-Propelled Artillery: Adapting to Modern Warfare

The necessity for modern SPAs arises from evolving military doctrines and battlefield realities. High-intensity conflicts, asymmetric warfare and the widespread use of drones, loitering munitions, and electronic warfare have reshaped artillery tactics.[49] The Nagorno-Karabakh conflict showcased how loitering drones like Harop and Bayraktar TB2 worked in tandem with artillery, providing real-time target acquisition and devastating precision strikes.[50] Traditional towed artillery, once the backbone of ground forces, has become increasingly vulnerable due to its static nature. Modern SPAs now focus on mobility, precision and survivability, ensuring they can deliver sustained firepower while remaining evasive against counter-battery fire.

The Russia–Ukraine conflict has proven the effectiveness of highly mobile artillery, particularly in countering enemy positions and disrupting supply chains.[51] The war has demonstrated how networked artillery assets, real-time battlefield intelligence and precision-guided strikes can neutralise enemy defences while minimising collateral damage. Western artillery systems like the M109A7 Paladin, PzH 2000 and Archer have underscored the significance of high-precision, rapid-strike capabilities, while Russia's use of BM-30 Smerch, 2S19 Msta and Koalitsiya-SV has highlighted the role of long-range, heavy-calibere artillery in modern conflicts.[52]

The ongoing shift towards multi-domain integration ensures that SPA units can operate effectively across land, air, cyber and space-based platforms. Artillery no longer functions in isolation but works in tandem with UAVs, satellites and electronic warfare units to deliver devastating, real-time firepower.

The Rise of Autonomous Systems in Artillery

The integration of autonomous and advanced computational technologies into artillery is reshaping modern warfare. Artillery is evolving into a highly strategic asset capable of precise, efficient and adaptive combat operations.[53]

This evolution is accelerated by developments in artificial intelligence (AI), quantum computing and autonomous logistics.

AI-Enhanced Munitions: Artificial Intelligence has revolutionised artillery munitions, transitioning from traditional ballistic shells to sophisticated, intelligent projectiles. Modern artillery rounds, including the US Excalibur and China's AI-powered laser-guided shells, use onboard sensors combined with AI algorithms to dynamically adjust their trajectories mid-flight. These intelligent systems can autonomously identify targets, avoid countermeasures, and adapt to rapidly changing battlefield environments, significantly enhancing precision and reducing collateral damage, especially crucial in urban warfare.[54]

Multi-Target Engagement (MRSI/SWSI Technology): Modern artillery has evolved to deliver rapid, synchronised and highly effective firepower through advanced technologies like Multiple Round Simultaneous Impact (MRSI) and Split Warhead Simultaneous Impact (SWSI).

MRSI empowers artillery platforms to fire multiple rounds that strike their targets simultaneously, overwhelming enemy defences. Advanced systems such as India's K9 Vajra, Germany's Panzerhaubitze 2000 and Sweden's Archer utilise intricate computational methods to meticulously calculate firing sequences, drastically increasing lethality and reducing enemy reaction time.[55]

SWSI, on the other hand, enables a single artillery shell to disperse multiple submunitions mid-flight, each programmed to strike different targets simultaneously across a wide area. This approach maximises battlefield coverage and effectiveness against dispersed or mobile threats. Systems like the BONUS shell (France/Sweden) and SMArt 155 (Germany) employ sensor-fuzed munitions to autonomously identify and engage targets, enhancing precision-strike capability while minimising the need for multiple firing units.[56]

Together, MRSI and SWSI represent cutting-edge multi-target engagement technologies that redefine artillery effectiveness in modern warfare.

Autonomous Targeting and Fire Control: Artillery targeting and fire control systems increasingly rely on AI-driven autonomous systems, reducing the need for human intervention. Integrated machine learning algorithms utilise data from UAVs, ground-based sensors and advanced computational methods to enable swift threat detection and prioritisation.[57] Examples like Israel's Harop UAV demonstrate significant improvements in real-time intelligence, facilitating immediate and precise artillery targeting actions.

Intelligent Aiming and Guidance: Innovations in intelligent aiming systems leverage neural networks and fuzzy logic algorithms. These advanced computational techniques rapidly calculate optimal trajectories, ensuring high-precision strikes under challenging conditions. This significantly enhances artillery accuracy, mitigating errors traditionally associated with manual and mathematical methods.[58]

Quantum Computing and Quantum Technologies: Quantum computing promises substantial advancements in artillery capabilities, particularly in optimising fire control and target prediction. Quantum algorithms can solve complex optimisation problems, such as Weapon-Target Assignment, more efficiently than classical computing. Quantum Machine Learning (QML) offers faster, more accurate predictive models for target movement and engagement, improving responsiveness and accuracy in artillery operations.[59]

Quantum sensors and quantum radar systems dramatically enhance navigational accuracy and targeting precision, even in GPS-denied environments.[60] Secure quantum communication channels, employing Quantum Key Distribution (QKD), ensure robust and unbreakable data transfer between artillery units, command centres and forward observers, maintaining secure communication against cyber threats.

Autonomous Logistics and Ammunition Management: Modern artillery logistics is undergoing a transformation through the integration of automatic resupply systems and robotic arms. These intelligent solutions dramatically improve ammunition handling efficiency and battlefield responsiveness. Systems such as South Korea's K10 ARV, the US M99A2 and Turkey's POYRAZ showcase advances in automated ammunition transfer, inventory tracking and "tail-to-tail" resupply operations. Concurrently, artillery platforms like the Archer and PzH2000 leverage self-loading technologies—featuring electric drives, robotic arms and adaptive control systems—to enable fast, autonomous reloading. These developments reduce crew workload, minimise exposure and enhance sustained fire capabilities, positioning intelligent resupply as a cornerstone of future artillery operations.[61]

Enhanced Mobility and Survivability: Autonomous navigation and obstacle avoidance technologies enhance the mobility and survivability of self-propelled artillery systems. Autonomous capabilities enable rapid repositioning to evade enemy counter-battery fire, crucial in contested terrains, enhancing operational flexibility and survivability.[62]

Swarm Intelligence and Cooperative Operations: Swarm intelligence enables coordination among multiple autonomous artillery units. Inspired by biological systems, swarm-based artillery can execute complex missions collaboratively with minimal human oversight. This collective approach provides superior adaptability, targeting efficiency and operational resilience.[63]

Digital Coordination: Ukraine's innovative GIS Arta system has demonstrated the strategic advantage of digitally networked artillery coordination during the ongoing Ukraine–Russia conflict.[64] Utilising smartphones, tablets and drones, the system enables rapid targeting and engagement through shared geospatial networks. Front-line observers can quickly upload targets into the system, which then assigns artillery units for immediate action, greatly reducing target acquisition and engagement time. This method significantly enhances operational efficiency and effectiveness, as seen notably during critical battles such as the Siverskyi Donets river crossing, proving a robust model for digitally integrated artillery operations.[65]

Conclusion

The integration of autonomous, AI-driven and quantum-enabled systems marks a transformative era in mobile artillery. These technological advancements significantly enhance battlefield precision, adaptability, security and operational tempo, positioning artillery as an essential, highly efficient and resilient component of modern and future warfare.

Future of Artillery Firepower

Smart Munitions: Precision Firepower for the Digital Battlefield

Smart munitions in artillery have revolutionised the accuracy, efficiency and operational flexibility of fire support on the modern battlefield. Unlike traditional unguided shells, these precision-guided munitions—such as the US M982 Excalibur, Russia's Krasnopol, or China's GP1—are equipped with GPS, laser or inertial navigation systems, enabling pinpoint targeting with minimal collateral damage. They significantly reduce the number of rounds required to neutralise a target, thus conserving logistics and enhancing mobility. Smart artillery shells are particularly valuable in urban, mountainous and asymmetric warfare, where precision is critical. Some variants can even adjust their trajectory mid-flight or switch detonation modes (airburst, impact or delay) depending on the battlefield scenario. As militaries worldwide adopt digital fire control systems and real-time targeting data from drones or forward observers, smart munitions are becoming central to the doctrine of networked, responsive and scalable artillery operations.

Precision Guidance Kits for Semi-Smart Ammunition: The development of kits to convert traditional, unguided artillery shells into semi-smart ammunition represents a cost-effective approach to enhancing artillery precision. Kits such as the M1156 Precision Guidance Kit (PGK) employ GPS guidance and aerodynamic control surfaces to significantly reduce circular error probability (CEP). These kits enable conventional artillery rounds to achieve near-precision-strike capabilities without the expense of fully smart munitions, greatly enhancing effectiveness in various operational scenarios.[66]

Ammunition innovation is central to the transformation of SPA capabilities. The evolution from unguided "dumb" shells to precision-enabled projectiles has significantly impacted logistics, mobility and combat effectiveness.

Smart and semi-smart ammunition reduces the number of rounds needed for target neutralisation, thereby decreasing logistical burdens and resupply frequency.

- Enhanced precision lowers the risk of collateral damage and ensures safer use in complex urban terrains.
- Integration with autonomous and AI-driven fire control systems allows real-time adjustments to flight paths and target coordinates.
- Reduced backblast and tighter impact zones allow for coordinated operations even in densely populated or congested environments.

Experimental Munitions: Pushing the Boundaries of Firepower

While precision kits and semi-smart shells have redefined accuracy and affordability, experimental munitions are ushering in a new era of capabilities for mobile artillery. Electromagnetic projectiles (railguns) and directed-energy payloads promise hypersonic velocities, rapid engagement and low collateral damage—ideal for high-value, time-sensitive targets. Within this broader experimental landscape, ramjet-assisted artillery shells, co-developed and tested in late 2025 by the Indian Army and the Indian Institute of Technology Madras, represent a more evolutionary rather than disruptive line of development. By exploring air-breathing propulsion within conventional gun-launched projectiles, these ramjet concepts aim to address range, velocity retention, and time-of-flight limitations of existing extended-range munitions without altering the underlying artillery platform or force structure.[67] Sensor-fused and AI-enabled rounds are being developed to autonomously scan, track and engage multiple moving targets, with in-flight decision-making and post-impact loitering. Programmable, multi-effect warheads offer selectable detonation modes (airburst, delay, impact), enhancing adaptability in urban and hybrid warfare. Non-kinetic artillery payloads—electronic warfare and cyber rounds—are in testing to disrupt enemy communications and radar without physical destruction, extending artillery's role into the information domain. Meanwhile, green munitions with reduced-smoke propellants and composite casings address stealth and environmental concerns. Collectively, these advances signal a future where artillery delivers not just explosive force but also precision, disruption and domain-spanning lethality.[68]

Hybrid and Electric Propulsion: Redefining Mobility

Traditional SPA platforms rely on diesel engines, which, while effective, create logistical burdens in prolonged engagements. Future artillery units are transitioning towards hybrid and electric propulsion, significantly improving operational efficiency, reducing fuel dependency and enhancing battlefield stealth.[69]

- **Hybrid Propulsion**: Combines diesel and electric power, reducing fuel consumption and extending the operational range of SPA units.
- **Silent Operations**: Electric-powered SPAs significantly reduce acoustic and thermal signatures, making them harder to detect in combat zones.
- **Sustainability and Maintenance**: Modern SPA platforms require fewer maintenance checks, lowering downtime and ensuring prolonged operational readiness.

As battery technology advances, fully electric SPAs may become a viable reality, offering long-range, high-endurance firepower with minimal logistical challenges.

Networked Warfare and Electronic Countermeasures

In modern conflicts, SPA platforms are no longer isolated battlefield assets—they are part of a fully integrated, multi-domain network where real-time intelligence and electronic warfare capabilities define success.[70]

- **Integration with Drones and UAVs**: Artillery units now coordinate strikes with UAVs, which act as forward observers, identifying and marking targets before shells are fired.
- **Cyber and Electronic Warfare (EW)**: With increased reliance on digital connectivity, SPA units must counter cyber threats and

electronic jamming, ensuring continuous communication and battlefield coordination.

- **Data-Driven Fire Control**: Cloud-based targeting systems will analyse real-time battlefield data, optimising SPA fire missions on the fly.

The ability to connect SPAs to a battlefield network ensures faster, more accurate fire missions, improving combat effectiveness while minimising risks.[71]

Strategic Role of SPAs in Future Warfare

Despite the rise of missile systems, drones and AI-driven warfare, self-propelled artillery remains irreplaceable due to its long-range, cost-efficient and sustained firepower.[72] The strategic advantages of SPA include:

- **Long-Range Fire Support**: Artillery provides sustained firepower over prolonged periods, making it ideal for holding and securing key positions.[73]
- **Cost-Effectiveness**: Compared to missile strikes, artillery remains cheaper and more sustainable, making it a preferred choice in prolonged conflicts.
- **Urban Warfare Readiness**: Unlike airstrikes, which risk excessive collateral damage, SPAs can deliver pinpoint accuracy, making them essential in urban and counterinsurgency warfare.[74]
- **Nuclear and Strategic Deterrence**: Some SPA systems retain nuclear-strike capability, ensuring their role in strategic deterrence and power projection.

The next generation of self-propelled artillery will be more intelligent, mobile and resilient than ever before. By incorporating AI-driven automation, precision munitions, hybrid-electric propulsion and advanced cyber defences, future SPAs will remain a dominant force on the modern battlefield.[75]

The Russia–Ukraine War and Azerbaijan–Armenia conflict have reinforced the strategic importance of highly mobile, precision-strike artillery, demonstrating that SPA platforms will continue to play a pivotal role in high-intensity, networked warfare. As global militaries continue to refine next-generation artillery platforms, SPAs will evolve into autonomous, AI-integrated and fully networked battlefield assets, ensuring their indispensable role in future wars.

Co-existence, Not Competition: The Complementary Evolution of Artillery Systems

While self-propelled artillery (SPA) has gained prominence for its mobility, automation and digital integration, it has not replaced towed artillery, ultra-light howitzers (ULHs), or emerging mounted gun systems (MGS). Instead, global artillery doctrines reflect a complementary evolution of all systems—SPA (typically 155mm), towed guns (including ULHs), rocket artillery (MLRS), and MGS (usually lighter 105–130mm calibres). Each system fills distinct operational needs shaped by terrain, logistics, threat levels and cost-efficiency, as is shown in Table 3.

Table 3 Artillery Systems

System type	Primary purpose	Typical use case
Towed artillery	Cost-effective, large-volume indirect fire support	Static defence, prepared firebases, infantry support
Ultra-light howitzers	Rapid deployment, high – mobility in inaccessible terrain	Mountain warfare, airborne or heli-lifted operations
Mounted gun systems	Mobile firepower with high road/terrain mobility, modular upgrades	Border skirmishes, low-to-medium intensity combat, wheeled logistics
Self-propelled artillery (SPA)	High-survivability, rapid fire-and-move with digital fire control	Mechanised warfare, shoot-and-scoot in open and contested terrain
Rocket artillery (MLRS)	Saturation and/or precision long-range strikes with fast response	Area denial, counter-battery fire, deep strike in mobile operations

Major militaries maintain deliberate mixes. The US leans on tracked SPHs (M109A7) for mechanised warfare, ULHs (M777) for rapid airlift into mountainous or expeditionary zones, and HIMARS for long-range precision strikes. Russia emphasises layered fires and mass effect, using a balanced mix of towed (e.g., Msta-B), tracked (2S19), wheeled SPAs (2S43 Malva), and powerful MLRS (Smerch, Tornado-S) for operational depth. China blends towed artillery for economy, tracked SP (PLZ-05) for high-intensity thrusts, wheeled SP (PLZ-07B) for high-altitude roads, and versatile MLRS (PHL-03, PHL-16) across strategic zones. NATO doctrines, emphasising mobility and interoperability, prefer SP and wheeled platforms (e.g., PzH 2000, CAESAR), with towed artillery retained in reserves or mountain units. India aligns artillery mix with geography: towed guns (ATAGS, Dhanush) dominate in plains/semi-mountainous zones; tracked SP (K9 Vajra) serve in deserts and plateaus; ULHs (M777) in high-altitude sectors; and 105mm MGS for rapid deployment across difficult terrain and varying intensity of conflict. MLRS (Pinaka) supports high-volume firepower.

This evolution reflects convergence. Towed guns now feature APU for limited mobility; ULHs bridge lightness and lethality in inaccessible zones; MGS provide cost-effective, road-mobile firepower; and MLRS with guided munitions encroach upon ballistic missile roles. Rather than competing, these systems complement each other: towed artillery offers scalable support for infantry and static defences; ULHs enable fast, high-altitude insertions; MGS fill flexible, fast-response roles; and SPAs remain vital for mechanised, shoot-and-scoot fire missions.

In modern doctrine, no single system suffices across all terrains and threats. The result is a modular, terrain—and threat-adaptive force mix—one where artillery evolution is integrative, not linear, and thrives on flexibility and interoperability.

Conclusion

The evolution of mobile artillery—spanning from ancient siege engines and camel-mounted guns to today's networked, AI-driven self-propelled systems—has been a story of continuous adaptation to the changing face of warfare. Technological leaps, doctrinal shifts and evolving battlefield demands have transformed artillery from a static, support arm into a precision, survivable and digitally integrated force multiplier. From the Cold War's focus on massed fires and nuclear-capable SPAs to the post-1991 embrace of precision, mobility and network-centric operations, artillery systems now reflect a convergence of traditional firepower with cutting-edge technologies such as smart munitions, quantum-enhanced guidance, autonomous fire control and hybrid-electric mobility.

Rather than one system replacing another, global militaries have adopted a complementary mix of towed artillery, ultra-light howitzers, mounted gun systems, self-propelled howitzers, and rocket artillery. This mix is carefully aligned with terrain, threat intensity, logistical feasibility and doctrinal preferences. For instance, India tailors its artillery assets across plains, deserts and mountains; NATO emphasises modularity and digital integration;

Russia maintains depth through volume and layered fires; while the US leads in precision and C4ISR-driven engagements.

The ongoing integration of swarm intelligence, EW payloads and real-time digital coordination—as seen in Ukraine's GIS Arta system or Azerbaijan's drone-guided artillery strikes—marks a shift towards artillery as a central node in multi-domain warfare. As experimental munitions, AI-assisted targeting and autonomous logistics redefine the possibilities, artillery is no longer just a tool of destruction but a versatile instrument of control, denial and precision across the modern battlefield. In the wars of tomorrow, artillery's relevance will not diminish; instead, it will evolve—smarter, faster, and more connected than ever before.

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