Defense and Security

FIRE FOR EFFECT
INTO THE FUTURE OF LAND ARTILLERY

May 2025

CeSI | CENTRO STUDI INTERNAZIONALI

FIRE FOR EFFECT

INTO THE FUTURE OF LAND ARTILLERY

May 2025

Focus report by:

Emmanuele Panero – Head of the Defense & Security Desk
Daniele Ferraguti – Junior Fellow of the Defense & Security Desk
Francesco Bellato – Intern of the Defense & Security Desk

CONTENTS

Introduction

The dominant thunder of artillery fire and the concussion of terrain under the relentless fall of shots have dominated the battlefields, at least since the 19th century. Indeed, the capability to generate effects through the depth of the opponent's device and the saturation of destruction caused in the deployment of enemy forces constitute the defining elements that have led the Artillery Weapon to be nicknamed, in Armies around the world, the "*God of* War." A highly technological component, profoundly transformed from conflict to conflict, significantly increasing precision, intervention arm and timeliness of fire action, diversifying its possible effects on the target and consolidating its fundamental tactical and operational role.

The re-emergence of high-intensity conventional warfighting as a more than possible extreme within the spectrum of increasingly fierce cross strategic competition and prone to triggering recurring conflict dynamics in both *peer* and *near-peer competitors* as against asymmetric adversaries with increasingly advanced capabilities, has reaffirmed, should the need arise, the enduring centrality of artillery in contemporary military operations. A deployment of indirect fire that nevertheless addresses a battlespace marked by multi-domain hybridization, transparency, speed and lethality that is substantially unprecedented. Indeed, air superiority, and even more so supremacy, constitutes an incrementally difficult objective to achieve, at most for limited times and in circumscribed sectors, promoting an increasingly pronounced contribution of land-based sources of fire to both rear interdiction and frontline support. An action of disarticulation and degradation of the adversary extended increasingly in the depth of the enemy military device and necessary in all phases of combat, as well as aimed at an increasingly broader selection of targets, including with reference to the same air and integrated air defence capabilities of the opposing deployment. Fire missions to be conducted in an electromagnetic environment systematically contested, or denied, by the adversary and under the unrelenting threat of being detected and neutralized by a pervasive network of integrated, manned and unmanned sensors and effectors capable of generating counter-fire

solutions with hitherto unknown rapidity. A battlefield in which to manoeuvre in the near absence of safe zones and in which device dispersion, tactical mobility and multispectral masking represent indispensable principles not only for the survivability of forces, but also for all adherence logistics, decisive for preserving their combat potential over time. An operational scenario in which, however, the unpredictable and sudden massing of fire will continue to be a key assumption for exploiting adversary vulnerabilities and generating ruptures in the opposing deployment, enabling the manoeuvre and penetration of allied forces.

A future for land-based artillery, then, marked by a challenging doctrinal and capacitive coexistence between long-range precision targeting against time-critical targets (*time sensitive targets*) and concentration of fires for areal effects (*weight of fires*), closely interrelated and dependent on the one hand on the technical development of new platforms and on the other on the integration of these into a modern and adaptive *Tactical Reconnaissance Fire Complex* (TRSFC). An evolutionary effort by no means limited to the mud of training ranges but inexorably extended to the assembly lines of a broader military-industrial complex, whose production potential is crucial to sustaining the consumption of ammunition and the wear and tear of artillery systems peculiar to a clash of attrition that cannot be ruled out from the outset. In fact, the deterrence of the whole military instrument and each of its components, including land artillery, is a function not only of the overwhelming operational effectiveness of individual pieces and batteries, but of the depth of the national arsenals and their capacity for regeneration.

Starting from a comparative analysis of the doctrinal, organizational and capacitive paradigms that inform the artilleries of contemporary Armies, this *Focus Report* delves into the lessons identified and learned of the segment originating from the most relevant theatres of war of the last five years and the projections of employment in potential conflict scenarios in the near future, in order to define the most significant trends in operational requirements for indirect fire capabilities. The same then carefully details the evolving specifics of the technical requirements peculiar to the tube and missile components, with

reference to both weapon systems and munitions, before outlining an industrial mapping of the international sector market. Indeed, the contribution to deterrence ensured by land artillery depends on its ability to dominate the metamorphosis of combat, continuing to project its unstoppable thunder, if necessary, on the adversary.

I Evolution in artillery manoeuvring: between fire support and deep fires

Theatres of conflict over the past five years have highlighted the centrality of artillery use, which is in a transitional phase between the re-emergence of the operational centrality of its traditional tasks and adaptation concerning flexibility of employment in different combat scenarios. During the Second Nagorno-Karabakh War of 2020, the employment of land artillery in this perspective represented an emblematic case regarding doctrinal transformation, including increasing integration into multi-domain *Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance* (C4ISR) systems. Indeed, the Azerbaijani Armed Forces conducted operations characterized by the fusion of distributed sensors on *unmanned* air and ground assets, conjoined with *electronic warfare* (EW) equipment and long-range indirect fire assets. This has been made possible by the reduction of the targeting cycle enabled by *Medium Altitude Long Endurance* (MALE) drones such as the Turkish *Bayraktar TB2s* and by loitering munitions such as Israeli-made *Harops*. The disruption of Armenian air defences was conducted by reducing the *sensor-to-shooter loop* to minimal times, ensuring the destruction of adversary systems, infrastructure and *Command and Control* (C2) centres. The innovative element, which marked a discontinuity with the traditional Soviet-derived approach, was the reorientation of the Azerbaijani military apparatus toward a deployment hinged on mobility and rapid fire capability, which favoured the decentralization of artillery units. The use of *Precision Guided Munition* (PGM) and the consequent use of precision fire has also replaced saturation fire in this context. This reshaping was supported by increased and efficient capillarity in target engagement, also reducing collateral damage during targeting. In comparison with what had been learned from previous conflicts, which were characterized by a substantial separation of sensors and effectors, as well as a prevalence of unguided indirect fire, the Second Nagorno-Karabakh War recorded a deployment of ground artillery that was seamlessly integrated into an interconnected combat system, capable of generating effects across enemy lines through deep fires, rather than producing an increased rate of attrition near the *Line of Contact* (LOC).

The Russian Ukrainian conflict then immediately underscored the renewed centrality of indirect fire with the pivotal role played using areal saturation effects of fire from two Ukrainian artillery brigades in the successful halt of the Russian advance in Kiev. The importance of volume and concentration of fire was then combined in the specific theatre with a rapid evolution of *Tactics, Techniques and Procedures* (TTPs) and employment patterns, with a convergence between traditional maneuverer doctrine and elements of technological innovation, with reference to the new tactics observed in the Armenia-Azerbaijan conflict.

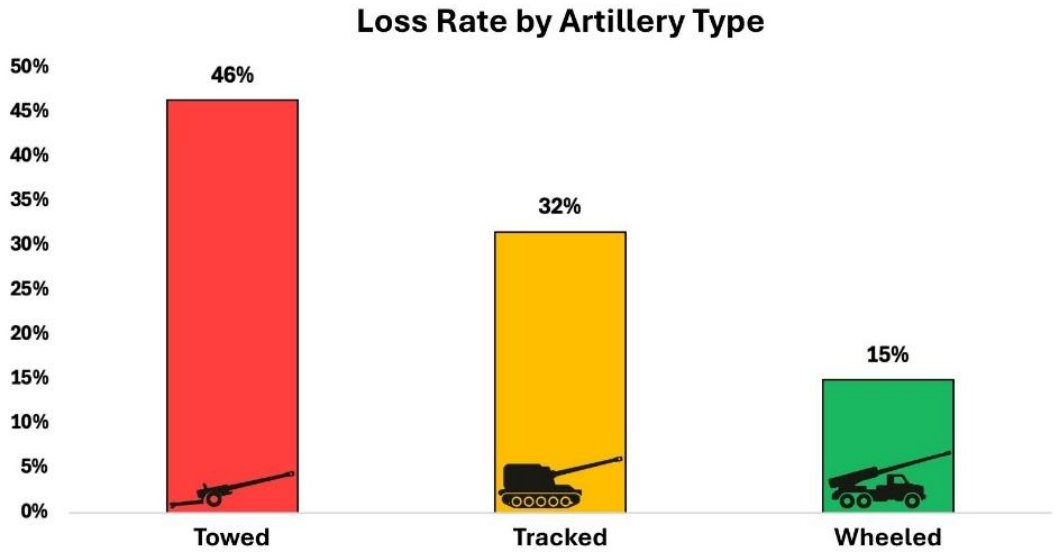

Fig.1 : The graph shows the loss rate by type of artillery delivered to Ukraine, calculated as the percentage ratio of systems lost to total systems delivered or estimated as produced. The three categories considered are towed artillery (M777A2, L118/119), rotating self-propelled artillery (CAESAR, 2S22 *Bohdana*) and tracked self-propelled artillery (AHS *Krab*, AS-90).

The data have some limitations due to the nature of the analysis, which is based only on open sources. The losses considered refer only to artillery systems visually confirmed through photographic material, implying how the actual number of losses could be higher. Similarly, estimates of systems delivered or produced are based on publicly available information, which may not accurately reflect the totality of assets delivered.

Indeed, the Armed Forces of the Russian Federation, in a first phase, deployed artillery assets by assigning to each *Battalion Tactical Group* (BTG) two batteries of towed or self-propelled systems and one of rocket launchers, pursuing a doctrinal approach focused on saturation fire in

support of organic units. However, the high dispersion of forces, increasing exposure to counterbattery fire, and the degradation of the logistic support chain forced the reshaping of this tactic. The artillery gradually tended toward a mobile riser, coupled with a retreat of about 15 kilometers. While this dispersion has reduced vulnerability to countermeasures taken by the Ukrainian Armed Forces, it has also increased the need to concentrate fire, imposing a significant dependence on the accuracy and speed of targeting data acquisition and transmission.

The massive use of *Unmanned Aerial Vehicle* (*UAV*) systems for target engagement, as well as the use of *loitering munitions* and *Fist Person Vision* (FPV) drones, have had significant impacts in the conduct of operations due to increased sources of fire and from the compression of kill chains. The combined effect of UAVs and artillery has led to the adoption of *shock-fire tactics*, while the use of guided munitions and scatter mines has increased the ability to interdict and channel adversary movements on the ground. The rationing of conventional ammunition then prompted a return to the use of 120mm mortars, which are more flexible and sustainable than conventional 152mm howitzers. Both deployments also extensively integrated EW systems aimed at disrupting communications, which resulted in degraded targeting and target coordination cycles, while active battery protection was reinforced through thermal *camouflage* techniques and frequent repositioning.

The Kiev Armed Forces have relied heavily on the integration of conventional artillery, long-range strike systems provided by Euro-Atlantic Countries, and a wide range of commercial and military UAVs for reconnaissance and fire correction. The adoption of a digitized and decentralized kill web, based on a dispersion of fire mouths across the battlefield, and the use of open source targeting software have made it possible to drastically reduce reaction times and increase the accuracy of engagements, despite the numerical disparity with Russian artillery units. From a technical-operational perspective, the conflict brought back to the forefront the so-called *gunnery problem*, or the need to acquire meteorological data, to constantly calibrate systems and ammunition, to quickly correct target coordinates through *Forward*

Observers (FOs) and UAVs, as well as to integrate a growing amount of information within C2 systems to maximize the effectiveness of attacks also according to an *any sensor to best shooter* logic.

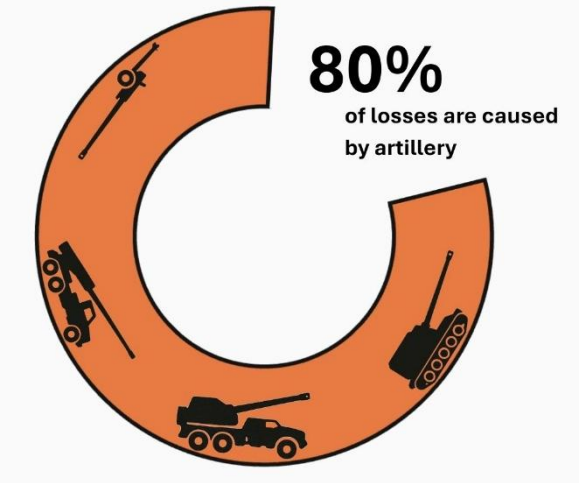

Fig.2 : Percentage of losses caused by artillery fire during the Russian Ukrainian conflict.

Another relevant window of observation regarding the different ways in which ground artillery is employed is what happened during the Israeli military campaign in the Gaza Strip and Southern Lebanon. In fact, the doctrine applied by the *Israeli Defense Forces* (IDF), matured through decades of confrontation with hybrid actors such as Hamas and Hezbollah, has progressively integrated artillery into a multilevel C4ISR system, in which speed of acquisition, precision of effects and interagency coordination are decisive factors in generating decisive effects, especially in urban settings with high population density and critical infrastructure. Historical comparisons with other urban scenarios, such as Fallujah and Mosul, have also placed particular emphasis on limiting collateral damage during attacks conducted on sensitive targets. Indeed, Israeli artillery, consisting mainly of M109 *Doher* self-propelled howitzers and M270 *Menatetz* missile launcher systems, has been deployed both for the systematic suppression of adversary fire capabilities and for the destruction of strategic infrastructures, logistics depots and C2 centres. It has consequently often implemented a so-called *fire complex* doctrine, which involves the coordinated use of artillery, air fire and special forces to rapidly saturate rocket launching areas and tunnels, with a strong emphasis on minimizing collateral damage using guided munitions, controlled effect strikes and detailed planning of fire missions. The adoption of low-lethality rounds, programmable fragmentation munitions, and the selective use of special munitions (such as white phosphorus for

creating smoke screens or reclaiming fortified areas) have become essential operational tools to meet the requirements of precision and compliance with rules of engagement in complex urban settings. Within this framework, we highlight the heavy use of tube artillery by the IDF, which employed about 10,000 shells in the first 45 days of operations. The use of artillery and precision-guided munitions enabled them to effectively neutralize Hamas infrastructure and disrupt enemy concentrations before the infantry advance. A further example of selective and accurate use of artillery in the context of *Military* Operations *in Urban Terrain* (MOUT) operations is the Battle of Mosul between 2016 and 2017, where artillery from the *Inherent Resolve* coalition and the Iraqi Armed Forces was deployed in an intensive but targeted manner in coordination with precision airstrikes and *Intelligence, Surveillance and Reconnaissance* (ISR) assets, succeeding in providing continuous fire support, even under conditions of *Troops In Contact* (TIC) units in compartmental spaces, limiting collateral effects.

On the opposite front, and in a hybrid-asymmetric perspective, Hamas and Hezbollah have adopted an artillery deployment that is also highly adaptive, based on the dispersion, mobility and resilience of launch platforms. These, often improvised or mounted on civilian vehicles, have been concealed and camouflaged in residential areas, schools, hospitals, and mosques, taking advantage of the cover offered by the urban fabric and the network of underground tunnels to reduce vulnerability to ISR sensors and counter-battery fires. The *shoot-and-scoot* mode, in this context, found a particularly emblematic catalysation in which launch systems were rapidly activated from civilian buildings or densely populated areas and immediately redeployed through the underground network, reducing the window of vulnerability to IDF response fires. Hezbollah, in particular, further shaped these TTPs by building protected, bunkered firing positions connected by tunnels, supplementing artillery fire with advanced *Anti-Tank Guided Missile*

(ATGM) attacks, such as *Kornet-EMs*, and armed UAVs, increasing <lethality against armoured vehicles and fortified positions

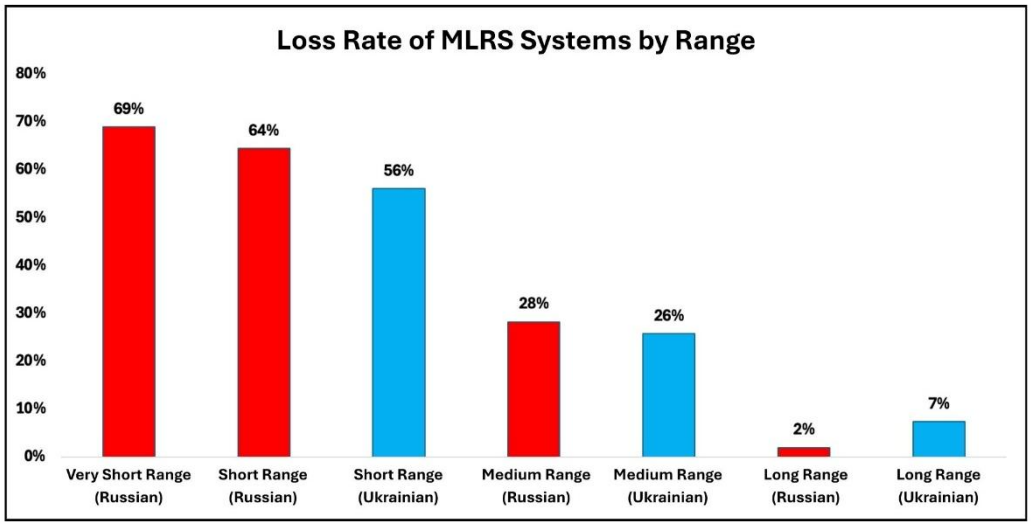

Fig.3 : The graph shows the loss rate of Russian and Ukrainian multiple rocket launcher systems (MLRS) by range category: very short, short, medium, and long. The loss rate was calculated as the ratio of the total number of systems lost to the number of known systems in service for each category. For the Russian Federation, the very short range category includes the *TOS-1A* system. Short range includes the 122mm 9P138 *Grad-1*, 9P139, BM-21 *Grad*, and 2B26 *Grad-K* systems. The medium-range category includes the 2B17 *Tornado-G* and the BM-27 *Uragan*. The long range includes the BM-30 *Smerch* system. For Ukraine, the short-range category includes the BM-21 *Grad*, the 9P138 *Grad-1* and the APR-40. Medium range includes the BM-27 *Uragan*. The long range includes HIMARS and M270 in all their national variants.

The data have some limitations due to the nature of the analysis, which is based solely on open sources. The losses considered refer only to artillery systems visually confirmed through photographic material, implying that the actual number of losses may be higher. Similarly, estimates of systems delivered or in inventory at the beginning of the conflict are based on publicly available information, which may not accurately reflect the totality of assets present.

The prospect of increased *peer* and *near-peer competitor* capabilities and the prospect of high-intensity conventional conflict, especially in the Indo-Pacific theatre are then driving a specific doctrinal evolution, pertaining to the artillery segment, by the U.S. Armed Forces. In relation to this, the *United* States *Marine Corps* (USMC) is in a phase of restructuring its indirect fire component under the *Force Design 2030* initiative. In fact, the USMC plans to reduce the number of tube artillery batteries from 21 to 5 and increase the number of rocket batteries from

7 to 21, tripling the capacity of those batteries compared to the current ones.

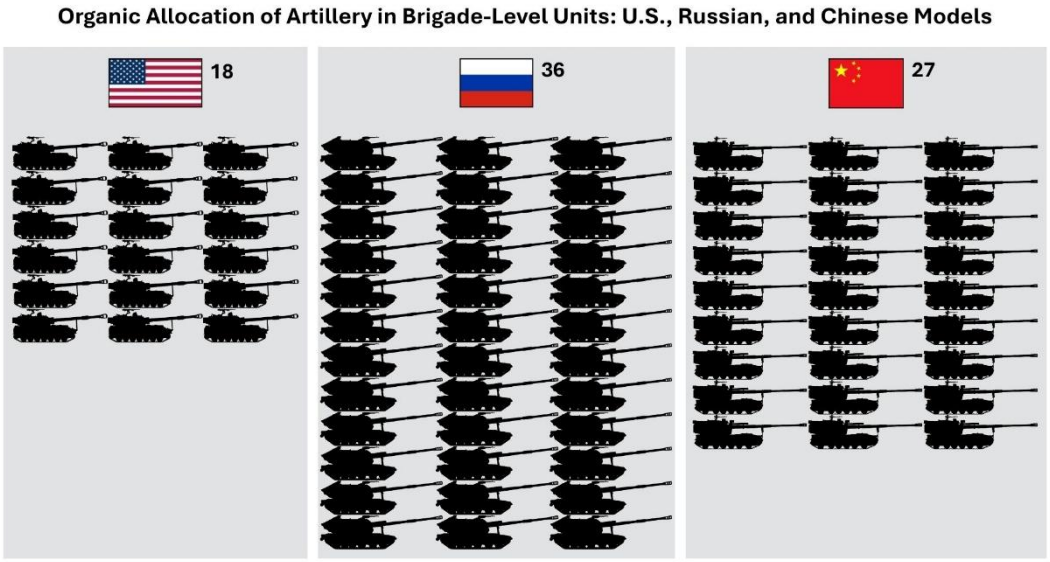

Fig.4 : This infographic reflects an average compared to common tabular organic allocations, which are, however, subject to variations in units and over time, as well as changes in the case of

This goal is in the context of supporting *Expeditionary Advanced Base Operations* (EABO) and *Littoral Operations in Contested Environment* (LOCE), which are particularly focused on mobility, dispersion and deep fires. The emerging concept of *Long Range Precision Fires* (LRPF) also involves the integration of the land and sea domains, in a broader scenario of redefining the role of land artillery according to its capabilities to generate effects in littoral and maritime environments through the development of guided munitions with anti-ship capabilities as well, in combination with distributed sensors and interoperable C2 networks. In line with this, the *Multi-Domain Task Force* (MDTF) concept, developed by the US Army, significantly expands the role of land-based fire capabilities, particularly in terms of range. Indeed, each MDTF pivots its combat potential (*combat power*) around a *Strategic Fires Battallion* composed of three batteries, equipped with M142 *High Mobility Artillery Rocket System* (HIMARS), respectively, potentially armed with short-range ballistic missiles *Precision Strike Missile* (PrSM), with *Strategic Mid-range Fires System* (SMRF*) Typhon*, capable of launching *Standard SM-6* and *Tomahawk* missiles, and the last one in the future structured to employ *Long-Range Hypersonic Weapon*

(LRHW). These evolutions are part of a broader framework that aims to ensure the planning and conduct of *Joint All-Domain Operations* (JADO), the execution of synergistic operations in different domains and operational environments, through which *Distributed Lethality* (DL) finds application. The dispersion of forces and the ability to generate long-distance kinetic effects then become key tools in order to deny the adversary the ability to freely concentrate and maneuverer its forces

The convergence between the return of experience from recent conflicts and the projection of the role of artillery in any potential operational scenario on any battlefield outlines a profound metamorphosis of indirect fire. This is not limited to doctrinal and organizational evolution alone, but rather determines new capacitive requirements, implying technical and technological upgrades for related existing and developing platforms.

II The future of tube artillery

Looking ahead, *lessons learned* from recent conflicts and the evolution of land artillery employment doctrines highlight the increasing centrality of *Self-Propelled Howitzer* (SPH) platforms in high-intensity combat with *peer* and *near-peer competitors*. Indeed, the main criticality of towed artillery lies in its vulnerability to new threats related to the increased transparency and speed that characterize the battlefield, with reference to counterbattery fire and the proliferation of UAVs and loitering munitions. A prerequisite for the effective use of towed systems is the need for clear air superiority combined with extensive control of the electromagnetic environment, without which the immobility of towed pieces poses a significantly higher risk of detection and neutralization. The ongoing conflict in Ukraine has underscored the exposure of towed artillery despite frequent and rapid repositioning due to multispectral detectability at every stage of static dwell. In contrast, modern self-propelled platforms, employing *shoot-and-scoot* tactics, generally succeed in evading counterbattery fire due to their ability to move immediately upon engagement, with a mobility on the ground that is difficult to replicate by towed systems. Despite these operational limitations, towed howitzers nevertheless remain widely in service globally, by virtue of their easier transportability through fixed and rotary wing set-ups, lower logistical requirements, and reduced costs compared to their self-propelled counterparts.

Net of this, several Euro-Atlantic Armed Forces have reduced, or phased out, the use of towed artillery, reflecting a doctrinal and organizational evolution. As an example, the *Armée de Terre* officially retired its 155mm TRF1s in 2022, ending their use by operational units. *The Bundeswehr*, which previously had 150 FH155-1 towed howitzers, similarly ended their use in 2002 with the conversion of the last unit to employ them, the 225th Mountain Artillery Battalion, into a unit equipped with self-propelled tracked artillery. In Canada, 33 towed M777s are still in service with several departments, but they are slated for replacement under the *Indirect Fires Modernization* program, which calls for the acquisition of about one hundred self-propelled systems. The British Army continues to employ the L118 *Light Gun*, with plans to keep it in service until at least 2030, although it has initiated a search for a self-propelled

successor. These developments highlight a broader trend within NATO toward the gradual decrease of towed artillery in favour of systems that are more adaptable to the battlefield requirements of the future, such as rapid deployment, survivability, and multi-domain integration of assets.

Nevertheless, the Ukrainian case illustrates functional tactical applications of towed artillery when favourable conditions exist. The Ukrainian Armed Forces have effectively employed 155mm M777 and FH70 howitzers, as well as older generation 152mm and 122mm systems dating back to Soviet times, more intensively when the counterpart's rate of fire was more diluted or in phases when conditions existed to provide greater protection for assets.

Fig.5 : A composition of towed tube artillery systems currently in service.

As evidence of the persistence of employment space for towed howitzers, Ukraine is in the development phase of a new 155mm version based on the artillery group of the 2S22 *Bohdana* self-propelled system, centred on a Soviet-era towed shaft, with candidate platforms including the *Msta-B*, *Giatsint-B*, and D-20. Development is also supported by increased domestic production of 155mm artillery barrels, with *output* currently estimated at more than ten systems monthly. Newer towed systems also aim to improve mobility and deployment and re-deployment times. In fact, the M777, made of titanium, is designed to be lightweight and able to be positioned or withdrawn extremely quickly, while its digitized fire control system and compatibility with GPS-guided projectiles, such as the *Excalibur*, make it considerably more accurate than conventional towed howitzers. The same line is followed by the Chinese-made 155mm AH4 system, which can also be easily risked by means of fixed and rotary wing set-ups. A different trend, however, is represented by India's 155mm *Advanced Towed Artillery Gun System* (ATAGS), which, while reporting a significant weight, (12 tons versus 4.2 and 4.5 tons for the M777 and AH4, respectively) has been engineered for rapid deployment once in position thanks to an automated hydraulic blade and a motorized elevation and pivoting system.

More specifically, in addition to a pronounced shift toward self-propelled systems, there is a specific trend in favour of rotated artillery platforms, such as the *Truck Équipé d'un Système d'Artillerie* (CAESAR), the *Archer*, the *Autonomous Truck Mounted Howitzer System* (ATMOS), the *Zuzana*, and the RCH 155. Indeed, these offer significant advantages in terms of strategic mobility, including the ability to rapidly project over long distances along arterial roads without the use of specialized transporters, simplified maintenance, and high airlift, while also being suitable for deployment in the context of *expeditionary* or *counter-insurgency* (COIN) operations. Such systems are also on average 30 to 40 percent less expensive than their tracked counterparts, with a generally longer operational life cycle. This underlies a predilection for wheeled self-propelled vehicles, in the modernization processes of their respective artillery components, by many European Armed Forces, particularly those lacking an established tradition of employing heavy

armoured units. On the other hand, the vastness and environmental heterogeneity of possible theatres of operation, prevent the crystallization of an overwhelming trend. As demonstrated in the context of the war in Ukraine, tracked platforms remain dominant within large armoured units and in spaces subject to more complex maneuverer activities, as occurs in swamps, muddy or snowy terrain, where tactical mobility becomes central. These types of conditions have indeed penalized wheeled systems such as the CAESAR, but without limiting the operability of tracked platforms such as the *Panzerhaubitze 2000* (PzH 2000) or the AHS *Krab*. Thus, a future balance of assets is likely, in which advanced tracked artillery will be maintained at the division level for direct frontline engagement, while highly mobile wheeled systems will be employed at the brigade level.

Fig.6 : A composition of self-propelled tube artillery systems in service.

This gap, however, shows room for reduction by means of hybridized systems such as the *Boxer-based* RCH 155, which improves mobility in hostile environments and self-protection, while some tracked platforms are designed based on lighter tonnage to increase their projectability.

Within this framework, lessons identified underscore a dependence of firepower on strategic mobility, in which lightweight systems capable of providing tactical and logistical resilience are expected to provide greater survivability. Recent industry macro-trends confirm this predilection, especially for Armed Forces with a Euro-Atlantic military maneuverer approach. In the past two decades, some 30 rotated SPH designs have been submitted, nearly 50 if the Russian Federation and People's Republic of China initiatives are included, compared with fewer than five new *designs* intended for tracked platforms. Although several prototypes are likely to remain as such or not saturate the industry market, advanced systems such as BAE Systems' *Archer*, KNDS' CAESAR *Mk2* or Elbit's *Roem/Sigma* highlight a definite market direction. A trend that has also found a foothold in South Korea by Hanwha, which is promoting a rotated variant of its flagship tracked system, the *K9 Thunder*.

Future battlefields will be extremely lethal to any detectable attitude, making survival closely tied to the concealment capabilities of assets, from the use of jammers to decoys. While past conflicts fought in the terrestrial domain highlighted a primary threat posed by counterbattery fire, today there is a gradual marginalization of the latter over fire sources such as loitering munitions and attack drones. Such assets extend the intervention arm of units on the frontline to the different levels, stationing for several time within the operational area waiting to locate and hit the target. The techno-operational requirements of artillery systems in the future, therefore, will require a structured survivability capability that, in addition to the high mobility, will need to focus on reducing thermal and radar tracking, as well as active defence systems. It is conceivable that most future advanced SPH platforms will in fact be equipped with *Active Protection Systems* (APS), similar to those already in use on *Main Battle Tanks* (MBTs) and capable of intercepting precision guided munitions or approaching drones. Several Armies have

already initiated evaluations regarding the integration of *Counter Unmanned Aerial System* (C-UAS) in direct support of artillery units, including electromagnetic jamming *pods* and directed energy weapons to neutralize hostile drones in the terminal targeting phase.

Prefiguring then transformative scenarios, the future deployment of artillery systems will be complied according to a logic hinged on network-centric systems. Indeed, rapid target acquisition through the exploitation of a multiplicity of sensors including UAVs, radar, and satellites, complemented by *Artificial Intelligence* (AI) support, will be crucial in reducing the *targeting* cycle and margin of error in deep fire missions. In Ukraine, both sides have already demonstrated experimental or rudimentary versions of this approach, combining drone support in different domains with artillery fire, and achieving the generation of optimized kinetic effects. In this framework, the Russian Armed Forces' use of the *Strelets* system and on the Ukrainian side of the *Arta* and *Kropyva GISs*, in both cases capable of synchronizing reconnaissance assets and artillery systems, denotes a first operational implementation in warfighting contexts of the metamorphosis of the kill chain into kill web, with times between detection and engagement reduced to a few tens of seconds.

The emergence of new technologies also forces thoughts on the operational impacts, and the resulting tactical implications, that will affect the deployment of artillery platforms. In fact, these will likely be increasingly integrated *by design* with *unmanned* ISR and attack-type assets, deployed and operated directly by the SPHs themselves. AI support will also assist in analysing images captured by drones to more quickly identify camouflaged targets or possible decoys to thoughtfully direct smart munitions to high-priority targets. In this scenario, therefore, an ever increasing interdependence between the air and ground domains is emerging, with a complementary need to control and deconflict the airspace at lower altitudes to generate synergistic effects. The U.S. Army, in this direction, is in the process of developing such capabilities with several programs, including *Firestorm*, which uses

AI to automatically assign targets to the system for targeting, ensuring continuous coordination between platforms, sensors and effectors.

Fig.7 : A selection of tube-turned self-propelled artillery systems showing the main user Countries.

In terms of strictly technical requirements, then, modern wheeled or tracked self-propelled vehicles predominantly employ 155mm (NATO standard) or 152mm (Russian standard) howitzers, generally with 52-caliber barrels, capable of achieving ranges between 30 and 40 kilometres with conventional ammunition and over 50 kilometres with self-propelled special projectiles. The highest-performance platforms also integrate on board ballistic computers, flight speed sensors, and inertial navigation/GPS systems, allowing precision fire to be conducted rapidly without the need for external topographical surveys. Fully (or partially) automated loading mechanisms will be able to incrementally increase the rate of fire (usually between 6 and 12 rounds per minute), equally enabling the reduction of human operators. The South Korean K9A2 *Thunder* represents an emblematic example of the evolution of modern tracked artillery in this regard. Expected to be in service by 2027, this next-generation self-propelled gun, developed by Hanwha Defence in collaboration with the Agency for Defence Development, introduces a fully automated loading system that reduces manning from 5 to 3 units, increasing the rate of fire to 9-10 rounds per minute,

with a sustained capacity of 4-6 rounds per minute in which all 48 rounds are stored in the turret to facilitate rapid reloads. Major improvements include a new 155mm howitzer for 52-caliber rifled and chrome core, all-electric turret movement, improved mine and ballistic threat protection, remote weapon station, and automatic fire suppression systems. The combat weight of about 48.5 tons can be reduced by more than 2 tons by adopting rubber composite tracks, increasing stealth and reducing maintenance. South Korea plans to upgrade its entire K9 fleet to the A2 standard by 2034, laying the groundwork for future deployment of the K9A3 *unmanned* variant. In the United States, the M109A7 *Paladin*, developed by BAE Systems under the *Paladin Integrated Management* program, is an evolution of the previous M109A6 and adopts a hull derived from the *Bradley Fighting Vehicle*. The system mounts a 155mm M284 cannon with an automated magazine, capable of hitting targets at 22 kilometres with standard projectiles and 30 kilometres with assisted ammunition. In addition, advanced survivability measures include reinforced armour, automatic firefighting systems and *shoot-and-scoot* capabilities. Concomitantly, compatibility with precision munitions, such as *Excalibur* and the M1156 *Precision Guidance Kit* (PGK), ensures high lethality and reduced collateral damage.

As far as European artillery production is concerned, the German PzH 2000, represents one of the best performing products. The system is armed with a 155mm L52 howitzer equipped with a highly automated magazine, capable of a three round burst in nine seconds and maintaining a sustained firing rate of up to 10 rounds per minute. The vehicle carries 60 rounds on board and has *Multiple Round Simultaneous Impact* (MRSI) capability, being able to release up to five projectiles on different ballistic trajectories to converge simultaneously on the same target. Standard NATO projectiles achieve a range of 30 kilometres, extendable to a range of about 40 to 54 kilometres through specialized munitions. Experience gained in the context of operations conducted in Afghanistan and the Ukrainian theatre has confirmed the high effectiveness of the system, while at the same time highlighting critical issues related to the rate of mechanical wear and tear and the logistical requirements resulting from intensive use. The British Army has in the

past replaced its own fleet of M109s with AS-90s, while several European Armed Forces have opted for the PzH 2000. Recently, Ukraine has cautiously considered the massive acquisition of the German system, only to revise this orientation considering logistical complexity and high unit cost, exploring alternatives deemed more functional, such as the CAESAR and the RCH 155 on a rotary base. The latter represents a hybrid evolution, combining the howitzer of the PzH 2000 with the 8×8 hull of the *Boxer*. Characterized by a weight of less than 39 tons, the same is equipped with a fully automated and unmanned turret, enabling it to operate with a crew reduced to just two members.

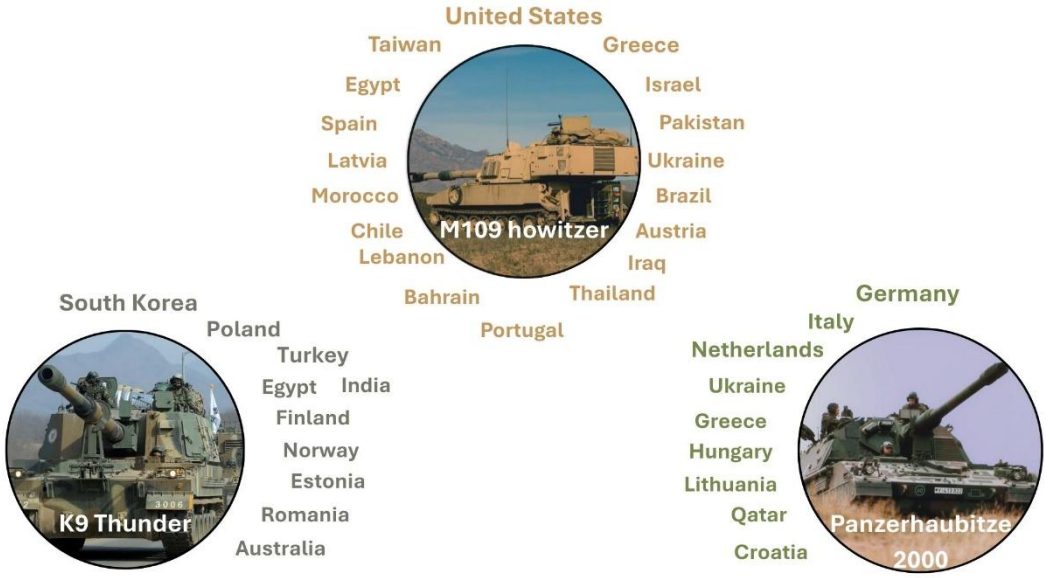

Fig.8 : A selection of self-propelled tracked tube artillery systems showing the main user Countries.

Particularly high performing among self-propelled artillery guns, the RCH 155 is capable of opening fire even on the move, drastically reducing vulnerability. Its performance in range is similar to that of the PzH 2000 with full compatibility for advanced munitions and can incorporate sophisticated stabilization and feedback force management systems. In parallel with recent developments on an international scale, the Russian Federation has also begun a process of modernizing its artillery, simultaneously developing a wheeled self-propelled, the 2S43 *Malva* and a tracked, the 2S35 *Koalitsiya-SV*. The *Malva* aims to provide greater operational flexibility and lower maintenance requirements,

which can be associated with the operational concepts expressed by CAESAR, while the *Koalitsiya-SV* adopts a heavy tracked chassis, automated turret and increased firing cadence. This dual approach highlights the continued complementarity between tracked and rotated artillery in the modern battlefield, although both undergo operational changes to improve their respective long-term survivability.

On the ammunition side, the ongoing conflict in Ukraine has highlighted how, despite advances in *Precision-Guided Munitions* (PGMs), unguided *High Explosive* (HE) rounds remain essential, according to reports of massive employment conducted by both sides. The Russian Armed Forces, to date, have fired an average of between 12,000 and 38,000 rounds daily, while their Ukrainian counterparts have averaged around 8,000 per day. Standard HE rounds, such as the 155mm M795 for the U.S. side or the 152mm OF-45 for the Russian side, have formed a large base of the artillery ammunition used, employed mainly for sustained suppressive fire and engagement of areal targets. Manufacturers have improved the performance of these conventional rounds through technologies such as *base-bleed* and *Rocket-Assisted Projectile* (RAP), which have enabled a significant increase in useful range. In parallel, the introduction of *Insensitive Munitions* (IM) improved logistical safety by reducing the risk of accidental detonations. Precision munitions, such as the GPS-guided U.S. M982 *Excalibur* and the laser-guided Russian 2K25 *Krasnopol*, have also significantly transformed the conduct of artillery operations due to their high accuracy in terms of proximity to the target. *The Excalibur*, in a first phase, enabled the Ukrainian Armed Forces to neutralize high-value targets, C2 centres and logistics nodes, with an optimized number of shots. On the opposite side, *Krasnopol*, guided by laser designators often mounted on *Orlan-10* drones, demonstrated a *Circular Error Probability* (CEP) of less than one meter within 20 kilometres of range, proving particularly effective in destroying Ukrainian armoured vehicles. At a second stage, electronic countermeasures taken by the Russian military device, degraded the effectiveness of *Excalibur* rounds, reducing the accuracy in target destruction from about 55% to approximately 6%, implying the significant increase in ammunition required per single fire mission. Contextually, sensor-based submunitions, such as the German *SMArt*

155 and the French Swedish *Bofors Nutating Shell* (BONUS), have proven extremely effective against armoured targets dispersed within a confined area. In detail, Ukrainian forces successfully employed the *SMArt 155*, destroying several Russian self-propelled units and MBTs with single hits on target areas in the range of 150 meters. Despite their higher cost, their demonstrated effectiveness in counter-battery and counter-tank fire missions makes these munitions highly relevant for use in *warfighting* contexts. Net of the currently existing models, there are significant lines of development in artillery munitions, supported by technological innovations in propulsion systems, with particular reference to *ramjet assisted* projectiles, which have the potential to achieve ranges more than 100 kilometres, marking a tactical hybridization between the boundaries of conventional and missile artillery. Such capabilities significantly expand the ability to conduct *deep fires*, enabling incremental numbers of targets conducted beyond the rear and into the adversary's depth. The U.S. Army's *Extended Range Cannon Artillery* (ERCA) program follows precisely this trajectory, with the development of advanced rounds such as the XM1113 (RAP) and XM1155 (*ramjet*), with the goal of integrating them with future 58-caliber *Paladin* howitzers.

The specific capacitive and technological evolution of tube artillery systems, within a broader doctrinal and organizational metamorphosis pertaining to the employment of indirect fire on the battlefield, outlines highly mobile platforms capable of generating effects from the front line to the adversary depth. A transformation, based on *survivability*, maintainability and logistical sustainability, that envelops towed, wheeled and tracked assets without preconceived exclusions, identifying for each of them a decisive role in organically supporting units of all levels, light, medium and heavy, imposing dilemmas on the enemy, ensuring saturation of fire and precise lethality.

III The horizon of missile artillery

Recent developments in rocket artillery have also progressively favoured wheeled, lightweight and highly mobile platforms over heavier tracked systems. Although they have long been predominant, systems such as the M270 *Multiple Launch Rocket System* (MLRS) indeed appear to be yielding prominence on the battlefield to platforms deemed more versatile and resilient such as the U.S. based M142 HIMARS, the South Korean K239 *Chunmoo*, and the Israeli *Precise & Universal Launching System* (PULS). These platforms emphasize strategic mobility, ensuring rapid deployment, simplified maintenance, and increased airlift suitability that significantly increases their projectability. A superiority that was demonstrated in the conflict in Ukraine, where HIMARS were able to operate for long periods without losses due to their high mobility and rapid deployment capability.

Likewise, the development of *unmanned Multiple Rocket Launchers* (MRLs) is growing. The push toward robotization is encompassed by the potential for reduction in overall system weight, decrease in the *unexpendable* component, and increased battlefield survivability. Exemplary of this trend is the USMC's *Remotely Operated Ground Unit for Expeditionary Fires* (*ROGUE-Fires*) project, which involves mounting two anti-ship missiles on an unmanned *Joint Light Tactical Vehicle* (JLTV), placing the emphasis on extreme simplification and the centrality of missile capability. In parallel, Hanwha has initiated some studies on an *unmanned* MRL, while the *U.S. Army* conducted a successful firing test with the *Autonomous Multi-Domain Launcher* (AMDL) system, a robotic variant of the HIMARS system. Rocket artillery appears, from a potential perspective, to be particularly integrable with positioning and launch automation, as it requires fewer hostile logistics than MBTs or *Infantry Fighting Vehicles* (IFVs). Although the permissibility of large-scale deployment of MRLs remains to be tested, such systems possess significant transformative potential for artillery employment tactics and the structuring of related brigades in the Armies of the future.

A second industry trend is the progressive move toward the adoption of modular systems based on interchangeable *pods*. Although early U.S. systems, such as the MLRS and HIMARS, introduced an evolutionary element early on by integrating 227mm rockets and *Tactical Ballistic Missile* (TBM) into the same platform, more recent developments by other Armed Forces have greatly expanded the potential offered by multimodality. The South Korean K239 *Chunmoo* system is a prime example of this evolution, thanks to its ability to employ a broad spectrum of munitions through interchangeable *pods* adaptable to different operational requirements. In fact, the *Chunmoo* can rapidly switch from launching low-cost area salvoes with 40 130mm unguided rockets, like those of the Russian BM-21 *Grad*, to employing medium-range PGMs, and even releasing 400mm and 600mm TBMs.

Fig. 9: A composition of rocket artillery and missile systems currently in service.

Hanwha Aerospace has also indicated its intention to integrate anti-ship ballistic launchers as well, giving a single *Chunmoo* launcher the ability to interoperate with separate systems previously dedicated to specific roles. Similarly, the Israeli PULS platform is capable of employing a wide range of munitions, from 122mm rockets to TBMs to small UAVs, demonstrating high scalability hinged on multi-calibre. This developmental concept has also been progressively adopted in the latest Chinese-made rocket artillery systems, which are explicitly marketed for their multi-role flexibility.

The logistical and tactical advantages of modular *pod* systems are significant compared to traditional launchers, which implied prolonged period of potential exposure to enemy fire during reloading phases, especially in cases of highly contested environments. Generally, Euro-Atlantic production systems have long favored containerized reloading modes, drastically mitigating such vulnerabilities. The M270 MLRS, for example, uses modular *pods* that contain six rockets or a single TBM, reloadable in about five minutes each via an integrated crane. The low-mass version of the HIMARS system, while forgoing the crane to balance overall weight, still maintains rapid reload capabilities through logistics support vehicles equipped with forklifts or cranes, substantially reducing crew exposure and reload times. The EuroPULS system incorporates lessons learned from both U.S. models, equipping itself with an on-board crane on its rotated chassis to provide autonomous charging capabilities. Its modular architecture also allows munitions of different types to be carried simultaneously, giving tactical-level commanders the ability to dynamically adapt payloads as the operational scenario evolves. Modular *pod-based* systems allow a single platform to both execute precision targeting to strategic targets and generate area saturation fire, a versatility that has proven its operational effectiveness in the Ukrainian theatre, where *pod-equipped* launchers have been able to employ *shoot-and-scoot* tactics, quickly repositioning and reloading with largely sustainable adherence logistics.

A third trend relates to the growing, and previously mentioned, demand for extended range munitions, where the need to extend the requirement beyond large calibre TBMs to smaller calibre tactical rockets is crucial. In the United States, production of a long-range

variant of the *Guided Multiple Launch Rocket System* (GMLRS), capable of achieving a range of about 150 kilometres, has found approval. On the European industrial side, MBDA recently unveiled a 227mm guided artillery rocket concept with an engagement capability of up to 150 kilometres, developed specifically to meet the requirements of the *Armée de Terre*. Likewise, the People's Republic of China is also noticeably active in this segment, with the PHL-16 system in the 370mm configuration, which is attributed a range of about 220 kilometres, reflecting a *Go Big to Go Long* approach, marked by maximizing calibre to achieve range. The diriment element for the purposes of multilevel integration of such assets lies in the structuring of C4ISR architectures capable of dramatically reducing the *targeting* cycle and subsequent engagement, as well as enabling coordinated high-precision targeting. Modern rocket artillery systems then make use of digital *fire* control systems (FCS) that can automate acquisition, targeting, and firing functions. These apparatuses allow rapid entry of digital coordinates, automated targeting and execution of complex fire sequences, such as *Time on Target* (ToT) salvoes, in which multiple rockets converge simultaneously on the target.

Fire control systems of the future, such as the U.S. *Advanced Field Artillery Tactical Data System* (AFATDS), show, especially in the missile artillery segment, an increasing ability to fully integrate into advanced multi-domain C2 systems. This integration goes so far as to enable digital activation of the firemouth from *inputs* provided by advanced observers, UAVs, or satellite ISR sources, with transmission of fire data to the launchers in extremely short time frames. This capability proved instrumental in the Ukrainian conflict, where HIMARS units were able to exploit real-time targeting data provided by a plurality of ISR assets, enabling rapid, accurate and high-impact attacks. U.S. and allied forces have also developed coordinated and dispersed fire techniques, in which multiple launchers, operating from different positions, simultaneously strike the same target. This is made possible by synchronization of digital communications and encrypted data links, which ensure consistency and security in information exchange. The use of GMLRS by the Ukrainian Armed Forces, as noted, has produced impactful effects on the battlefield, disrupting Russian logistics and C2

centres. To extend these capabilities, the U.S. Army is under evaluation regarding the operation of *Extended Range* GMLRS (ER-GMLRS), an increased range variant that, with aerodynamic improvements and a new engine, would double the effective range to about 150 kilometres while remaining compatible with existing launchers. For engagements beyond this threshold, the *Army Tactical Missile System* (ATACMS), with a range of up to 300 kilometres, is additionally available, but being phased in for replacement by the *Precision Strike Missile* (PrSM), a next-generation 406mm weapon designed to cover the 60- to 499-kilometer segment.

Alongside U.S. systems, several Allied Armed Forces have developed guided munitions compatible with modular launchers such as PULS and EuroPULS. Indeed, Israeli *ACCULAR* family rockets, in 122mm and 160mm calibres, provide precision targeting capabilities up to 40 kilometres, while the 306mm *Extended Range Artillery* (EXTRA) system reaches 150 kilometres with a 120-kilogram warhead. Similarly, South Korean 239mm guided rockets for the K239 *Chunmoo* system are credited with a range of 160 kilometres and an expected CEP of less than two meters. In addition to conventional rockets, the emergence of hybrid and smart munitions has expanded the tactical role of modular systems. The *Ground-Launched Small Diameter Bomb* (GLSDB), for example, combines an M26 rocket motor with a GBU-39 gliding bomb, resulting in a precision armour-piercing warhead munition having a range of 150 kilometres. Launchable from standard systems, the GLSDB is a cost-effective solution for reusing obsolete stockpiles in *deep fire* roles, particularly relevant in supporting Ukraine in a context of limited ATACMS availability. EuroPULS has also demonstrated compatibility with *loitering munitions*, such as the *Sky Striker*, enabling combined ISR and precision engagement missions from a single platform. Integration of cruise missiles on land-based platforms with systems adapted for launching existing launchers, such as the Kongsberg *Naval Strike Missile* (250 kilometres), or under development, such as MBDA's Joint *Fire Support Missile* (JFS-M) and Kongsberg's *Super Sonic Strike Missile* (3SM) *Tyrfing* also designed to strike targets on the land and sea surface up to 500 kilometres away, is also under development.

Fig. 10: A selection of rotary rocket and missile artillery systems showing the main user Countries.

Such developments foreshadow a new generation of multi-domain missile artillery, capable of striking land and naval targets in the adversary depth from a single modular platform. However, the precision revolution also introduces new vulnerabilities. High reliance on GPS guidance exposes munitions to the risk of *jamming*, a critical issue that the Russian Federation has exploited with some degree of success on the Ukrainian battlefield. Although inertial navigation can partially mitigate these effects, there is still a significant degradation in accuracy in the presence of disturbances in the electromagnetic environment. The extensive use of guided munitions also entails significant logistical pressure. Indeed, Ukraine is reported to have used more than 9,500 GMLRS in the first eight months of the conflict alone, demonstrating the high consumption of ammunition nevertheless also associated with precision fire. This forced an increasing production effort. By way of example, Lockheed Martin passed the threshold of 9,000 GMLRS produced per year in 2021 and is working on a further increase in production capacity.

The evolution of missile artillery aims, therefore, to place the entire adversary warfare apparatus at increasing risk, even under conditions of contested and disputed air dominance, by significantly expanding the

tasks of indirect land fire toward interdiction beyond the rear, targeting in depth and even neutralizing obstacles to multi-domain maneuverer, including enemy air defences. While this evolution hinges on generating rapid asymmetries in the balance of forces to enable the rapid success of the allied military device, the quantitative and qualitative arsenals that such an approach implies and the not-excludable risk of protracted engagement reiterates the need for significant industrial competitiveness and resilience in the production of systems and munitions.

IV An industrial perspective on land artillery

The Russian Ukrainian conflict has highlighted, over all, a return to the massive use of land-based artillery, generating an extremely high attrition rate in terms of both weapon systems and ammunition. This factor, in addition to the repercussions it had on the configuration of the conflict, implied some crucial reflections related to the industrial sector and the regeneration capabilities of the assets. Logistical and military support to Ukraine has posed significant critical issues for the European defense industry, which is exposed to a higher rate of ammunition consumption than the rate of production. The use of ground artillery, to date, has affected about 80 percent of the total losses recorded by both sides involved in the war. In the apical intensity phases during the year 2022, the Armed Forces of the Russian Federation would come to employ close to 70,000 rounds of ammunition daily, with a monthly projection in the millions. Contextually, the numerically less well endowed Ukrainian Armed Forces had an average consumption that could be roughly estimated at 12,000 rounds daily, with a monthly projection of about a quarter of that of the opposing forces. The continuation of the conflict and the massive (not always effective) targeting of assets behind enemy lines resulted in a large overall rate of fire, despite numerous standoffs and variations in intensity. This implied a considerable depletion of artillery fire capacity, both in terms of ammunition and equipment. From 2022 to the present, the Russian Federation has lost more than 1,850 systems, including towed pieces, self-propelled pieces, and rocket launchers. On the other hand, Ukraine, having more limited resources, has suffered fewer losses in absolute terms, quantified at approximately 835 systems.

The conflict, therefore, had a major impact on the logistical supply chains of both sides, which resorted to alternative solutions to avoid the paralysis of their respective war capacity. Moscow, at first, drew on ammunition stores derived from Soviet-era stocks and then, later, significantly increased the production capacity of its industrial apparatus. In the pre-conflict period, the Russian supply chain produced about one million artillery shells per year, managing to double its production output by 2023. Likely, by the end of 2025, it is possible that Russian production could be around a figure of just over four million

per year. To the adoption of a substantial war economy, the Russian Federation has added the importation of about five million of projectiles from North Korea in the last two years, which has made up for the drying up of war resources. At the same time, Ukraine's contingent production capacity has been filled by the transfer of systems, assets and ammunition from Atlantic Alliance member Countries, with only the United States already supplying some two million 155mm projectiles to the Kiev Armed Forces in the early part of 2023. Over the abundant three years since the beginning of the conflict, the European Union, parts of Eastern European Countries, and Pakistan have also equipped Ukraine with tens of thousands of 152mm rounds of ammunition, assembling a heterogeneous but layered war support compartment. Despite this, at various stages of the conflict, Ukraine has been forced to reduce the rate of fire, equalizing it to ceilings of less than 4,000 rounds per day during periods of greatest shortage. Numerical data show a reduction in fire capacity of about 30 percent from the peaks, a factor that provides an incontrovertible discrepancy with Russian forces.

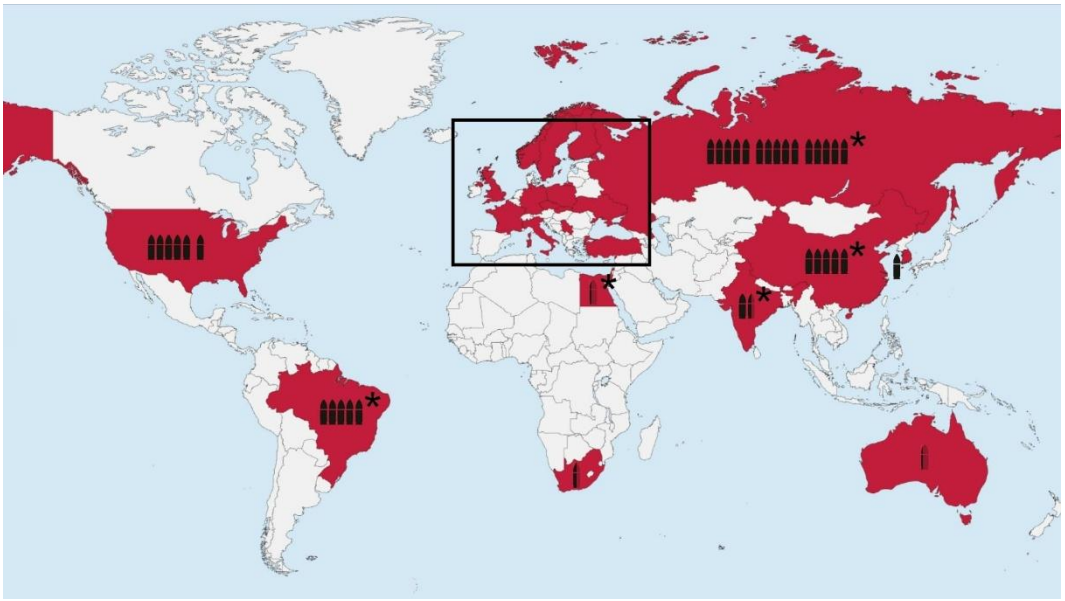

Fig. 11: The cartogram illustrates the annual artillery ammunition production capacity by country. Each solid bullet icon corresponds to 200,000 units per year. The data used are taken from *open sources* and refer to publicly available information. The asterisk next to the icons represents the estimated character of some production capacities.

Support for Ukraine from Contact Group Countries has generated the adoption of a circular economy for the Euro-Atlantic defence industrial segment, dictated by the transfer of assets and systems to Kiev, often part of assets with considerable operational longevity. In a parallel manner, demand in the market for the artillery segment has been growing strongly, motivated by the need to replenish depleted ammunition stocks and needs arising from geostrategic contingencies that have arisen. There has been a sharp increase in international demand for both towed and self-propelled artillery systems, such as the M777, CAESAR, and PzH 2000, with urgent supplies destined for both Ukraine and the Allies who have reduced their arsenals for transfers destined for the Ukrainian front. This has led to a growth in *Government-to-Government* (G2G) contracts, stimulating the pace of production by major European and non-European companies, including Rheinmetall, KNDS, BAE Systems and Hanwha. The sudden increase in demand has forced the industry to embark on a rapid process of adaptation, which has included the operational restoration of decommissioned plants, expansion of the professional pool, and the investment of significant economic resources to build new infrastructure. The United States, for example, has allocated more than $3 billion for the expansion of artillery shell production facilities, tripling the production rate of 155mm rounds. The European industry, coming from a long period of production stagnation, also partially repaired its standards. In the period prior to the war in Ukraine, aggregate production was about 500,000 rounds per year; by 2023 that figure had doubled, until reaching an approximate fivefold increase in 2025. In reaction to this fluctuation, there has been capacitive deployment at the plants of General Dynamics, Nordic Ammunition Company (Nammo), KNDS and other major industrial entities. In France, the company Nexter, part of the KNDS Group, which produces the self-propelled CAESAR gun, has tripled its monthly production from two units in 2022 to six in 2023, with the goal of reaching 12 monthly units in 2025, expressing an overall potential increase of 600 percent. The European industrial landscape, among others, has also seen companies Rheinmetall and BAE Systems leading the way in this evolutionary trend. Indeed, the former have expanded their annual artillery ammunition production capacity from 450,000 to a potential of about 700,000 rounds, while the latter have

announced the opening of a new artillery production facility in Sheffield planned by 2025.

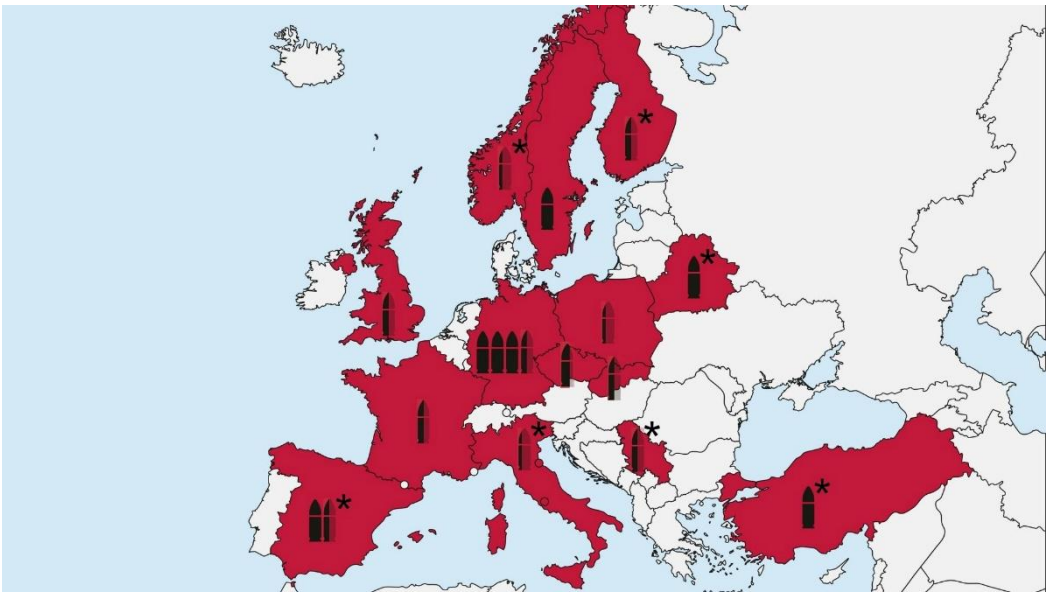

Fig.12: The cartogram illustrates the annual artillery ammunition production capacity by country. Each solid bullet icon corresponds to 200,000 units per year. The data used are taken from open sources and refer to publicly available information. The asterisk next to the icons represents the estimated character of some production capacities.

The conflict revealed major criticalities, in some respects physiological, of the European industrial apparatus in sustaining a massive rate of consumption of vehicles and ammunition. What emerged, in a particular way, was the insufficient remanufacturing capacity, supported almost entirely by the U.S. supply chain, which benefited from increased reserve storage. In parallel, there has been a significant expansion of the market for artillery systems. In addition to the substantial demand from Poland for K9 self-propelled guns, several Countries, including Finland, Estonia, Australia, Egypt, India, and Norway, have increased their acquisition of such assets. The French 155mm CAESAR self-propelled howitzer has received new acquisition requests, as from Belgium and Lithuania between 2022 and 2023, while the German PzH 2000 is being restarted for production to support Ukraine's operational needs. One of the most significant indicators in the post-2022 period is then outlined by the annual production of artillery ammunition. If, as mentioned above, the Russian Federation, in 2024, produced and remanufactured about 4.5 million 152mm rounds, in response, the European Union aspires to narrow that gap with a

production of about 2.5 million rounds per year, which, when added to the projected U.S. production, would reach an aggregate total close to 4 million rounds. Washington has significantly increased funding for ammunition production: from a prewar production of about 14,000 155mm rounds per month to 28,000 rounds per month in September 2023, with an ultimate goal of reaching 100,000 rounds per month by 2025. The industrial expansion of the artillery-related segment has also involved South Korea, which, in addition to exporting weapon systems, has consolidated its role as an ammunition supplier. In fact, Korean production capacity stands at around 200,000 155mm rounds per year and is being expanded about the production of new extended-range ammunition. The Poongsan company represents a major player, active in the production of 155mm, 105mm and rocket artillery ammunition. India also produces ammunition in Soviet and NATO calibres, although in limited quantities, in the tens of thousands of rounds per year, mainly for domestic use.

In more detail, the US currently has in production the 155mm M109A7 *Paladin* self-propelled howitzer produced by BAE Systems and the 227mm M142 HIMARS rocket launcher developed by Lockheed Martin. The *U.S. Army* has ordered a total of 689 units of the *Paladin*, with a delivery rate of 30 to 60 systems per year, while production of the HIMARS has been increased in 2023 from 60 to 96 per year to meet domestic demand and exports to international partners such as Poland. Although large-scale production of M777 towed howitzers has now ended, except for earlier exports to India, BAE Systems still maintains industrial capacity for eventual reactivation. On the ammunition front, the U.S. industry is going through a real artillery renaissance, particularly for 155mm rounds output of about one million rounds per year is expected by 2025, including both standard explosive ammunition, such as the M795, and precision-guided variants such as the *Excalibur*. In parallel, GMLRS production for the HIMARS and M270 launchers is growing, with an expected increase to about 14,000 units per year by 2025. These will be supplemented by 105mm ammunition, 120mm mortar rounds, and 227mm unguided rockets, to which upgrades of decommissioned ammunition stocks will presumably be added. Major contractors, including General Dynamics, BAE Systems

and Northrop Grumman, have collectively expanded monthly production of 155mm rounds from about 28,000 to close to 85,000 over the past two years, taking advantage of interventions made on the supply chain to maximize output.

The same industrial process has affected the Russian Federation, which has hinged its production growth on platform quantity rather than platform innovation. The main systems include self-propelled 152mm howitzers such as the 2S19 *Msta-S* and the older 2S3 *Akatsiya*, towed howitzers such as the 122mm D-30, the *Giatsint-B* and the 152mm *Msta-B*, as well as the 2S7 *Pion* from 203mm. However, multiple rocket launchers such as the 122mm BM-21 *Grad*, 220mm BM-27 *Uragan* and 300mm BM-30 *Smerch* also remained central. Although Moscow has introduced more modern models, such as the 2S35 *Koalitsiya-SV* (a highly automated 152mm howitzer) and the 2S43 *Malva* (a 152mm rotary self-propelled system), production remains on an extremely limited scale. Only a few prototypes of the *Koalitsiya* have been deployed, with the first operational units of the *Malva* being delivered in late 2023. Russia's real production strength, however, lies in ammunition, with state-owned plants operating on a continuous cycle under Rostec's control, ensuring both new production and remanufacturing of 122mm, 152mm, and 300mm ammunition. Estimates indicate production of about two million rounds between 2022 and 2023, with a target of at least four million in 2024. The reduced costs of Russian scale production compared to Euro-Atlantic scale production (about $1,000 for a 152mm round, compared to $4,000 for a 155mm equivalent) have also allowed for a largely unequal war remanufacturing capability. Despite the industrial acceleration of the European and U.S. supply chains, by the end of 2023, the Russian industrial sector was producing nearly three times as many rounds per month as the aggregate capacity of Europe and the United States.

The People's Republic of China, on the other hand, in line with the across-the-board and structured growth of the military over the past two decades, now has one of the most significant artillery forces on a global scale, supported by the state-owned industrial conglomerate North Industries Corporation (Norinco). The PLZ-05 and PLZ-05A 155mm tracked self-propelled howitzers constitute the main heavy

platform of the *People's Liberation Army* (PLA), while the PCL-181 wheeled howitzer, also 155mm, was rapidly introduced into the artillery brigades with a view to increasing deployment mobility. The PHL-16 modular rocket launcher system (also known as PCL-191) is capable of employing 370mm guided rockets or short-range ballistic missiles, replacing the old 300mm platforms. Beijing also produces 122mm and 155mm howitzers for export, particularly the SH series, such as the SH-15 supplied to Pakistan, and several models of MLRS for Asian and Middle Eastern markets.

The PLA modernization program then led to the large-scale introduction of new artillery systems, with several hundred units produced in recent years. Between 2019 and 2022, about twelve brigades were equipped with the PCL-181, estimating a production rate of more than a hundred units per year. From an industrial perspective, the ability to fulfill large-volume orders is demonstrated by the Pakistani acquisition of 236 SH-15 howitzers, delivered in batches, while other Countries, such as Algeria, have acquired Chinese-made MLRSs. Alongside these systems, China is believed to maintain large stocks of ammunition and is capable of producing all standard calibres, with automated lines that could triple production capacity. Although exact figures remain confidential, peacetime production would amount to several hundred thousand rounds per year, with a capacity increase that could equal that of Russia. Consequently, China's strategy to ensure readiness for large-scale conflicts is likely to include both the proactive stockpiling of millions of rounds in reserve and a major output of modern systems for domestic needs and additional units for export, with ammunition production potentially at or above half a million rounds per year.

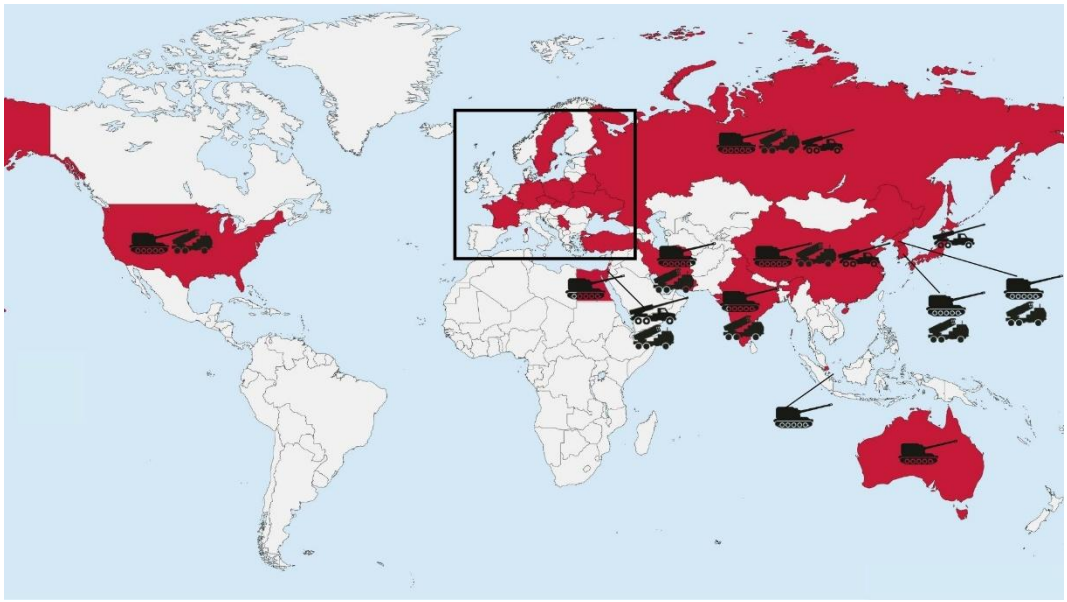

Fig.13: The map highlights Countries with artillery production facilities in red, using three different silhouettes to indicate their main type. The *silhouette* of the multiple rocket launcher identifies rocket system producers; the self-propelled tracked howitzer marks the Countries producing tracked systems; and the self-propelled howitzer on a rotating frame identifies the producers of wheeled systems. Each country shows the silhouette corresponding to the category of artillery actually produced nationally; the presence of multiple silhouettes indicates that the nation produces both types represented. The information is based on *open sources* and may be subject to limitations due to possible omissions or variations in the data. The map is for illustrative purposes only.

European artillery production is distributed among several key players and Countries and is increasing significantly in response to the profoundly changing strategic environment. In Germany, Krauss-Maffei Wegmann (KMW) and Rheinmetall jointly developed the 155mm self-propelled howitzer PzH 2000, but after building more than 300 units for Germany, the Netherlands, and other buyers, production had been suspended. This is now being reactivated to meet new demand, including small batches of 10-20 units destined for Ukraine and other customers by 2025. KNDS, the result of the union between KMW and Nexter itself, then developed the RCH 155, a *Boxer* hull-mounted turreted howitzer, of which 18 units were ordered for the *Bundeswehr* at the end of 2022 with the first deliveries scheduled for 2025. In ammunition, Rheinmetall has historically produced hundreds of thousands of 105mm and 155mm rounds, and after incorporating several subsidiaries, including Spain's Expal, which alone adds about 120,000 rounds/year, production has risen to more than 300,000

rounds annually. The goal for 2025 is to reach over 600,000 rounds/year to meet domestic and foreign demand. In France, the main manufacturer is Nexter, part of the KNDS holding company, known for its 155mm CAESAR wheeled howitzer, of which the *Armée de Terre* has acquired 77 units, while exports have included 15 systems for Denmark, 37 for Indonesia, some 132 for Saudi Arabia, as well as recent orders from the Czech Republic (52) and Belgium (19). Increased demand, particularly following the French commitment to Ukraine, has prompted Nexter to increase production capacity, which is currently estimated at around 12 units per month. In the ammunition arena, Nexter Munitions

Fig.14: The map highlights Countries with artillery production facilities in red, using three different silhouettes to indicate their main type. The *silhouette* of the multiple rocket launcher identifies rocket system producers; the self-propelled tracked howitzer marks the Countries producing tracked systems; and the self-propelled howitzer on a rotating frame identifies the producers of wheeled systems. Each country shows the silhouette corresponding to the category of artillery actually produced nationally; the presence of multiple silhouettes indicates that the nation produces both types represented. The information is based on *open sources* and may be subject to limitations due to possible omissions or variations in the data. The map is for illustrative purposes only.

and Eurenco have begun a production ramp-up from about 60,000 155mm rounds annually in the prewar period to a target close to 120,000, flanked by smaller-scale productions of 120mm mortar rounds and 122mm projectiles. In the U.K., BAE Systems has ended production of the AS90 howitzer and awaits the start of a new program, which could

include existing commercial solutions or co-developments with the U.S. But the U.K. industry maintains significant capabilities in munitions: the BAE Glascoed plant produces 155mm rounds, Chemring supplies propellants, and BAE also offers precision solutions such as the L20 charging system. London has announced a plan to expand production to eight times previous levels in 2023: from a base of about 5,000 rounds produced in 2022, it aims to reach 40,000 rounds annually. The UK has also entered into cooperation with the Finnish Norwegian company Nammo to secure additional supplies of 155mm rounds. In Italy, Leonardo has previously produced systems such as the *Palmaria* self-propelled gun and supplied turrets for the PzH 2000. Currently, the national focus is on modernizing the PzH 2000 fleet and possible participation in the Franco-German project for a new artillery system. In terms of ammunition, Leonardo and RWM Italia finally produce the Vulcano series of 155mm guided projectiles.

In contrast, Poland, through Huta Stalowa Wola (HSW), produces the 155mm AHS *Krab* self-propelled tracked howitzer, which combines a British turret with a South Korean-derived hull. The Polish Army has ordered just under 200 of them, with about 78 already built by the end of 2022, some of which were later transferred to Ukraine. In parallel, Warsaw has initiated an industrial cooperation plan with South Korean Hanwha Techwin for licensed production of the K9 *Thunder* starting in 2026, putting itself in a position to significantly expand its domestic capabilities. Staying in the Eastern European landscape, Slovakia, through the company Konštrukta, produces the 155mm *Zuzana 2* rotary howitzer, of which it has already delivered eight of the sixteen units destined for Ukraine between 2022 and 2023, with an estimated annual capacity of about 20 units. In the Czech Republic, the Excalibur Army company is involved in remanufacturing 152mm *Dana* rotary howitzers and is in the process of developing a new 155mm system, the *Morana*, although the current production pace is constrained. Both Countries mentioned, in addition, have 152mm and 122mm ammunition production facilities currently for war support in Kiev.

South Korea has in parallel reported considerable growth within the global industry market, offering both platforms and ammunition. The main trim produced is the 155mm K9 *Thunder* self-propelled tracked

howitzer, the export of which has met the operational needs of a wide range of Countries. Following the Ukrainian conflict, the company has significantly increased production of the K9 to meet the Polish order, delivering 24 units by the end of 2022 and another 40 in 2023. In parallel, South Korea continues to produce K9s for its Armed Forces (mostly in upgraded versions) and has developed the K239 *Chunmoo* multiple rocket launcher. By 2027, 290 orders are expected from Poland, of which about 90 have already been delivered. In the area of ammunition, South Korean companies, on all of them Poongsan and Hanwha, produce an annual aggregate output of about 200,000 155mm rounds, combined with other 105mm ammunition and various types of rockets. Although Seoul does not directly supply Ukraine, it has signed agreements to transfer hundreds of thousands of rounds to the United States for stockpile replenishment. The country also produces high-tech munitions, including 155mm GPS-guided grenades and 239mm guided rockets for the *Chunmoo*. Hanwha is also capable of producing up to 100 K9 howitzers per year at full capacity, with the Polish contract having already confirmed such large-scale capabilities, with some of the assembly set to move to Poland from 2026.

In addition to South Korea, several other major manufacturers play a significant role in the international artillery production landscape. Turkey, for example, has reactivated its T-155 *Fırtına* program in 2022. The Roketsan company also produces rocket-powered artillery systems, including the 122mm *Sakarya* (TR-122), the 300mm *Kasirga* (TR-300), and the TRG-230 guided artillery missile. As for ammunition, the state-owned MKE makes tens of thousands of 155mm rounds each year, part of which has been supplied to Ukraine and is in the process of expanding its production capacity in line with NATO initiatives. India, meanwhile, pursues an accelerated modernization process through the state-owned Ordnance Factory Board, which produces the 155mm *Dhanush* towed howitzer and has begun development of the 155mm ATAGS system. In parallel, the country has acquired a license to produce a local variant of the Korean K9 self-propelled howitzer, named *Vajra*, with 100 units delivered between 2018 and 2022, as well as ongoing negotiations for an additional 100 units. The 214mm *Pinaka* missile system is then mass-produced to equip multiple regiments and has

been exported to Countries such as Armenia. India also currently has a production capacity of about 300,000 155mm artillery shells per year.

While Pakistan does not have significant production of artillery systems, it appears to be a significant producer of ammunition through *Pakistan Ordnance Factories* (POF), which specializes in the production of 155mm projectiles for M198 howitzers and *legacy* calibres. Islamabad would, among other things, supply significant quantities of 122mm and 152mm ammunition to Ukraine through intermediary channels between 2022 and 2023. In 2024, at the 12th *International Defence Exhibition and Seminar* (IDEAS), Pakistan and Turkey additionally signed an agreement to establish a mega factory on Pakistani soil with a planned annual capacity of 120,000 155mm artillery shells, significantly expanding the country's production potential. Iran's defence sector also has a strong focus on ammunition production, including artillery shells in 122mm, 152mm and 155mm calibres, as well as replicas of Soviet-derived towed howitzers and a wide range of rocket launcher systems, including the *Fajr-5* compatible with BM-21 *Grad* launchers. Tehran took a significant step in the development of self-propelled artillery systems with the *Raad-2M*, a national tracked platform equipped with a 155mm cannon, designed to improve firepower, tactical mobility and field survivability.

Finally, Israel also has an advanced industrial sector in the artillery segment, led by Elbit Systems, which is currently engaged in the transition from *legacy* M109 howitzers to the new 155mm *Roem/Sigma* self-propelled automatic howitzer system, the commissioning of which for the IDF is likely to occur by 2027. The 155mm ATMOS wheeled howitzer is exported in relatively small batches, generally less than 20 units, but Israel maintains significant ammunition production capacity, particularly for 155mm projectiles for both domestic and export use.

Thus, a highly fragmented and extremely dynamic picture emerges regarding the artillery systems and ammunition market, with a significant trend toward concentration of production potential not only in a small number of Countries, but even individual industrial players. This trend takes on an even more pronounced character about precursors and industrial semi-finished products, with supply chains often concentrated and thin. However, the credibility of deterrence and

the sustainability of defence appear to be increasingly dependent on the competitiveness and resilience of the military-industrial sector, and the artillery segment, from platforms to projectiles, precisely because of the converging importance of quality and mass, as well as the massive consumption and wear and tear accruals that would characterize any high-intensity conventional conflict with regard to indirect fire, is the ultimate expression of this.

Conclusions

The future of land artillery is resolutely at the heart of the multi-domain maneuverer of future. A lethal organic fire source supported by flexible and resilient logistical ramification and deep industrial roots, capable of supporting allied forces in contact and striking high-value targets in the adversary depth. The elusive and adaptive pinnacle of a *kill web* enabled by advanced and interconnected *Intelligence Surveillance Target Acquisition and Reconnaissance* (ISTAR) capabilities, ready to disrupt and degrade without warning the enemy military device with accurate and overwhelming fire. As a whole an essential component of the inter-force targeting potential (*joint fires*) and in individual complex platforms functional to ensure the most diverse, pregnant and timely generation of desired effects on designated *targets* (*smart fires*). A land artillery capable of surviving and persisting on the battlefield, looming with its massive destruction potential over the adversary from the front line to beyond the rear. A composite panoply of fire sources capable of dispersing while continuing to concentrate their effects, able to operate at length and with high autonomy from emplacements for nothing or minimally prepared, making mobility, both tactical and strategic, even before masking, the pivot with which to constantly surprise the adversary. A tireless cause of attrition for the enemy, functional in ensuring an always unequal confrontation, in terms of morale, resources or capabilities, to the advantage of the frontline Allied units. A land artillery capable of shaping and affecting the battlefield with a renewed and expanded arsenal of diversified ammunition, suitable for generating the optimal effect on each type of target.

The future of indirect fire is thus destined for increasingly refined integration with a distributed *network* of ISTAR systems both organic to artillery units at every level, with reference to UAVs of increasing class and size, and external to these and spanning all domains up to and including fifth- and sixth-generation air platforms as well as *Low Earth Orbit* (LEO) satellite assets. A crucial capability to complement and enhance, among other things, the *suppression and* destruction of enemy air defences (SEAD/DEAD – *Suppression and Destruction of Enemy Air Defences*) functions traditionally carried out by fixed-wing aircraft,

ensuring each time a large reserve of ready to use munitions with which to make up for the reduced load potential of *stealth* aircraft, while enhancing their advanced ISTAR *suites*. An artillery component that will conceivably continue to include towed and self-propelled, wheeled and tracked pieces in order to balance cost, complexity and specific requirements for support to light, medium and heavy departments, but profoundly transformed in TTPs, with an emphasis on a triad of factors: multispectral masking, rapid risking and mobility. Rising from the single platform to the largest artillery formation, disappearing upon enemy detection on the battlefield is indeed an inescapable requirement in contemporary *warfighting*, even more so for assets at the apexes of adversary *target lists*. If *Standard Operating Procedures* (SOPs) focusing on visual and thermal concealment, light and sound discipline, and piece dispersal form the basis for *survivability*, advances in both vehicle camouflage and the organic availability of advanced *decoys* are bound to unveil new options for obstructing and delaying *the targeting* cycle of the opposing array.

Units and pieces, moreover, are at their most vulnerable at the very moment they deploy their destructive power, with developments in counterfire capabilities registering significant across-the-board improvement. *Shoot-and-scoot*, combined with an upgrade in firing cadences, thus becomes a pivotal principle of indirect fire, potentially taken to extremes with the planning, even at the battalion level, of sequential firing positions for each individual piece on the occasion of each fire mission, even when involving the synchronous action of multiple mouths, achieving concentration of effects in the dynamic dispersion of sources. As much as it is related to rapidity of redeployment, mobility transcends the latter, articulating itself as much in a tactical need to operate through broken or poorly indexed terrain as in a strategic need for projectability of firepower. Indeed, the latter turns out to be crucial for theatre level manoeuvring of fires that can cause persistent dilemmas for the adversary, threatening without warning every nook and cranny of its relative military device. The suitability of pieces for transport and expeditious deployment from fixed and rotary wing assets is thus a critical requirement, confined not only to horizontal risers along the front, but potentially also to insertion

into enemy depth, as in the case of massive airborne operations (L2A2 – *Large scale, Long range Air Assault*).

An evolution of land artillery that concerns both the tube component, destined to remain the imperishable lintel of indirect fire capabilities, and the missile component, both enhancing an increased intervention arm. Indeed, if the former must be able to generate effects at least at 45 kilometres, the latter appears destined not only to reach 150, but plausibly to exceed 300 kilometres. A capacitive challenge, the latter, that is decisive in defining the role of land artillery in multi-domain combat and aimed at drawing new boundaries. Indeed, the LRPF concept has the potential to foster a true metamorphosis from a tactical-operational to an operational-strategic conception indirect fire, selectively combining a trend toward increasing accuracy with one toward increasing range. A trajectory, however, coexisting with the operational requirement of generating mass and opposing mass, even in the dialectic of fires with the adversary, and in which cost efficiency of ammunition and enduring added value of massing shots on target will prevent the marginalization of unguided projectiles, especially in a *warfighting* scenario.

A horizon for ground artillery, finally, interpenetrated by the advancing convergence of robotics and AI, and their relative implementation on the battlefield. Indeed, the manoeuvring of indirect fires appears particularly suited to the experimentation of collaborative combat (MUM-T – *Manned-Unmanned Teaming*), with the prospect first of gregarious ammunition carrying vehicles and then of entire batteries autonomous in the execution of deployment, firing and re-deployment procedures, coordinated by a small core of operators acting as indirect fires battle managers. A future marked, therefore, by profound doctrinal, organizational, capacitive, and technological changes, but one in which indirect fire will remain pivotal to the deterrence, and to the necessity, of battle, for without fire there is no advance, but without artillery there is no victory.

AUTHORS

Emmanuele Panero – Analyst, Head of the Defense & Security Desk at CeSI. In five years, attended as a civilian at the Italian Army School of Applied Military Studies, he graduated *summa cum laude*, earning a MA in Strategic Sciences and a BA in Strategic and Security Sciences, from the Interdepartmental University School in Strategic Sciences (SUISS) of the University of Turin. Concurrently, he successfully completed multiple courses at the national and European levels, including at the Italian Army Infantry School and the European Security and Defense College.
Subsequently, he earned a II Level MA in International Strategic-Military Studies with honors, attending the 25th Joint Services Staff Course, at the Centre for Higher Defence Studies (CASD) in Rome.
He is an author for *RID-Rivista Italiana Difesa* and *Rivista Marittima*, take periodically part in Armed Forces military exercises, and is regularly invited to speak as a subject matter expert on international security, military affairs and defense industry issues at seminars and conferences, as well as at in-depth radio and television programs, including on Rai and Sky.

Daniele Ferraguti – is Junior Fellow at the Defence and Security Desk of CeSI, he is about to graduate with a Master's Degree in International Relations and Global Security from the University of Rome "La Sapienza", where he obtained a Bachelor's Degree in Political Science and International Relations. Former Intern at the Defence and Security Desk of CeSI, he previously held various positions dealing with security and military issues at IARI.

Francesco Bellato – Intern at the Defence and Security Desk of CeSI. Currently enrolled in the Master's Degree in International Relations at Luiss Guido Carli University, he earned his Bachelor's Degree in Political Science with the highest grades, during which he completed a study period at King's College London.

CeSI | CENTRO STUDI INTERNAZIONALI

CeSI - Center for International Studies is an independent think tank founded in 2004 by Andrea Margelletti, who has been its President ever since.

The activity of the Institute has always focused on the analysis of international relations and the dynamics of security and defense, with particular attention devoted to areas of crisis and the dynamics of radicalization and extremism, afterwards expanding its analytical tools also in the field of geoeconomics and conflict prevention.

The flagship of CeSI is certainly its analytical methodology which is based on an in-depth knowledge of the analyzed context, on a daily and transversal information research and on a periodic visit in the areas of interest, which allows the analysts of the Institute to carry out timely and dynamic work. Furthermore, the Institute has created a wide network of collaborations and partnerships with other think tanks, universities, institutional and non-institutional stakeholders in the reference countries.

The goal is to provide tools which will contribute to help to better understand the reality and provide useful elements for decision making. What the CeSI intends to provide is a multifaceted approach which, in the complexity of the contemporary world, is based on an understanding at 360° of the dynamics in action by the actor.

CONTATTI

Website
www.cesi-italia.org

Social
Fb: Ce.S.I. Centro Studi Internazionali
X: @CentroStudiInt
LinkedIn: Ce.S.I. Centro Studi Internazionali
IG: cesi_italia
Telegram: Ce.S.I. Centro Studi Internazionali

Office
Phone: +39 06 8535 6396
Address: Via Nomentana 251, 00161 – Roma, Italia

CeSI | CENTRO STUDI INTERNAZIONALI