Unmanned Aerial Systems as a Catalyst for Artillery Kill Chain Compression: Lessons from the Nagorno-Karabakh Conflict

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Abstract

This paper examines the compression of the artillery kill chain in a UAS-saturated battlefield, using the Nagorno-Karabakh conflict (2020) as an empirical case. Based on OSINT analysis, the kill chain is decomposed into measurable phases and their temporal intervals estimated. Results indicate a total duration of 60–120 seconds, making time a dominant tactical constraint. The findings highlight implications for artillery tactics, simulation models, and officer education within Joint Fire Support and Multi-Domain Operations. The study provides a transparent framework linking empirical observations with operational practice.

KEY WORDS: *artillery kill chain; fire support; Nagorno-Karabakh conflict; OSINT analysis; unmanned aerial systems.*

Citation: Havlik, T.; Mušinka, M.; Miko, S.; Krompolc, F. Unmanned Aerial Systems as a Catalyst for Artillery Kill Chain Compression: Lessons from the Nagorno-Karabakh Conflict. In *Proceedings of the 5th International Conference on Challenges to National Defence in Contemporary Geopolitical Situation (CNDCGS'2026)*, Brno, Czech Republic, 7-10 September 2026. ISSN 2538-8959, https://doi.org/10.47459/cndcgs.2026.14

1. Introduction

Conflicts of the past decade show ever more clearly that combat effectiveness is determined not only by weapon systems, but also by the speed and coherence of the entire command, control, intelligence, and fire system. The concepts of Joint Fire Support and Multi-Domain Operations rest on the assumption that effects can be generated across domains, and that the decisive advantage goes to the actor able to connect sensors, decision-making processes, and effectors into a single time-optimized system [1, 2]. In this context, unmanned aerial systems act not merely as reconnaissance assets but as integral components of a sensor-to-shooter chain that significantly reduces the time from target detection to its destruction [3, 4, 5, 6].

The Nagorno-Karabakh conflict of 2020 is widely regarded as the first war in which this principle manifested at a systematic and operationally decisive scale [7]. The employment of tactical UAS, loitering munitions, and digitally supported fire assets allowed Azerbaijan to achieve effects previously reserved for advanced air forces and complex C4ISR architectures [8, 9, 10]. Subsequent developments in the war in Ukraine have further accelerated and broadened this trend to the level of brigades, battalions, and in some cases even companies, where UAS have become routine components of the fire cycle [11]. In an MDO environment, artillery thus faces persistent cross-domain ISR that fundamentally diminishes the value of traditional approaches based on longer dwell times at firing positions, sequential fire direction center (FDC) procedures, and the relative anonymity of fire action.

Although professional literature and military analyses widely describe the "democratization of precision strike" and the growing importance of UAS in modern combat, most works remain at a qualitative level and deal in general claims about kill chain acceleration [3, 8, 12]. What is lacking, however, is systematic quantification of the temporal intervals of individual kill chain phases, especially in relation to artillery as a key element of JFS. This shortcoming limits the ability to translate lessons from conflicts into simulation models, wargaming, and training, where time is one of the most sensitive and simultaneously least precisely defined variables [13, 14, 15].

Peer-review under responsibility of General Jonas Žemaitis Military Academy of Lithuania and University of Defence, Czech Republic

Particularly problematic is the fact that current simulation tools and tactical models used in the preparation of artillery officers often rest on assumptions that do not reflect the reality of a UAS-saturated battlefield. The adversary's kill chain is implicitly assumed to be longer, less persistent, and more fragmented than what is observable in actual conflicts [16, 17, 18, 19]. The result is a discrepancy between learned procedures and real conditions of combat that directly affects an officer's ability to correctly estimate risk, choose dwell time at a position, and plan the maneuver of fire assets [17, 20].

This article aims to bridge that gap by decomposing the artillery kill chain into individual phases and, on the basis of open sources, estimating their duration in specific combat situations. The research objective is not to achieve laboratory precision but to produce a sufficiently robust and transparent temporal framework that can be used in simulations of artillery tactics, JFS planning, and especially in the education of artillery officers for MDO, thereby contributing to better linkage of empirical lessons from modern conflicts with decision-making practice and doctrinal development.

2. Theoretical background and literature review

Within NATO, in an MDO environment, fire is understood less as an isolated artillery activity and more as a joint function of generating effects (joint fire effects) across domains, where the decisive factor is the tempo of sensor–decision–effector integration [21]. U.S. doctrine shifts the emphasis from linear "request–calculation–execution" towards targeting management and integration of JFS within joint planning and operations management [22]. *Army Targeting* emphasizes that targeting is a continuous activity linked to the commander's decision-making and to the dynamic allocation of effectors [23], while *Fire Support and Field Artillery Operations* frames fire as a system whose combat value depends on coordination, speed, and the ability to act in conditions where the adversary is capable of rapidly detecting and reacting [24]. At the alliance level, NATO Conduct of Operations and Land Operations emphasize adaptive, integrated joint combat and interoperability [25, 26]. For targeting, AJP-3.9 describes joint targeting as a systematic process of selecting and prioritizing targets and generating effects in accordance with the commander's intent [27]. In sum, "speed of process" is becoming the determining factor more than caliber or range [22, 23, 27].

The concept of "kill chain" in this article corresponds to the F2T2EA logic ("find–fix–track–target–engage–assess") [22, 27]. Modern conflicts show that UAS and loitering munitions compress this sequence: persistent ISR reduces "Find/Track" costs, digital connectivity shortens "Fix/Target", and organic or tightly linked effectors compress "Engage" [3, 8, 11, 28]. In Nagorno-Karabakh this has been described as "democratization of precision strike" [3, 8]. Academic literature notes that drones do not themselves "revolutionize war", but what is decisive is the "hider–finder competition" between the capability to seek/detect and the capability to conceal/disperse and jam [29]. Kill chain compression is therefore not merely "faster shooting" but a consequence of a change in information dominance in the tactical space, where firing positions become observable and predictable and the adversary can close the cycle faster than traditional "shoot-and-scoot" procedures allow [24, 29]. Loitering systems function as "sensor-shooter-in-one" with low latency [30], while emerging research models the kill chain as a network optimization problem with constraints (time, jamming, node losses) directly relevant to MDO/JFS [31, 32].

From the perspective of artillery tactics simulation, this literature introduces two things often underestimated in traditional models: (1) persistent observation and probability of detection as a function of time, signature, and unit behavior [33]; (2) dynamic decision-making and data-transmission latency in the JFS/MDO network [34]. The growing importance of UAS in modern operations is also reflected in research focused on optimization of aerial reconnaissance and persistent surveillance in complex operational environments. Recent modelling approaches demonstrate that effective monitoring and surveillance depend not only on the technical capabilities of UAS, but also on the optimization of flight paths, coordination of multiple platforms, and the ability to maintain continuous situational awareness within a defined area of responsibility. These studies highlight that persistent ISR generated by UAS significantly enhances operational responsiveness and supports faster decision-making processes, which directly contributes to the compression of the sensor-to-shooter chain in contemporary operations [35]. Doctrinally, these correspond to the parameterizable layer of *Observed Fires* [36, 37]. NATO positions M&S as a tool for increasing alliance readiness and adaptation [38, 39]. If simulation environments do not incorporate realistic temporal budgets of the adversary's kill chain in a UAS-saturated space and do not model the signatures and behavior (pattern-of-life) of fire units, they will systematically teach officers false intuition about risk, dwell time, and the value of EMCON. Empirical quantification of kill chain timing is therefore a necessary bridge between joint effects theory and tactical practice, directly applicable to wargaming, scenario design, and assessment of JFS/MDO competencies [23, 24, 27, 38].

3. Methodology

The methodological approach combines qualitative analysis of combat events with quantitative estimation of temporal intervals of individual kill chain phases. The approach reflects the reality of contemporary research into modern conflicts, where direct access to classified data is unavailable and OSINT represents a legitimate and widely used analytical basis [40]. The aim is not absolute temporal precision but a transparent, reproducible, simulation-applicable framework enabling case comparison and operationally relevant conclusions for JFS in MDO.

The research is based on event-based analysis of selected combat incidents from Nagorno-Karabakh (2020), chosen because it represents the first systematically documented employment of UAS as a persistent sensor within an integrated kill chain, and because it offers a relatively rich set of publicly available video records enabling temporal reconstruction [11, 29, 40]. The need for timely processing of up-to-date tactical information is also reflected in related research on autonomous systems and tactical geographical data processing [41].

The kill chain is operationalized as three temporal intervals compatible with F2T2EA logic: T_1 - detection to unambiguous identification of the target as legitimate; T_2 - identification to decision to engage the effector; T_3 - decision to actual target strike (munition flight, effector maneuver, or projectile time of flight). $T_1 + T_2 + T_3$ = total kill chain duration = survival time window following detection. The structure of the kill chain and the role of UAS within it are illustrated in Fig. 1.

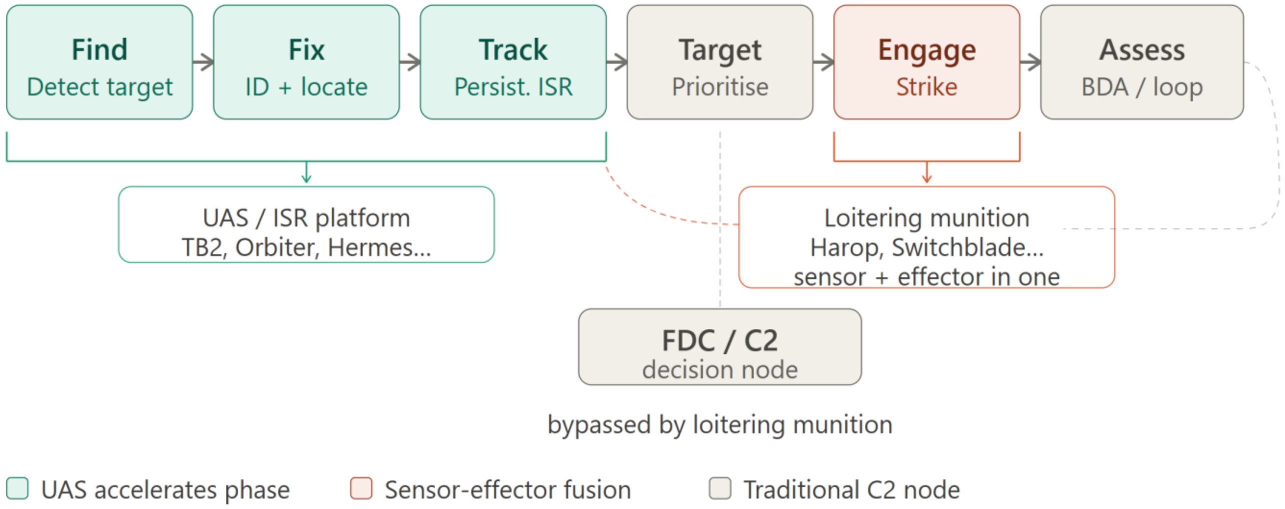


Fig. 1. The F2T2EA kill chain decomposition and UAS integration (authors, based on [22, 27])

Case selection maximized analytical value and minimized speculation, requiring: a visually verifiable moment of detection or tracking; clear transition to the engagement phase; confirmed effect; UAS role in at least one kill chain phase; and interpretability within JFS logic [42]. Temporal estimates were produced by combining video time-code analysis with expert estimation based on knowledge of artillery and UAS …procedures, presented as ranges and typical values consistent with OSINT methodological standards [30, 43]. Measurement uncertainty is understood as an input for probabilistic simulation rather than a limitation.

The methodology reflects the MDO perspective by treating the kill chain as a network process in which each node (sensor, C2, effector) can be replaced or degraded, allowing the results to be interpreted as inputs to JFS resilience analysis and opportunities for disrupting the adversary's kill chain [37, 38, 44, 45].

4. Results

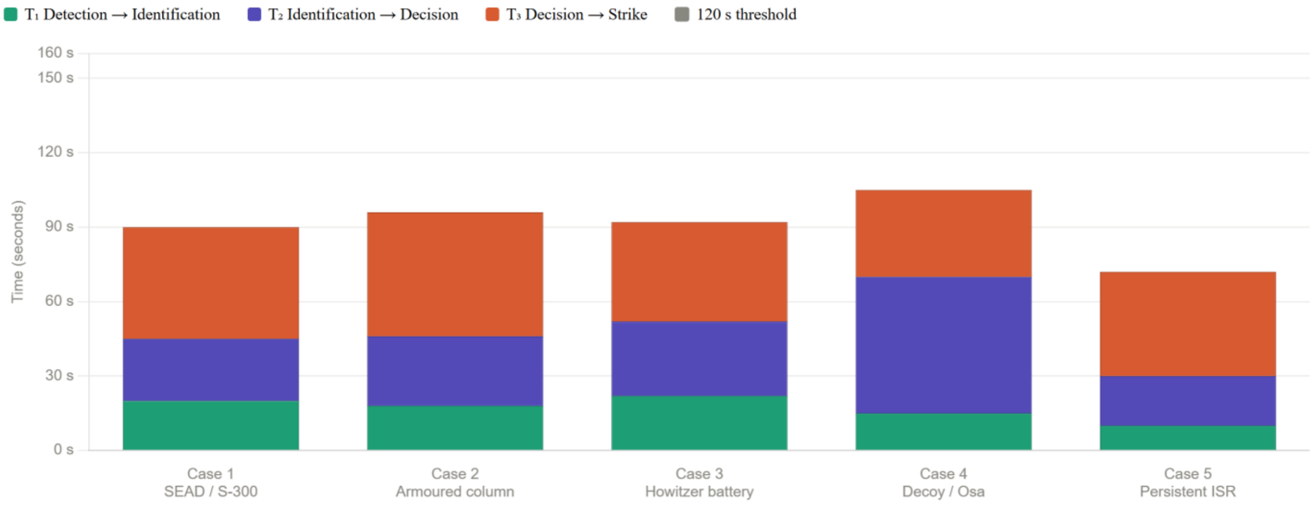
This section presents the empirical findings derived from the analysis of selected combat engagements, including case characteristics, quantified kill chain intervals, and key factors influencing kill chain compression.

Five representative cases from Nagorno-Karabakh (2020) were selected and cross-referenced against independent analytical sources (RUSI, ARES, CNA). Selection criteria: (a) clearly identifiable detection/tracking moment; (b) key UAS role in at least one kill chain phase; (c) separable kill chain phases; (d) video-confirmed target destruction.

1. **Case 1: Strategic SEAD Operation.** Gubadli, 10 October 2020. Destruction of Armenian S-300PS. Sensor: Orbiter 1K UAV; decoy: An-2 biplane; effector: IAI Harop loitering munition. The Harop functioned as both sensor and effector within a coordinated single sequence.
2. **Case 2: Armoured Column Destruction via UAS-Corrected Fire.** Vicinity of Jabrayil, early October 2020. Destruction of T-72 tanks and BMP-2 IFVs. Sensor: Bayraktar TB2 with Wescam MX-15D; effectors: BM-21 MRL and LORA. TB2 transmitted corrections directly to effector fire control, markedly shortening the engagement cycle.
3. **Case 3: Destruction of an Entrenched Howitzer Battery.** Northern Jabrayil, early October 2020. D-30 howitzer position. Counter-battery detection by ELM-2084 radar confirmed by Bayraktar TB2; effector: TB2 with MAM-L (sensor-effector fusion); supporting DANA-M1 fire.
4. **Case 4: Deception of the Sensor-to-Shooter Complex.** 30 September 2020, near Papravend. Azerbaijani sensor identified high-priority air defense signature and immediately initiated SEAD without close target examination, expending precision munitions on 9K33 Osa decoys. The case demonstrates that a compressed kill chain is structurally susceptible to deception because time pressure in decision-making generates inherent risk.
5. **Case 5: Persistent ISR Leading to Artillery Position Strike.** Multiple engagements throughout the conflict. Destruction of Armenian artillery assets through sustained TB2 observation and subsequent directed strikes.

Illustrates cumulative effect: once a unit's pattern-of-life is established, Find phase runs continuously.

A representative reconstruction of the engagement timeline, based on OSINT data, is shown in Fig. 2.



Values are mid-point estimates (seconds). Ranges: T_1 10–60 s · T_2 10–70 s · T_3 20–100 s. Case 4 (decoys) shows extended T_2 due to misidentification delay before engagement.

Fig. 2. T_1–T_2–T_3 breakdown across five NK 2020 cases; mid-point estimates in seconds (authors)

The quantitative analysis of these cases allows estimation of temporal intervals across all five cases. Table 1 summarizes aggregated results, expressed as ranges due to the inherent limitations of OSINT-based reconstruction.

Table 1.

Aggregated Kill Chain Results, Nagorno-Karabakh 2020

Kill Chain Phase	Average Time	Typical range
T_1: Detection → Identification	15–25 s	10–60 s
T_2: Identification → Decision	20–35 s	10–70 s
T_3: Decision → Strike	30–50 s	20–100 s
Total Kill Chain	60–120 s	45–180 s

Source: Authors' own analysis based on OSINT data.

These aggregated results provide a quantitative basis for comparing traditional and UAS-enabled kill chains. As shown in Fig. 3, the temporal compression is most evident in the transition between identification and engagement phases.

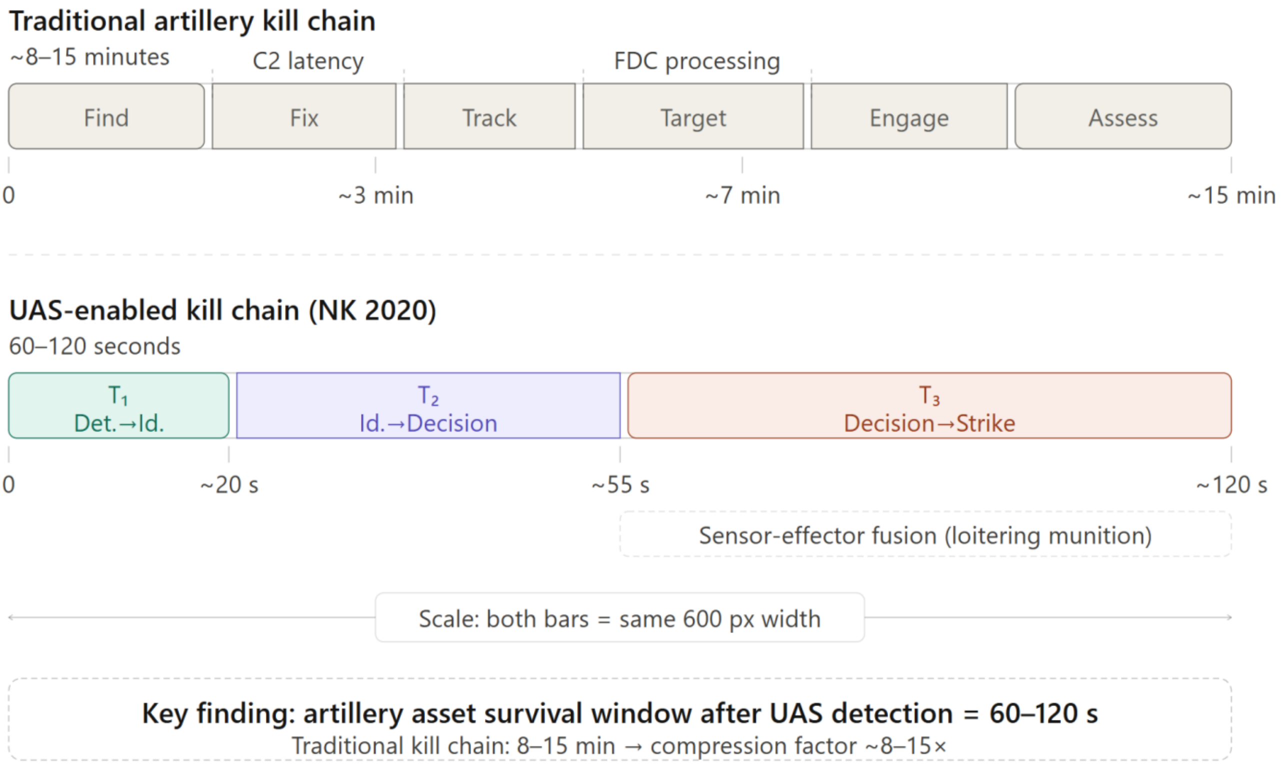


Fig. 3. Kill chain compression: traditional vs. UAS-enabled artillery kill chain (authors, based on OSINT analysis NK 2020)

The analysis further identifies key factors driving kill chain compression. First, persistent ISR enables continuous execution of the Find phase, significantly reducing detection time. Second, sensor-effector fusion, particularly in loitering munitions, eliminates coordination delays between observation and strike. Third, templated unit behavior allows prediction of target presence, effectively reducing the search phase. Fourth, insufficient multispectral concealment exposes units through thermal and electromagnetic signatures. Fifth, automation of fire direction enables rapid data transfer directly to effectors [46]. Sixth, deception techniques exploit compressed timelines by forcing rapid engagement decisions. Finally, time pressure itself introduces decision-making errors, as demonstrated by misidentification in Case 4.

Differences in survivability across target types were also observed. Self-propelled artillery exhibited shorter kill chains due to stronger observable signatures, while towed systems could achieve slightly longer survival when concealed. However, both were vulnerable during movement along predictable routes. Logistics assets were consistently engaged most rapidly due to constrained mobility and visibility. Overall, survivability is determined primarily by the integration of mobility, concealment, temporal discipline, and operational behavior rather than mobility alone.

5. Discussion

The results confirm that kill chain compression in a UAS-saturated environment is not an exception but a systemic feature of the contemporary battlefield. From the perspective of JFS and MDO, artillery can no longer be understood as a relatively autonomous fire tool but as a continuously observed node in a networked effects system where every action generates a detectable signature [11, 12, 16]. The 60–120 second window represents not merely a technical parameter but a new operational limit that must be integrated into planning, command, and training.

In the context of JFS, the traditional concept of fire support, based on relatively stable firing positions and sequential target processing, is unsustainable in a persistent ISR environment. The adversary's kill chain closes faster than the classical "fire–assessment–decision to displace" cycle can complete. Dwell time must therefore be shorter than the adversary's kill chain, not merely optimal for ammunition consumption or accuracy. This shift resonates directly with the doctrinal emphasis of the United States and NATO on tempo and decision-making as the key success factors in MDO.

From an MDO perspective, kill chain compression is not caused solely by UAS technology but primarily by cross-domain integration, namely detection in the air domain, decision in the information domain, and effect in the ground or air domain. Artillery finds itself in a paradoxical position, as it remains one of the most effective generators of combat effects while being extremely vulnerable due to the need to generate detectable signatures (thermal, acoustic, electromagnetic) and to operate in environments where GNSS availability cannot be assumed [47]. The discussion of survivability thus shifts from "how powerful should it be" to "how quickly and unobtrusively can it function as part of a joint system".

The most important new tactical-technical constant identified: an artillery firing position must not exist longer than the duration of the adversary's kill chain (i.e., fewer than 60–90 seconds). Traditional tactics based on longer dwell, separated firing and movement, inflexible decision-making, and limited multispectral concealment have become non-functional in the presence of persistent UAS. Adaptation requires: extremely rapid shoot-and-scoot procedures; pre-prepared secondary and tertiary firing and waiting positions; battery decentralization into smaller independent nodes; organic counter-reconnaissance UAS; active C-UAS; and strict EMCON discipline [48, 49].

Simulation models that do not incorporate realistic temporal budgets of the adversary's kill chain systematically underestimate risk. If a simulation allows a battery to remain at a firing position for five or ten minutes without consequence, it does not correspond to the reality of a UAS-saturated battlefield and distorts the decision-making intuition of trained officers. Integration of T_1–T_3 as variables with variance allows modelling not only of "what happens" but "when it happens" (decisive for JFS planning) [38, 39, 50].

The implications for artillery officer education are equally significant. Traditional instruction focused primarily on technical correctness of fire, ballistics, and procedural precision must be supplemented by instruction in process-based thinking over time [51]. An artillery officer in MDO is no longer merely a "fire specialist" but a kill chain manager who must understand where in F2T2EA he stands at any given moment, which nodes are most vulnerable, and when it is necessary to abandon the task in favor of unit survival. Without this mental transformation, even the most modern equipment will remain ineffective [23, 24, 27, 38].

6. Limitations of UAS in high-intensity conflict: Evidence from Ukraine

Although UAS fundamentally contribute to kill chain compression, their effectiveness directly influences the duration and reliability of individual kill chain phases (T_1–T_3). The Russo-Ukrainian conflict reveals significant limitations arising not only from adversary action and technological constraints but also from environmental and meteorological conditions [52, 53]. In some cases, these factors lead to complete degradation of ISR capability, corroborating RUSI conclusions that overestimating the role of UAS without accounting for operating conditions is a systemic error in contemporary military thinking [54].

1. **Battery degradation.** Low temperatures cause voltage drop and power loss, reducing flight time and range [55, 56]. Field observations from Ukraine show significant efficiency losses in winter conditions; in extreme cases drones fail unpredictably at any phase of flight, including final target approach.

2. **Mechanical and sensor degradation.** Field reports document camera freezing, condensation inside electronics, and rotor icing [52, 53, 57, 58], causing loss of flight stability and image quality, which directly affect the Fix and Track phases.
3. **Combined environmental and EW effects.** Snow, fog, and wind reduce range and visibility; combined with electronic jamming this multiplies degradation and substantially reduces precision strike capability [59, 60].

These factors do not act in isolation but directly degrade the temporal performance of the kill chain, particularly by extending detection and identification phases and increasing the probability of failure during engagement. Table 2 quantifies the impact of environmental conditions on UAS endurance, directly affecting the reliability of the T_3 phase of the kill chain.

Table 2.

Effect of Temperature on UAS Endurance

Ambient Temperature	Endurance Reduction	Typical Manifestation
+15 °C to +25 °C (optimal)	0%	nominal performance
0 °C	−25 to −30%	voltage drop, reduced range
−10 °C	−30 to −50%	unstable performance, risk of cutout
−20 °C	−50% (typically)	"half endurance", pre-heating required
−25 to −30 °C	up to −90%	extreme degradation, practically unusable

Source: compiled by authors based on [55, 56].

To illustrate the operational impact of environmental factors on kill chain performance, selected OSINT-documented cases are summarized below:

1. **Winter FPV Drone Operations.** OSINT materials repeatedly document FPV drone failures in winter. Typical sequence: detection proceeds normally; operator initiates attack; during approach the drone suffers sudden power loss due to battery voltage collapse under maximum load [52, 61], which occurs precisely during the Engage phase, the most critical stage of the kill chain.
2. **ISR Degradation in Low Visibility.** In several documented cases (Pokrovsk, Dobropillia, Myrnohrad, October–November 2025), low cloud cover and fog prevented target identification even after detection. Operators aborted missions, extending the kill chain duration from seconds to tens of minutes or even hours, thereby directly undermining the assumption of persistent ISR.
3. **Combined EW and Environmental Effect.** RUSI analyses show that in EW-saturated environments the effective UAS range is shortened; combined with adverse weather this can lead to complete collapse of the sensor-to-shooter chain, rendering it tactically irrelevant [54].

These findings demonstrate that environmental factors are not merely secondary constraints but a structural element influencing the duration, reliability, and variability of all three kill chain intervals: T_1 is extended (degraded detection), T_2 is disrupted (poor image quality undermines identification confidence), and T_3 may fail entirely (platform failure). From the perspective of artillery, adverse weather may temporarily restore the relative advantage of traditional fire assets not dependent on battery performance, electro-optics, or data-link line-of-sight. In the MDO context, environmental conditions represent not only a constraint but also an opportunity to disrupt the adversary's kill chain, which should be reflected in operational planning, simulation models, and training.

7. Conclusion

This study demonstrates that UAS has fundamentally disrupted traditional artillery paradigms. The kill chain compressed to 1–2 minutes during the 44-day Nagorno-Karabakh war in 2020, fundamentally constraining artillery combat and requiring transformation of established tactical procedures. Azerbaijan effectively degraded Armenian combat capability through efficient rear-area destruction, while Armenia with outdated assets was able to inflict losses primarily at the front line. Future artillery units in a UAS environment will be defined not by range or caliber, but by speed of process, level of multispectral concealment, mobility, organic sensor integration, and the ability to disrupt the adversary's kill chain.

However, as the Ukrainian theatre demonstrates, this paradigm shift is neither absolute nor irreversible. Environmental conditions, including low temperatures, precipitation, and combined electronic warfare, can substantially degrade UAS effectiveness and partially restore the relative advantage of traditional fire systems. Kill chain compression is therefore best understood as a probabilistic rather than deterministic process: its speed and reliability vary with available technology, C2 integration, environmental conditions, and adversary countermeasures.

For European artillery, adaptation to kill chain compression is a strategic necessity, but equally important is understanding the conditions under which that compression is constrained. The sub-90-second dwell time limit must be internalized not as a rigid rule but as a decision variable sensitive to weather, terrain, countermeasures, and adversary EW capability. Integration of these empirically grounded temporal parameters into simulation environments, wargaming scenarios, and professional military education represents the most direct path from the lessons of contemporary conflicts to enhanced battlefield effectiveness of future artillery forces. The growing importance of immersive and technologically advanced training environments also confirms that future artillery effectiveness will increasingly depend not only on technical fire proficiency, but on the ability of personnel to operate within rapidly evolving sensor-to-shooter networks and digitally integrated combat systems [62].

Acknowledgements. This work was supported by Czech Ministry of Defence from project LANDOPS (grant number DZRO-FVL22-LANDOPS).

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