Proceedings of 5th International Conference CNDGS'2026
ISSN 2669-2023 (print) / ISSN 2538-8959 (on-line) **/ https://doi.org/10.47459/cndcgs.2026.102**

Analysis of the Military Last-Mile Logistic Support Concept Using Uncrewed Systems

Martin ŠKVAŘIL[1*], Milan VÁBEK[1]

[1] Department of Logistics, Faculty of Military Leadership, University of Defence, Kounicova 65, 682 01, Brno, The Czech Republic

*Correspondence:*martin.skvaril@unob.cz*

Abstract

The transformation of the modern battlespace, defined by pervasive surveillance and precision-strike lethality, has fundamentally reshaped tactical logistical requirements. Last-mile logistics represents a critical vulnerability in high-intensity conflicts, where conventional crewed resupply is hindered by prohibitive risks and operational friction. The paradigm of Distributed Logistics in Contested Environments (DLCE) demands the integration of uncrewed and autonomous systems capable of penetrating Anti-Access/Area Denial envelopes under severe electronic warfare conditions. Nevertheless, a doctrinal gap remains in uncrewed aerial system (UAS) classification for logistics, existing North Atlantic Treaty Organisation (NATO) and the United States Department of Defense frameworks, primarily focused on mass and Intelligence, Surveillance and Reconnaissance (ISR) capabilities, overlook logistical imperatives such as payload efficiency and specialized cargo requirements. This article evaluates current classification constraints and introduces the functionally oriented Military Logistics UAS Taxonomy (UAS-L). Through Multi-Criteria Decision-Making and tactical scenario validation, the study identifies optimal operational modalities for uncrewed and hybrid logistical architectures in near-peer conflicts.

KEY WORDS: *military logistics; last-mile resupply; uncrewed systems (UxS); UAS Logistics Taxonomy (UAS-L); MCDM; Payload Efficiency Ratio (PER)*

Citation: Škvařil, M.; Vábek, M. Analysis of the Military Last-Mile Logistic Support Concept Using Uncrewed Systems. In Proceedings of the Challenges to National Defence in Contemporary Geopolitical Situation, Brno, Czech Republic, 7-10 September 2026. ISSN 2538-8959, https://doi.org/10.47459/cndcgs.2026.102

1. Introduction

Last-mile logistics, the system of supply movements from a distribution node to the end user at the tactical edge, is widely described as the most complex and cost-intensive segment of distribution [1, 2]. While the commercial sector primarily optimizes this stage for economic efficiency and customer convenience, military last-mile logistics is defined by a contested environment where lethality and environmental austerity transform delivery into a critical survival challenge [3]. In high-intensity conflict, persistent Intelligence, Surveillance and Reconnaissance (ISR), precision fires and electronic warfare (EW) further increase the risk and cost of crewed resupply methods and can impose operational pauses. At the same time, dispersion of small units and growth of high-consumption items create a demand profile characterised by frequent, low-to-medium payload deliveries with strict time windows.

Traditional logistics models, which rely on centralized hubs and extensive ground convoys, are becoming untenable in environments characterized by high battlefield transparency and the omnipresent threat of precision strikes. In this sense, logistics is ceasing to be a mere support function and is becoming a decisive factor in operational success, as the ability to maintain the tempo of supply in contested environments directly affects a unit's ability to manoeuvre and survive.

Uncrewed systems (UxS), including uncrewed aerial systems (UAS), offer a means to reduce personnel exposure and create alternative delivery modalities. Recent defence and industry analyses underline renewed interest in tactical aerial logistics and rapid UxS platform evolution [4, 5]. Yet adoption is not merely a procurement problem: decisive factors are integration into the logistics system, command and control (C2), interoperability, and the ability to operate in Global Navigation Satellite System (GNSS)-degraded and contested electromagnetic environments [6, 7].

Distributed Logistics in Contested Environments (DLCE) necessitates a paradigm shift from centralized supply hubs to resilient, dispersed networks capable of sustaining operations under multi-domain threats. Uncrewed systems serve as critical enablers in this architecture, particularly for high-velocity, low-signature transport of essential materiel across last-mile segments. By leveraging autonomous navigation and vertical take-off capabilities, unmanned aerial vehicles (UAVs) mitigate risks associated with Anti-Access/Area Denial (A2/AD) envelopes, ensuring supply line integrity where traditional assets remain vulnerable. Consequently, integrating cargo UAS enhances operational agility and reduces the logistical footprint, proving vital for mission persistence in near-peer conflicts [8].

Despite this operations environment shift, existing international and national standards for UAS classification are still largely based on physical parameters or reconnaissance capabilities, creating a doctrinal gap in logistics planning and acquisition. A robust, functionally oriented taxonomy is essential for integrating UAS into modern logistics structures, establishing interoperability standards, and developing specific training programs. This analysis focuses on creating a new taxonomy framework that reflects the specific needs of military logistics and integrates technical parameters with functional roles in a dynamic and high-threat operational environment.

This paper analyses and validates a Last-Mile Logistic Support concept based on UAS and identifies the conditions under which unmanned resupply provides a net operational advantage over crewed delivery.

2. Method of Investigation

The research design combines three methods. First, a Systematic Literature Review of doctrinal and scientific sources on last-mile logistics and on uncrewed delivery systems, is conducted to derive mission requirements and constraint sets. The paper also reflects open-sourced lessons learned from the ongoing conflicts in Ukraine and the Gaza Strip. Second, a capability taxonomy maps UAS options across payload class, range/endurance, signature, autonomy level, and recovery/maintenance demands to connect platform characteristics to logistics effects (throughput, responsiveness and risk). Third, scenario-based validation is performed using representative tactical missions. The result is a multi-criteria decision framework, aligned with recent Multi-Criteria Decision-Making (MCDM) approaches used to assess drone adoption barriers, to support planning of crewed, uncrewed and hybrid solutions.

3. Analysis and Limits of Current Application and Classification Frameworks

As part of comprehensive literature review on classification approaches of UAVs, the Sabour et al. [9] offers UAV classification according to operational application with primary focus on multi-rotor systems. The authors categorize drones into six functional groups: reconnaissance, combat, logistics, research and development, civil and commercial applications, and target and decoy.

Furthermore, the study offers a detailed analysis of eight specific civilian application fields, including urban air mobility, disaster management, and agriculture, evaluating them through domains such as control, sensor fusion, and system design. The methodologies and taxonomies established in this paper provide a foundational framework for this research, facilitating a systematic analysis of UAV design trends and research gaps. Logistics applications represented 18% of the research focus within the multi-rotor UAS domain, establishing this field as one of the most prominent areas of study [9].

Logistical UAS have emerged as a pivotal element of military supply chains, with their structural design and operational deployment strictly contingent upon the nature of the cargo, as categorized under military classes I–V and VIII. While the transport of conventional commodities, such as rations, spare parts, and ammunition, prioritizes volume and the ability to bypass enemy surveillance while maintaining environmental resilience, the conveyance of medical materiel represents the technical pinnacle of UAS logistics. For blood derivatives, these systems must ensure absolute mechanical stability to mitigate the risk of haemolysis and maintain a rigorous cold chain between 1–6 °C, even under extreme climatic conditions. Deploying these technologies for critical interventions during the critical period (Golden Hour) significantly reduces battlefield mortality by providing delivery speeds that far exceed the capabilities of ground-based medical evacuation [10].

The technological landscape of UAS cargo transfer is defined by a strategic trade-off between delivery precision, energy efficiency, and platform survivability. Modern logistical doctrines increasingly favor non-landing methods to mitigate the risks associated with the aircraft becoming a static target on the ground. Winch systems utilize lumped-mass link modeling and high-strength polymer lines to achieve high accuracy in complex or contaminated terrains while maintaining a stable hover. For fixed-wing platforms, High-Altitude Low-Opening (HALO) techniques and GPS-guided parafoils provide a critical balance between tactical standoff distances and precise delivery of sensitive materials. While mechanical free-drops remain the most cost-effective solution for durable supplies, they necessitate sophisticated onboard ballistic calculations to compensate for environmental variables. Ultimately, although ground landing remains indispensable for heavy payloads and casualty evacuation (CASEVAC) missions, the integration of autonomous release mechanisms continues to shift operational focus toward rapid, standoff delivery methods.

The integration of logistical UAS into the Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) framework expands their utility from simple transport to active security and operational support. Through route reconnaissance utilizing Synthetic Aperture Radar (SAR) and change-detection algorithms, these platforms identify Improvised Explosive Devices (IEDs) and ambushes, demonstrating significant statistical effectiveness in modern high-intensity conflicts. In convoy overwatch roles, armed UAVs provide persistent surveillance and immediate fire support, with real-time data feeds integrated into Remote Optical Video Enhanced Receiver (ROVER) terminals to minimize tactical response times [11].

Furthermore, in contested airspaces where traditional Medical Evacuation (MEDEVAC) is restricted, UAVs serve as essential communication hubs for telementoring and the monitoring of safe evacuation corridors, directly enhancing the survivability of isolated ground units. To display current UAS military logistics applications the following map (Fig. 1) was constructed.

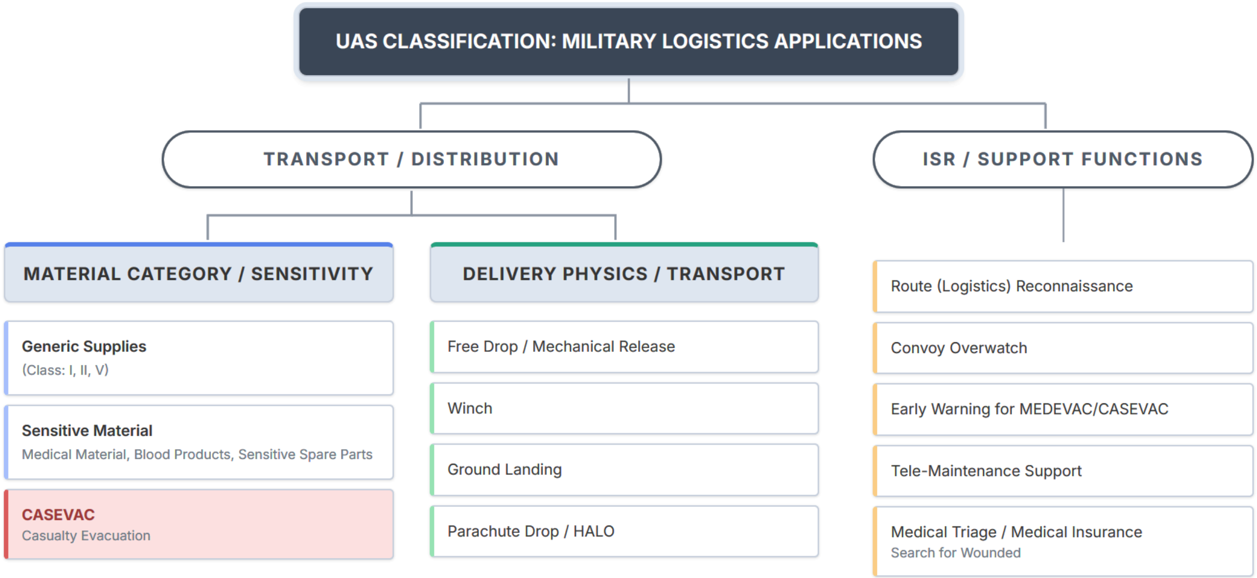

Fig. 1. UAS Military Logistics Applications.

Existing military classification systems, such as the NATO standards defined in STANAG 4670 or the United States Department of Defense (US DoD) UAS groups, were primarily designed for air traffic management, reconnaissance categorization, and operator training requirements. While these systems provide a basic structure, they exhibit significant indeterminacy from a military logistics perspective, particularly regarding payload capacity, modularity, and autonomous delivery capabilities in adverse conditions.

NATO classification (see Table 1) divides UAS into three main classes based on Maximum Take-Off Weight (MTOW), operational altitude and mission [12].

Table 1.

NATO UAS Classification

Class	**Category**	**MTOW**	**Operating Altitude**	**Operational Use**
Class I	Small	>15 kg	< 5.000 ft AGL	Platoon, Squad
	Mini	< 15 kg	< 3.000 ft AGL	Company, Platoon, Squad
	Micro	< 66 J**	< 200 ft AGL	Battalion, Regiment
Class II	Tactical	150 – 600 kg	< 18.000 ft AGL	Brigade-level support, ISR, Target Acquisition
Class III	Strike/Combat	> 600 kg	< 65.000 ft MSL*	Strategic ISR, Strikes, Long-endurance Missions
	High-Altitude, Long-Endurance (HALE)		< 65.000 ft MSL*	
	Medium-Altitude, Long-Endurance (MALE)		< 45.000 ft MSL*	

Source: [10]

Remarks: *Altitudes for Class III systems often exceed standard Above Ground Level (AGL) measurements and are typically conducted in controlled flight levels or Mean Sea Level (MSL) reference,

**UAS that have a maximum energy state less than 66 Joules.

The US DoD system (see Table 2) divides UAS into five groups defined by Maximum Gross Take-off Weight (MGTW), operational altitude, and speed [13]. From a logistics standpoint, this classification lacks a metric for payload efficiency ratio. Group 3, for instance, includes systems optimized for endurance (ISR) with very low payload capacities relative to their total weight, alongside new cargo drones capable of carrying significant supplies at the expense of flight time.

Table 2.
US DoD UAS Classification

Group	MGTW	Operating Altitude	Speed	Example
Group 1	0 – 9 kg	< 1,200 ft AGL	< 100 kt	RQ-11 Raven, WASP
Group 2	9 – 25 kg	< 3,500 ft AGL	< 250 kt	ScanEagle
Group 3	25 – 600 kg	< 18,000 ft MSL	< 250 kt	RQ-7 Shadow, RQ-21 Blackjack
Group 4	> 600 kg		Any	MQ-8B Fire Scout, MQ-1C Gray Eagle
Group 5	> 600 kg	> 18,000 ft MSL	Any	MQ-9 Reaper, RQ-4 Global Hawk

Source: [11]

For military logistics, the fundamental measure of a UAV's performance is not its maximum take-off weight, but its ability to carry a useful load relative to its own mass. This efficiency is expressed as the *Payload Efficiency Ratio* (PER), which is defined as the ratio of the payload weight to the maximum take-off weight of the aircraft (as shown in Equation 1).

$$PER = \frac{m_{payload}}{m_{MTOW}} \tag{1}$$

In traditional military UAV design, which has been dominated by ISR requirements, PER is often intentionally sacrificed in favor of flight endurance, specialized sensor suites, and fuel capacity. Technical studies focused on aircraft sizing state that while the average payload-to-MTOW ratio for unmanned combat aerial vehicles is only around 11%, for aircraft capable of carrying external loads or cargo, this ratio commonly exceeds 30%. For logistical applications, a PER of 0.3 to 0.5 (30% to 50%) is considered the threshold for an effective transport platform [14].

Uncrewed system autonomy level represents an additional factor carrying significant implications for logistical support within GNSS-denied environments. The autonomy of UAS is technically categorized according to the SAE J3016 framework, which defines six levels ranging from Level 0 (Manual Control) to Level 5 (Full Automation). Levels 1 and 2 are classified as Operator Support Systems, where a human remains the primary pilot while the system assists with specific lateral or longitudinal control functions. True automated functionality begins at Level 3 (Conditional Automation) and reaches operational maturity at Level 4 enabling fully autonomous travel and payload delivery under standard environmental conditions without pilot oversight [15].

In the context of modern military logistics, these levels of autonomy are vital for enabling DLCE, as they permit low-signature resupply and persistent operations in GNSS-denied or communication-degraded zones where manual remote piloting is untenable. Furthermore, cognitive autonomy at Level 4 and above is essential for last-mile success, empowering platforms to utilize visual-inertial navigation and real-time 3D terrain scanning to deliver critical supplies without a persistent data link to a Ground Control Station. This technical autonomy is standardized within military structures through Basic Qualification Levels (BQL I-IV), which align operator skills with the escalating complexity and autonomous capabilities of the platforms [16].

4. Comparison of Transport-Capable UAVs Using Standard Classification

The following Table 3 compares UAS platforms with material transport capabilities, including specialized systems from the conflict in Ukraine (e.g., the "Baba Yaga" family) and the Middle East (e.g., Elbit Thor), to highlight logistical efficiency.

The data shows that dedicated logistical platforms, such as the Postman or Malloy T-150, achieve much higher PER values than multi-role platforms, with the Postman reaching a 50% efficiency threshold. Ukrainian systems like the R18 and SkyFall Vampire (Baba Yaga) demonstrate the viability of using reusable medium multirotors for frequent resupply and tactical strikes in contested night environments. The Perun system further pushes the limits of tactical multirotors, capable of lifting up to 200 kg for casualty evacuation or heavy equipment transport.

Table 3.
UAS Classification Comparison

UAS Model Name	US DoD Group	NATO Class	UAS-L Class	MTOW [kg]	Max Payload [kg]	PER [%]	Primary Logistical Role
Zip 1 [17]	1	I	**L1**	13.0	1.5	**11.5**	Med/Blood Resupply
Elbit Thor (I) [18]	2	I	**L1/L2**	25.0	13.0	**52.0**	Tactical Mule
Aerorozvidka R18 (U) [19]	2	I	**L1**	17.0	5.0	**29.4**	Munition Drop
Malloy T-150 (U) [20]	2/3	I	**L2/ L-Mar**	123.0	68.0	**55.3**	Last-Mile Resupply
SkyFall Vampire (U) [21]	2/3	I	**L2**	40.0*	15.0	**37.5**	Night Resupply
Kazhan E630 (U)[22]	2/3	I	**L2**	70.0*	30.0	**42.8**	Logistics/Munitions
PD-2 (U) [23]	3	I	**L2/L3**	55.0	11.0	**20.0**	Multi-role/Cargo
Postman (U) [24]	3	II	**L3**	150.0	75.0	**50.0**	Battlefield Logistics
Windracers Ultra Mk2 (U) [25]	3	II	**L3**	670.0	200.0	**29.9**	Operational Shuttle
Mohajer-10 (I) [26]	4	III	**L3**	1,100.0	300.0	**27.2**	High-Cap Strategy
Kargo UAV [27]	4	III	**L3/ L-Med**	1,270.0	362.8	**28.5**	Expeditionary Resupply
Perun (U) [28]	3/4	II	**L3**	500.0	200.0	**40.0**	Operational Shuttle /CASEVAC
MQ-8C Fire Scout [29]	4	III	**L4**	2,721.0	1,200.0*	**44.1**	Heavy Sling Load Transport
BAE Systems T-650 [30]	4	III	**L-Med**	1,000.0*	300.0	**30.0**	CASEVAC
IAI Heron TP (I) [31]	5	III	**L4**	5,400.0	2,700.0	**50.0**	Strategic Heavy Lift
Black Swan [32]	5	III	**L4**	600.0	350.0	**58.3**	Strategic Theatre Cargo

Remarks: *Where verified manufacturer data was unavailable or classified, parameters were derived using analogy-based estimation and similarity metrics. This methodology utilizes the principle of dynamic similarity, extrapolating values from reference platforms with comparable geometric configurations, kinematics, and flight envelopes. Missing performance indicators were refined through parametric imputation and generalized models, an established approach in conceptual aircraft design. This inferential process may introduce a margin of variance, potentially influencing the precision of the calculated PER results.
Letter (I) or (U) indicates whether the UAS has been deployed within Middle East (I) or Ukrainian conflict (U).

5. The New Military Logistics UAS Taxonomy

To facilitate the classification of UAVs specifically for military logistical applications, a specialized framework titled the *Military Logistics UAS Categories* (UAS-L) have been proposed by the authors. This system categorizes platforms by evaluating five core performance dimensions: payload capacity, operational range, autonomy level, payload type, and the deployment environment.

Based on functional analysis and conflict experience, a six-category logistics taxonomy is proposed to complement existing classification systems (see Fig. 2).

The assignment of autonomy levels within the suggested framework was developed using a functional alignment methodology. This approach maps the degree of machine self-governance to the inherent complexity of the logistical echelon and the environmental difficulty of the mission. The levels were established as prescriptive operational requirements (recommended targets) rather than strictly descriptive summaries of current platform capabilities. This ensures that the taxonomy serves as a doctrinal goal for future acquisition, requiring systems in high-threat sectors to possess higher-order cognitive autonomy to mitigate the risks of signal detection and jamming. The framework mandates these autonomy levels as a necessity for achieving reliable, high-cadence resupply in Multi-Domain Operations.

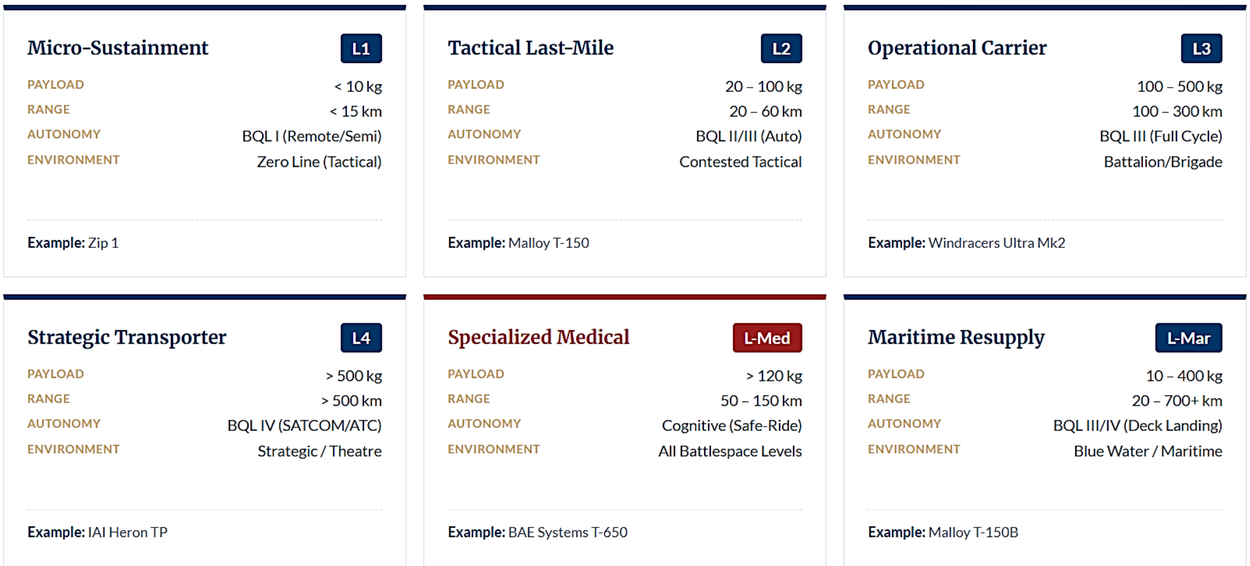

Fig. 2. Military Logistics UAS Taxonomy (UAS-L).

Category L1 focuses on the rapid transport of lightweight, high-value critical items at the squad and platoon level, typically with a payload capacity below 10 kg and an operational range under 15 km. Theoretically, these systems provide organic support for time-sensitive missions where infrastructure is non-existent. Practically, the Zip 1 has revolutionized medical logistics in Rwanda and Ghana, shortening blood delivery times by 61% and reducing health facility stockouts by up to 90% [33]. These platforms utilize BQL I autonomy, requiring minimal operator training and achieving stealth through low acoustic signatures.

Category L2 represents the primary logistical asset for company-level resupply, carrying 20 to 100 kg of cargo over 20 to 60 km distances. Theoretical utilization focuses on replacing light ground vehicles in high-IED risk areas using BQL II/III autonomy for obstacle avoidance in contested terrain. In practice, the SkyFall Vampire (Baba Yaga) has become an essential night-resupply tool in Ukraine, capable of delivering 15 kg payloads while withstanding Russian electronic warfare. Similarly, the Elbit Thor serves as a backpack–portable tactical mule for Israeli forces, emphasizing rapid deployment and operational flexibility in urban environments.

Category L3 systems bridge the operational gap between tactical drones and heavy strategic aircraft, offering payload capacities of 100 to 500 kg and ranges up to 300 km. Theoretically, these serve as an "air bridge" for brigade-level sustainment of palletized material and heavy weapons. Practically, the Windracers Ultra Mk2 has demonstrated its capability to transport 200 kg over 2,000 km, supporting diverse missions from humanitarian aid to Antarctic research and frontline resupply in Ukraine. Additionally, the Postman enables battalion logistics through autonomous mission cycles and Starlink integration, achieving a remarkable 50% payload efficiency.

Category L4 comprises strategic-level assets capable of lifting over 500 kg over distances exceeding 500 km, requiring BQL IV qualifications and full SATCOM integration. Theoretically, these platforms execute theater-wide material distribution and cross-border strategic resupply. Practically, the IAI Heron TP (Eitan) serves as a strategic heavy-lift asset with a 2,700 kg payload capacity and theatre-wide range of 7,400 km. The MQ-8C Fire Scout supports naval operations with a verified 1,200 kg external sling-load capacity, relieving the logistical burden on manned helicopter fleets for heavy component transport.

Category L-Med is defined by the requirement to safely transport human casualties (>120 kg capacity) over 50 to 150 km, adhering to specialized Safe-Ride standards. Theoretically, these systems integrate cognitive autonomy and real-time medical monitoring to preserve the Golden Hour in contested A2/AD zones. Theoretical frameworks, such as NATO HFM-184, conclude that UAV-based CASEVAC is ethically, legally, and clinically permissible if it does not increase risk compared to traditional methods [34]. Practically, the BAE Systems T-650 heavy-lift drone can carry a 300 kg payload, including a specialized concept casualty evacuation pod featuring patient protection systems. The Ukrainian Perun (Transport) could also be theoretically utilized for CASEVAC purposes, given its heavy-lift capacity (200 kg) and its use of battery-powered motors to remain stealthy against thermal imaging during night operations.

Category L-Mar addresses the extreme environmental challenges of the maritime domain, carrying 10 to 400 kg over ranges reaching 700+ km. Theoretical requirements focus on corrosion resistance and vision-based autonomous landing on moving, pitching ship decks. Practically, the Malloy T-150 achieved a historic first by executing autonomous ship-to-ship supply transfers in the United Kingdom Royal Navy between warships HMS Prince of Wales and HMS Dauntless. Analysis of naval carrier group data suggests that 95% of routine resupply items weigh less than 50 kg, underscoring the strategic efficiency of these UAS in naval logistics [35].

6. Operational Context

Successful last-mile deployment is conditional upon four enablers: GNSS-independent navigation, cyber-resilient control links, seamless C2 integration, and unit-level maintainability. Ultimately, uncrewed systems significantly enhance force protection by replacing human exposure in kill zones with a highly resilient, autonomous, and dispersed logistics network. Furthermore, the authors present additional use cases for the obtained insights within logistics support during emergency situations, including natural disasters.

In modern doctrine, UAV logistical modules are integrated directly into Forward Support Companies (FSC) at the battalion and brigade level. This logistics-centric classification categorizes UAVs by their payload capacity and the military supply classes they are optimized to carry. The FSC serves as the linkage between the Brigade Support Area (BSA) and units at the Forward Line of Troops (FLOT) [3].

At the initial operational stage, the Input Hub focuses on the transloading and modularization of supplies at the Brigade Support Area (BSA) or the Field Trains Command Post (FTCP). This phase involves transferring bulk materials from heavy ground transportation into standardized aerial containers or specialized delivery pods optimized for UAV transport. Heavy-lift platforms, such as the L4 MQ-8C Fire Scout or L3 Postman, are primarily utilized to move these large-scale supply classes—specifically NATO Class I, Class III, and Class V—from rear echelons to forward Combat Trains Command Posts (CTCP).

The Air Corridor represents the middle-mile segment of the logistical chain, where autonomous navigation and active threat mitigation are paramount. During this phase, long-range platforms like the L3 Windracers Ultra Mk2 establish a persistent air bridge to ensure high-cadence supply flow, even when ground-based Main Supply Routes (MSRs) are compromised by enemy interdiction. These operations are remotely monitored by operators using BQL III/IV systems, which leverage real-time data fusion from reconnaissance assets to identify and bypass electronic warfare zones, thereby ensuring the integrity of the autonomous delivery route.

The final operational stage, the Target Hub, centres on the precise delivery of cargo to units at the Forward Line of Troops (FLOT) while maintaining maximum platform and personnel mobility. By employing non-landing delivery methods such as winch systems or parachute drops, logistical elements can provide critical supplies—notably Class VIII medical materiel and urgent Class V ammunition—without the drone becoming a static target. Agile L1 and L2 systems, including the Zip 1 and SkyFall Vampire, execute these tactical insertions at the squad and platoon levels, facilitating just-in-time resupply directly at the point of need.

7. Operational Validation: Tactical Supply Scenarios

The integration of the UAS-L taxonomy into modern military structures is validated through representative tactical missions where uncrewed systems provide a net operational advantage over traditional delivery methods. It is critical to recognize that purely uncrewed end-to-end delivery is currently constrained by energy density, weather sensitivity (UAS), and complex terrain negotiation (UGV); therefore, modern operations can implement a hybrid mothership architecture. This architecture presents a mechanism that synchronizes UAVs and delivery trucks or UGVs, where trucks can work as mobile launching and retrieval sites [36]. In this model, protected logistics nodes or crewed tactical carriers operate up to the edge of the threat envelope, while UAS assets execute final distribution over the most dangerous portion of the route. This synergistic combination improves resilience through redundancy and minimizes manpower exposure in kilometers-deep kill zones.

To convert the qualitative scenario discussion into a reproducible analytical step, the validation stage was formalized as a scenario-based MCDM problem. Contemporary MCDM-focused literature emphasizes that such methods are appropriate where alternatives must be compared across mutually conflicting quantitative and qualitative criteria and where part of the evidence is still expert-driven rather than purely statistical [37]. In logistics and UAV-related selection problems, AHP- and TOPSIS-family approaches are especially common because they preserve traceability between criteria importance, alternative performance and the final ranking [37, 38, 39]. For the purposes of this paper, however, a transparent weighted additive model was preferred over a fully fuzzy architecture, because the article operates at the level of doctrinal concept validation and does not yet rely on a large combat-validated numerical dataset.

Validation is performed through three representative tactical missions: urgent medical delivery (S1), ammunition top-up distribution during contact (S2), and routine sustainment of dispersed tactical-level positions (S3). These scenarios reflect modern threats, such as persistent ISR and precision fires, which transform traditional supply routes into kill zones.

Three operational alternatives were evaluated in each scenario: A1 - conventional crewed ground delivery; A2 - direct UAS delivery across the full last-mile segment; and A3 - a hybrid mothership architecture in which a truck or protected ground platform carries supplies to the edge of the threat envelope, and the final segment is executed by UAS. This structure is consistent with current truck-drone and collaborative delivery research, which shows that hybrid architectures are often preferable when payload, range and survivability requirements must be balanced [36, 38, 40]. The alternatives were assessed against five criteria: delivery time (T_d), delivered mass per time window (M_w), manpower exposure (P_e), expected loss sensitivity (L_s), and robustness under EW conditions (R_{ew}).

Because the available evidence combines open-source performance data, doctrinal logic and conflict observations, each criterion was transformed into an ordinal utility score on a five-point scale, where 1 denotes poor suitability and 5 denotes excellent suitability. The composite score of alternative (i) in scenario (s) was then calculated as a weighted sum of scenario-specific utilities, as shown in Equation 2. This formulation preserves analytical transparency and can be readily extended in future work to AHP-, TOPSIS- or fuzzy-TOPSIS-based implementations once calibrated field data become available [37, 39].

$$S_i^{(s)} = \Sigma_{j=1}^{5} w_j^{(s)} u_{ij}^{(s)}, \Sigma_{j=1}^{5} w_j^{(s)} = 1 \quad (2)$$

Scenario 1 (Urgent Medical Delivery/Time Priority) addresses urgent medical support where the primary operational indicator is delivery time (T_d), specifically concerning the Golden Hour threshold for surgical intervention. In high-intensity contested environments, traditional MEDEVAC helicopters face extreme risk from integrated air defences. This scenario validates the use of uncrewed systems as the preferred modality for NATO Class VIIIb (blood/plasma) transport, prioritizing rapid response without risking high-value crewed airframes.

Scenario 2 (Ammunition Top-up During Contact /Weight Priority) focuses on ammunition replenishment during high-intensity contact, where delivered mass (M_w) per time window is the priority indicator. Heavy tactical carriers move bulk NATO Class V supplies to the edge of the threat envelope, while L3 systems like the Postman or Kargo UAV execute the final, most dangerous segment of the delivery. This approach balances high-volume mass throughput with precise, safe delivery to the tactical edge, effectively replacing vulnerable ground convoys in primary strike zones while maintaining suppressive fire tempo.

Scenario 3 (Routine Sustainment of Dispersed Positions/Exposure Priority) explores the routine sustainment of dispersed tactical positions, emphasizing the minimization of manpower exposure (P_e) and predictable logistical tracks. Traditional supply methods for isolated units are easily tracked by persistent enemy ISR, significantly increasing the risk to logistics personnel. By utilizing dispersed swarms of L2 platforms, such as the Vampire or Elbit Thor, units can achieve high-cadence delivery of rations, water, and batteries while reducing "cost of transaction" by up to 96.5% compared to truck delivery. This modality enhances force protection by eliminating detectable ground signatures and creating a highly resilient, autonomous logistics network that adapts dynamically to threat evolution.

Scenario weights were assigned according to doctrinal priority. For S1, the weight vector was {T_d 0.40; M_w 0.05; P_e 0.25; L_s 0.20; R_{ew} 0.10}, reflecting the primacy of the Golden Hour and the need to avoid exposing personnel to high-risk extraction routes. For S2, the vector {T_d 0.10; M_w 0.35; P_e 0.20; L_s 0.15; R_{ew} 0.20} emphasized throughput while preserving survivability and mission continuity under contested electromagnetic conditions. For S3, the vector {T_d 0.15; M_w 0.10; P_e 0.45; L_s 0.15; R_{ew} 0.15} prioritized the reduction of predictable logistical tracks and manpower exposure over raw payload maximization. The scenario-specific weight vectors are displayed in Table 4.

Table 4.
MCDM input matrix - scenario-specific weight vectors

Scenario	**T_d**	**M_w**	**P_e**	**L_s**	**R_{ew}**
S1	0.40	0.05	0.25	0.20	0.10
S2	0.10	0.35	0.20	0.15	0.20
S3	0.15	0.10	0.45	0.15	0.15

The baseline scoring produced stable rankings fully consistent with the qualitative conclusions of this paper. In S1, the direct UAS option (A2) achieved the highest score (4.35), ahead of the hybrid option (A3; 3.95) and crewed delivery (A1; 2.05), confirming that time-critical Class VIII delivery is the clearest niche for uncrewed logistics. In S2, the hybrid architecture (A3) ranked first (4.00), followed by crewed delivery (3.25) and direct UAS delivery (2.95), which indicates that ammunition resupply under contact remains dominated by throughput constraints and benefits most from combining protected bulk movement with uncrewed final delivery. In S3, dispersed UAS delivery (A2) ranked first (4.20), slightly ahead of the hybrid option (4.00) and distinctly above crewed delivery (2.30), supporting the argument that distributed sorties and the removal of predictable ground signatures provide the greatest advantage in routine sustainment of dispersed forces. The resulting composite scores are summarized in Table 5.

Table 5.
MCDM result matrix - composite scores of evaluated alternatives

Scenario	**A1 Crewed**	**A2 Direct UAS**	**A3 Hybrid**	**Preferred modality**
S1	2.05	4.35	3.95	A2
S2	3.25	2.95	4.00	A3
S3	2.30	4.20	4.00	A2

A one-at-a-time sensitivity test was performed by varying each scenario weight by plus/minus 20% and renormalizing the vector. The preferred modality remained unchanged in all three scenarios, which indicates that the ranking is not an artefact of a single narrowly tuned weight set but a structurally robust result at the conceptual level. Methodologically, the proposed framework should therefore be understood as a defensible baseline for doctrine development: it is simple enough to be audited by commanders and logisticians, yet sufficiently formalized to support later substitution of empirical performance data, pairwise expert elicitation, stochastic loss rates or fuzzy assessments. In this sense, the MCDM layer strengthens the article by translating the proposed UAS-L taxonomy into an explicit decision rule for selecting crewed, uncrewed and hybrid last-mile support architectures.

Table 6.

Results of the MCDM - validation

Scenario	Priority Indicator	Preferred Modality	Rationale
S1	Time (T_d)	UAS (L-1/L-Med)	Speed without person risk
S2	Weight (M_w)	Hybrid (Truck + L-3)	Mass throughput + safe final delivery
S3	Exposure (P_e)	Dispersed UAS (L-2)	Elimination of predictable tracks

The analysis indicates that the highest-value niche for UxS is time-critical, low-to-medium payload delivery into the most threatened segment of the route, where convoy exposure dominates overall operational risk. Purely uncrewed end-to-end delivery remains constrained by energy and weather sensitivity and by terrain, obstacle negotiation and recoverability. Across scenarios, a hybrid mothership architecture is consistently favoured: protected logistics nodes or crewed carriers operate up to the edge of the threat envelope, while UAS/UGV execute the final delivery over the most dangerous portion—a tactic supported by contemporary literature [41, 42]. This pattern improves resilience through redundancy (distributed sorties instead of a single high-value convoy), supports dispersion by servicing multiple demand points, and enables rapid re-tasking—especially when employing multiple platforms coordinated as a swarm or fleet [43].

Limitations. This study relies exclusively on Open-Source Intelligence (OSINT), utilizing publicly available technical specifications, declassified NATO doctrinal publications, and open-source analyses of ongoing conflicts in Ukraine and the Middle East.

A further limitation is the deliberate omission of a comprehensive Life-Cycle Cost assessment. This exclusion is justified by the operational primacy of last-mile logistics in high-intensity environments, where force preservation and the maintenance of tactical tempo outweigh purely economic efficiency. Furthermore, the scenario validation using MCDM is based on conceptual tactical models; while these are informed by real-world observations, they represent idealized doctrinal patterns rather than large-scale, combat-validated statistical datasets.

8. Conclusions

The presented analysis confirms that the integration of uncrewed systems into last-mile logistics is a critical step for maintaining operational tempo and force survivability in contested environments. The primary scientific contribution of this research is the proposed UAS-L functional taxonomy, which provides significant qualitative advantages over current NATO and US DoD standards. By addressing the weight blindness inherent in legacy frameworks, this taxonomy categorizes assets according to their specific logistical capability, allowing logisticians to allocate resources with significantly higher precision. Furthermore, the introduction of the Payload Efficiency Ratio serves as a superior indicator of logistical utility, identifying high-capacity transport platforms that are often obscured in weight-based systems by extensive sensor suites or fuel weight.

Validation of the proposed concept through a Multi-Criteria Decision-Making matrix confirmed the structural robustness of the solution across diverse operational contexts. The results of the decision matrix clearly demonstrate that for time-critical, high-risk missions—such as medical resupply (S1)—direct UAS deployment is the optimal modality, maximizing delivery speed with zero personnel exposure (scoring 4.35). Conversely, for high-volume ammunition replenishment (S2), the matrix validated a clear preference for hybrid architectures (scoring 4.00), which combine protected bulk movement with uncrewed final delivery to the tactical edge. This methodological approach offers to transform the UAS-L taxonomy from a theoretical framework into a decision-support tool for commanders. Successful implementation of these findings within military structures, particularly through integration into Forward Support Companies, will enhance logistical resilience in contested environments.

Acknowledgements. This work was supported by the Ministry of Defence of the Czech Republic under the project Implementation of new technologies and procedures into the logistic support of the Army of the Czech Republic (DZRO-FVL22-INTAL).

References

1. ROUTE4ME. What Is Last Mile Logistics in 2025? Trends and Software [online]. 2025 [accessed 2026-02-04]. Available at: https://support.route4me.com/faq/what-is-last-mile-logistics/.
2. ATS LOGISTICS. Last Mile Logistics: Strategies for Timely and Cost-Effective Deliveries [online]. ATS Logistics, 2025 [accessed 2026-02-04]. Available at: https://atslogistics.com/last-mile-logistics-strategies/.

3. HEADQUARTERS, DEPARTMENT OF THE ARMY. ATP 4-90: Brigade Support Battalion. Washington, DC: Department of the Army, 2026. Army Techniques Publication, No. 4-90.
4. MICHALSKI, Konrad and Marek NOWAKOWSKI. The use of unmanned vehicles for military logistic purposes. Ekonomika i Organizacja Logistyki [online]. 2020, vol. 5, no. 4, pp. 43–57 [accessed 2026-02-04]. ISSN 2450-8055. Available at: https://doi.org/10.22630/EIOL.2020.5.4.28.
5. UNMANNED SYSTEMS TECHNOLOGY. Breakthroughs in Unmanned Systems in 2025: Best New Technologies, Platforms & Innovations [online]. 2025-12 [accessed 2026-02-04]. Available at: https://www.unmannedsystemstechnology.com/2025/12/breakthroughs-in-unmanned-systems-in-2025-best-new-technologies-platforms-innovations/.
6. JAZAIRY, Ahmed et al. Drones in last-mile delivery: a systematic literature review from a logistics management perspective. The International Journal of Logistics Management [online]. 2024, vol. 36, no. 7, pp. 1–62 [accessed 2026-02-04]. ISSN 0957-4093. Available at: https://doi.org/10.1108/IJLM-04-2023-0149.
7. TARASOV, A. Is drone-based resupply viable? European Security & Defence (ESD) [online]. 2025-10-17 [accessed 2026-02-04]. Available at: https://euro-sd.com/2025/10/articles/armament/47250/is-drone-based-resupply-viable/.
8. KING, Jon Michael. Contested Logistics Environment Defined. Army Sustainment [online]. Winter 2024, vol. 56, no. 1, pp. 46–49 [accessed 2026-04-20]. Available from: https://asu.army.mil/alog/ARCHIVE/PB7002401FULL.pdf.
9. SABOUR, M. H., P. JAFARY and S. NEMATIYAN. Applications and classifications of unmanned aerial vehicles: A literature review with focus on multi-rotors. The Aeronautical Journal [online]. 2023, 127(1310), pp. 466–490 [accessed 2026-04-30]. Available from DOI: 10.1017/aer.2022.75.
10. GILMORE, Christopher K., Michael CHAYKOWSKY and Brent THOMAS. Autonomous Unmanned Aerial Vehicles for Blood Delivery: A UAV Fleet Design Tool and Case Study [online]. Santa Monica, Calif.: RAND Corporation, 2019 [accessed 2026-04-29]. RR-3047-OSD. ISBN 978-1-9774-0346-9. Available from: https://www.rand.org/t/RR3047.
11. PETERS, John E., Somi SEONG, Aimee BOWER, Harun DOGO, Aaron L. MARTIN and Christopher G. PERNIN. Unmanned Aircraft Systems for Logistics Applications [online]. Santa Monica, CA: RAND Corporation, 2011 [accessed 2026-04-29]. ISBN 978-0-8330-5044-1. Available from: https://www.rand.org/pubs/monographs/MG978.html.
12. NATO STANDARDIZATION OFFICE. NATO STANAG 4670 – ATP-3.3.8.1 (Edition B, Version 1): Minimum training requirements for unmanned aircraft systems (UAS) operators and pilots. NATO Standardization Office, 2019. pp. 2-2 [accessed 2026-04-20]. Available from: https://nso.nato.int/nso/nsdd/main/standards/ap-details/2678.
13. U.S. DEPARTMENT OF DEFENSE (DoD). Department of Defense Unmanned Aircraft Systems Airspace Integration Plan [online]. Washington, D.C.: Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, 2011 [accessed 2026-03-25]. Available from: http://www.acq.osd.mil/sts/docs/DoD_UAS_Airspace_Integ_Plan_v2_(signed).pdf.
14. G, C., G. GOWDA, A. SAYEEGANESH and R. VANNARTH. High Payload Fraction UAV Design and Performance Evaluation. SAE International Journal of Advances and Current Practices in Mobility [online]. 2025, **7**(2), pp. 934–944 [viewed 2026-04-30]. Available from DOI: 10.4271/2024-26-0442.
15. SAE INTERNATIONAL. Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Driving Automation Systems (J3016_202104) [online]. April 2021 [accessed 2026-04-21]. Available from: https://www.sae.org/standards/content/j3016_202104/.
16. MINISTRY OF DEFENCE OF UKRAINE. The Basic Qualification Levels for UAV operators have been finalized. MoD News [online]. [accessed 2026-04-21]. Available from: https://www.mil.gov.ua/en/news/2024/04/10/the-basic-qualification-levels-for-uav-operators-have-been-finalized/.
17. ZIPLINE. Zipline Fact Sheet: Our delivery platforms [online]. 2024 [accessed 2026-04-21]. Available from: https://www.zipline.com/about/zipline-fact-sheet.
18. ELBIT SYSTEMS. THOR: Military multi-purpose UAS [online]. 2025 [accessed 2026-04-21]. Available from https://www.elbitsystems.com/sites/default/files/2025-03/thor_2025_7.pdf.
19. AEROROZVIDKA. Aerorozvidka R18. In: Grokipedia [online]. [accessed 2026-04-21]. Available from: https://grokipedia.org/wiki/Aerorozvidka_R18.
20. MALLOY AERONAUTICS. T150: Heavy Lift UAS [online]. [accessed 2026-04-21]. Available from: https://www.malloyaeronautics.com/heavy-lift-uas/t150.
21. MINISTRY OF DEFENCE OF UKRAINE. The Vampire: A drone that terrifies enemies and assists Ukrainians. MoD News [online]. [accessed 2026-04-21]. Available from: https://mod.gov.ua/en/news/the-vampire-a-drone-that-terrifies-enemies-and-assists-ukrainians.
22. KAZHAN. Kazhan E620 & E630: Rugged military-grade drones for munitions deployment & logistics [online]. [accessed 2026-04-21]. Available from: https://kazhan.ua/en/e620-e630.
23. UKRSPECSYSTEMS. PD-2 UAS with 200+ km effective range [online]. [accessed 2026-04-21]. Available from: https://ukrspecsystems.com/drones/pd-2-uas.
24. UADEFENSE. UADEFENSE Presents Line of Strike and Logistics Drones [online]. [accessed 2026-04-21]. Available from: https://uadefense.com/en/news/uadefense-presents-line-of-strike-and-logistics-drones.

25. Windracers ULTRA Drone - Full Specifications. TheDefenseWatch.com [online]. [accessed 2026-04-21]. Available from: https://thedefensewatch.com/product/windracers-ultra-drone/.
26. MIDDLE EAST ONLINE. Iran unveils advanced 'Mohajer-10' drone with enhanced range. MEO [online]. August 22, 2023 [accessed 2026-04-21]. Available from: https://middle-east-online.com/en/iran-unveils-advanced-mohajer-10-drone-enhanced-range.
27. PIASECKI AIRCRAFT CORPORATION. KARGO II UAV [online]. [accessed 2026-04-21]. Available from: https://piasecki.com/aircraft/kargo-ii/.
28. RUAVIATION. The Perun attack and transport UAV is capable of evacuating the wounded and firing ATGMs [online]. August 21, 2024 [accessed 2026-04-21]. Available from: https://www.ruaviation.com/news/2024/8/21/24255/.
29. NORTHROP GRUMMAN. Fire Scout [online]. [accessed 2026-04-21]. Available from: https://www.northropgrumman.com/what-we-do/aircraft/fire-scout.
30. BAE SYSTEMS. T-Series Heavy Lift Uncrewed Air Systems (UAS) [online]. [accessed 2026-04-21]. Available from: https://www.baesystems.com/en/product/t-series-uncrewed-air-systems.
31. ISRAEL AEROSPACE INDUSTRIES. Heron TP: High-Endurance Drone for Long Missions [online]. [accessed 2026-04-21]. Available from: https://www.iai.co.il/p/heron-tp.
32. DRONAMICS. Autonomous Logistics [online]. [accessed 2026-04-21]. Available from: https://www.dronamics.com/.
33. ACKERMAN, Evan and KOZIOL, Michael A. The blood is here: Zipline's medical delivery drones are changing the game in Rwanda. IEEE Spectrum. 2019, vol. 56, no. 5, pp. 24-31.
34. GUBÁŠ, František. Feasibility of Casualty Evacuation by Unmanned Systems [online]. In: Proceedings of the Challenges to National Defense in Contemporary Geopolitical Situation. Brno, 2024, pp. 29–37 [accessed 2026-04-30]. ISSN 2538-8959. Available from DOI: 10.3849/cndcgs.2024.29.
35. Royal Navy Ship to Ship Delivery by Drone. Joint Forces News [online]. September 19, 2025 [accessed 2026-04-20]. Available from: https://www.joint-forces.com/uk-operations/84932-royal-navy-ship-to-ship-delivery-by-drone.
36. Das, D.N., Sewani, R., Wang, J. and Tiwari, M.K. Synchronized truck and drone routing in package delivery logistics, IEEE Trans. Intell. Transp. Syst., 2020, pp 1–11. doi: 10.1109/tits.2020.2992549.
37. TAHERDOOST, Hamed and Mitra MADANCHIAN. A Comprehensive Survey and Literature Review on TOPSIS. International Journal of Service Science, Management, Engineering, and Technology [online]. 2024, vol. 15, no. 1, pp. 1–65 [accessed 2026-04-23]. Available from: https://doi.org/10.4018/IJSSMET.347947.
38. DEB, Mousumi, Soumya JENA and Subhadip BISWAS. Determining sustainable last mile delivery mode from courier express & parcel establishments using Fuzzy-AHP and Fuzzy-TOPSIS: a case study of large, medium & small-sized Indian cities. Innovative Infrastructure Solutions [online]. 2026, vol. 11, article 197 [accessed 2026-04-23]. Available from: https://doi.org/10.1007/s41062-026-02611-3.
39. YALÇIN, Galip Cihan and Güvenç ARSLAN. Unmanned Aerial Vehicle Selection with Different MCDM Methods in Defense Industry. Journal of Industrial Intelligence [online]. 2026, vol. 4, no. 1, pp. 1–11 [accessed 2026-04-23]. Available from: https://doi.org/10.56578/jii040101.
40. DUAN, Jie, He LUO and Guoqiang WANG. Approaches to the truck-drone routing problem: A systematic review. Swarm and Evolutionary Computation [online]. 2025, vol. 92, article 101825 [accessed 2026-04-24]. Available from: https://doi.org/10.1016/j.swevo.2024.101825.
41. PARAZERO. The Last Mile Problem: Re-Thinking Modern Aerial Logistics [online]. ParaZero Blog, 2025-11-11 [accessed 2026-02-04]. Available at: https://parazero.com/2025/11/11/the-last-mile-problem-re-thinking-modern-aerial-logistics/.
42. MINCULETE, Gheorghe. Military Logistics Drones: The Innovative Solution for Transportation Challenges on the Battlefield. Land Forces Academy Review [online]. 2025, vol. XXX, no. 2(118), pp. 342–354. [accessed 2026-02-14]. Available at: https://reference-global.com/article/10.2478/raft-2025-0033.
43. THORNTON, S. and G. GALLASCH. Swarming Logistics for Tactical Last-Mile Delivery [online]. Defence Science and Technology Group (DSTG), 2018 [accessed 2026-02-04]. Available at: https://www.dst.defence.gov.au/sites/default/files/basic_pages/documents/ICSILP18_IntSes-Thornton_Gallasch-Swarming_Logistics_for_Last-Mile_Logistics.pdf.