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Ishchenko Valentyn

Expert in fire safety, emergency rescue operations and high-altitude engineering and technical works

(Ukraine)

STRATEGIES FOR ORGANIZING EMERGENCY-RESCUE OPERATIONS IN ACCESS-CONSTRAINED ENVIRONMENTS

Summary. *Against the backdrop of increasingly frequent and complex global disasters, emergency rescue operations in restricted-access environments (collapsed structures, high-rise developments, confined spaces) represent one of the most intractable challenges for emergency response systems. The aim of the study is to systematize and critically analyze current strategies for organizing such operations in order to develop an integrative model that combines adaptive management, breakthrough technological solutions, and the targeted development of human capital. The methodological basis includes a systematic review of scholarly publications in the Scopus and Web of Science databases and a content analysis of sectoral reports (UNDRR, CRED). The analysis revealed that traditional hierarchical schemes, exemplified in particular by the Incident Command System (ICS), prove insufficiently flexible in highly chaotic, multi-actor operational environments. The effectiveness of contemporary interventions is determined by a transition to networked forms of coordination grounded in the concept of distributed situational awareness (DSA), shaped through the integration of AI technologies, UAVs, and robotic platforms. Tactical models for typical scenarios are examined, including the REALE procedure for operations in confined spaces. As a result, an integrative model is proposed that synthesizes flexible management loops, technological support, and the human factor as a* *unified framework for improving the efficiency and safety of rescue operations. The materials presented in the article will be of interest to heads of emergency rescue services, risk management specialists, developers of technologies for emergencies, and researchers in the fields of security and crisis management.*

Key words: *emergency rescue operations, restricted access, Incident Command System, Common Operational Picture, unmanned aerial vehicles, human factor, decision-making, interdisciplinary training, high-rise buildings, confined spaces.*

Introduction. The contemporary situation is characterized by a rapid increase in the frequency and severity of disasters of both natural and technological origin. Global drivers—climatic shifts, uncontrolled urbanization, and deeply interwoven infrastructural interdependence—transform local incidents into complex cascading crises. According to the Centre for Research on the Epidemiology of Disasters (CRED), in 2023 there were 399 natural disasters, resulting in 86 473 human casualties and economic losses of USD 202.7 billion [1]. A special report by the United Nations Office for Disaster Risk Reduction (UNDRR, GAR 2024) notes a further systematization of risks and that insufficient preparedness turns hazardous events into full-scale catastrophes [2].

Against this background, the organization and conduct of emergency and rescue operations under restricted-access conditions acquire key importance. Such conditions are understood as environments in which basic procedures of reconnaissance, gaining access to victims, providing assistance, evacuation, and maintaining communications are sharply impeded or fundamentally unavailable. Within the present study they include:

- Structurally unstable objects, that is, buildings and structures partially or completely destroyed as a result of earthquakes, explosions, or structural defects and accompanied by a high risk of secondary collapses.

- High-rise buildings - objects with complex vertical logistics, a high concentration of people, and a specific dynamics of hazardous fire factors (OFP), above all smoke and elevated temperatures [3].

- Confined and limited spaces (confined spaces): industrial tanks, wells, underground utilities with complex geometry, a deficit of natural lighting, and a potentially hazardous atmosphere (toxic gases, lack of oxygen) [5].

- Non-Line-of-Sight (NLOS) zones: situations in which physical obstacles (walls, debris) shield radio signals, rendering standard means of communication and navigation, including GPS, unusable [4].

The scientific problem addressed by this work lies in the insufficient systematization and integration of knowledge about strategies of action under the listed conditions. Despite progress in individual areas—the improvement of management systems, the introduction of robotic means, the development of tactical techniques—the literature lacks a holistic approach that allows these components to be considered in interconnection. Command systems, technologies, and the human factor are often analyzed separately, which hinders the formation of an adaptive, coherent strategy.

The aim of the study is to systematize and analyze contemporary strategies for organizing emergency and rescue operations under restricted-access conditions and to propose an integrative model that combines adaptive management systems, breakthrough technological solutions, and approaches to the development of human capital.

The author's hypothesis is that the highest effectiveness of rescue operations under restricted-access conditions is achieved not by isolated improvement of individual components (technologies, protocols) but by the synergy of three key elements: a flexible networked management model capable of adaptation under conditions of chaos; technological support that ensures distributed situational awareness in real time; and a high level of interdisciplinary training of personnel that enables adequate decision-making under extreme stress and high cognitive load.

The scientific novelty lies in the development of a conceptual integrative model that synthesizes adaptive approaches to command, technological mechanisms for forming distributed situational awareness (DSA), and tactical protocols taking into account the cognitive aspects of the human factor, thereby creating a unified theoretical framework for the analysis and planning of complex rescue operations.

Materials and methods. Research on the organization of emergency rescue operations (ACP) in restricted-access environments coalesces around four intersecting clusters: the risk landscape and the institutional governance framework; command-and-coordination mechanisms and the common operational picture (COP); domain-specific methods for hard-to-access scenarios (high-rise fires, confined spaces); techno-human means for ensuring traversability, situation perception, and decision making. Together these strands form an architecture in which strategic risk planning is linked to tactical procedures and technological perception–decision–action loops.

At the macro level, the risk landscape and institutional requirements set the direction for ACP strategies. EM-DAT/CRED [1] record for 2023 an increase in aggregate exposure to extreme events and a growing complexity of access conditions to casualties. UNDRR (GAR Special Report 2024) [2] and UNDRR (GAR 2025) [9] point to real-time systemic data integration and interagency interoperability as preconditions for a resilient response. Wang Y., Zou Z., Zhou M. [8] justify the institutionalization of socialized (non-state) rescue formations with emphasis on standards, communication channels, and procedural compatibility. OSHA [10] underscore that a call 911 strategy is unacceptable for work in confined spaces: preplanned arrangements, specialized teams, and equipment are required.

The command-and-coordination subsystem and the common operational picture (COP) form the basis of operations in constrained/fragmented environments. Jensen J., Thompson S. [11] note that ICS is scalable and structures roles and resources, but struggles in interagency work and under high information turbulence. Moynihan D. P. [12], using cases from wildfires to Katrina, identifies the conditions for ICS success and the vulnerabilities of hierarchies when communications and SA collapse. Rubens D. [13] proposes a supra-hierarchical command paradigm—decentralized decision making and networked interaction of knowledge carriers—in response to extreme events. Treurniet W. [14] conceptualizes COP as a means of joint sensemaking in response networks and points to the risks of overload and false coherence when source quality is low. Tatham P., Spens K., Kovács G. [15] propose the humanitarian HCLOP as the logistical core of COP, reducing the transaction costs of inter-agent coordination. O'Brien A., Read G. J. M., Salmon P. M. [16] systematize models of situation awareness (SA) for multi-agent response and show a shortage of validated methods for (DSA), whereas O'Brien A. [17] applies DSA empirically to improve interagency interaction in natural disasters.

Disciplinary methods for restricted-access environments illustrate how strategic principles materialize tactically. Hu Y. L., Wang F. Y., Liu X. W. [3] build an ACP framework (agent–cyber–physical) for evacuation in high-rise fires, integrating modeling, control, and execution. Li K. et al. [4] and Jiang H. [7] describe autonomous–cooperative deployment of arrays of mobile base stations in vertically shielding built environments as a strategy of communications first, maneuver second. Selman J. et al. [5] propose for confined spaces a risk-reduction procedure: extended gas monitoring, a hierarchy of hazard controls, readiness of the rescue trio, and extraction/belay techniques. Rudolph S. S. et al. [6], in a clinical–applied review, emphasize airway management algorithms in constrained geometry, indicating the selection of compact devices and stepwise maneuvers; OSHA [10] codify the requirement for plans and on-call teams for permit-required confined spaces.

The technological layer provides visibility and accessibility where human presence is limited. Zhang Y. et al. [18] systematize air–ground pairings

(UAV/UGV) for mapping and navigation in GPS-denied, smoke-filled, and topologically complex environments. Schroth C. A. et al. [23] demonstrate a semi-autonomous SFCW radar on a robot for locating victims and assessing vital signs through obstacles—critical for rubble and smoke–gas environments. Dimou A. et al. [22], under FAST-er, integrate AR interfaces, indoor positioning, and robots into a unified operational–training ecosystem for first responders. Calle Müller C., Lagos L., Elzomor M. [19] review disruptive technologies (AI, IoT, digital twins), showing benefits when data flows are standardized and platforms are connected. Training–simulation approaches assess skill transferability: Liu D. et al. [21] treat simulation fidelity as a multidimensional construct (physical/functional/psychological), Willett M. M., Demir M. [20] identify a nonlinear influence of team cognitive load and compliance with DSS advice on USAR effectiveness, and Reale C. et al. [24] systematize markers of quality decision making under uncertainty (sensemaking, calibration of trust in automation, opportunistic heuristics).

The literature diverges between the universalism of ICS and the requirements of adaptive networked structures: Jensen J., Thompson S. [11] and Moynihan D. P. [12] defend the conditions for ICS success, whereas Rubens D. [13] and Treurniet W. [14] argue for the need for decentralization and a smart COP sensitive to data quality. Technological optimism (robotics, through-wall radar, mass communications) in [4; 7; 18; 23] confronts constraints of the real environment (multipath, energy, smoke). In the clinical–tactical segment, tension persists between strict regulation and the need for improvisation in airway management under constrained conditions (Selman J. et al. [5]; Rudolph S. S. et al. [6]; OSHA [10]). The following directions remain weakly illuminated: end-to-end performance metrics (from time to communications restoration to team cognitive balance) on real incidents; interface/protocol standards for stitching robotics data streams into the COP under channel degradation; cross-domain evacuation/medical algorithms for vulnerable groups in high-rise and underground environments; legal/ethical aspects of through-wall sensors and behavioral analytics; operationalization of the participation of socialized organizations in formal ICS with clear accountability and mutual learning (Wang Y., Zou Z., Zhou M. [8]).

Results and Discussion. The Incident Command System (ICS) is a unified hierarchical paradigm for organizing command, control, and coordination in emergency response [11]. Initiated in the United States in the 1970s as a response to the problem of wildland fires, ICS gained wide adoption due to its modularity, common terminology, and clearly delineated functional boundaries; collectively, these properties make it effective for resolving routine, localized events with relatively predictable dynamics [11].

At the same time, large-scale and turbulent disasters, compounded by limited access to operational zones, have exposed several fundamental deficiencies of this construct. An analysis of the aftermath of Hurricane Katrina showed that a rigid command hierarchy proved unable to adapt within a rapidly changing multi-actor environment, which led to a functional breakdown of the system [12]. The key vulnerabilities of the hierarchical model under such conditions include:

1. Information overloads: the centralized chain of command creates bottlenecks in which the top-level leader becomes saturated with incoming data, slowing decision-making.

2. Low adaptability: a rigid hierarchy responds belatedly to rapid changes in the situation at the emergency site.

3. Integration challenges: ICS has difficulty incorporating unanticipated participants — volunteer groups and interagency forces unfamiliar with its procedures [12].

In response to these challenges, a demand has emerged within the scholarly and practitioner communities for more flexible, networked, or hybrid management models. Drawing on the concept of organizational resilience (organizational resilience), such approaches entail the decentralization of authority, the strengthening of horizontal ties, and the deployment of adaptive teams capable of operating effectively under conditions of high uncertainty [13].

At the same time, tension persists between normative doctrine and operational reality. Despite accumulated evidence of the limited effectiveness of rigid hierarchy in complex crises, ICS de jure continues to serve as the backbone of public policy in emergency management across many countries [12]. This is sustained by the legal certainty and accountability provided by ICS, the high cost of fully overhauling personnel training systems, and bureaucratic inertia. Consequently, the most pragmatic course is not the abandonment of ICS, but the development of adaptive protocols that enable rapid switching between strict hierarchy and networked interaction depending on the scale, complexity, and tempo of the emergency's evolution.

Technological progress is radically rethinking the organization of rescue operations, especially under constrained access. The central task becomes constructing the most comprehensive and up-to-date picture of events to support well-grounded decision making. The classical concept of a Common Operational Picture (COP), focused on aggregating and displaying data in a single center, is transforming into a more dynamic model — Distributed Situation Awareness (DSA) [14]. Unlike COP, DSA shifts the emphasis from a centralized repository to continuous interaction and exchange of relevant information among all elements of the system — people, robots, sensor networks — with the aim of producing a shared, common understanding of the situation [16]. The formation of DSA is achieved through the integration of breakthrough technologies (Table 1).

Table 1

Comparative analysis of technologies for operations in constrained-access environments

Technology	Key applications in constrained-access environments	Advantages	Limitations
UAVs (drones)	Aerial reconnaissance, 3D mapping, communication relay, establishment of local navigation networks (NLOS)	Rapid deployment, high mobility, safety for personnel	Limited flight time, weather dependence, low payload capacity, vulnerability in GPS-denied areas
Ground robots (UGV)	Penetration under rubble, casualty search, delivery of medical supplies and equipment, assessment of structural integrity	Capability for physical interaction with objects, higher payload capacity, extended operating time	Limited terrain traversability, low speed, control complexity
Artificial intelligence (AI) and machine learning (ML)	Analysis of data from sensors and UAVs, predictive modeling of hazard propagation, route optimization, decision support	Processing of massive data volumes, discovery of hidden patterns, reduction of cognitive load (in theory)	Data quality requirements, difficulty interpreting results, risk of automation bias
Wearable sensors	Monitoring of responders' physiological state, location tracking, hazardous gas detection	Improved personnel safety, real-time data collection	Limited battery life, potential distraction

Source: compiled by the author based on [4; 6; 8; 18; 19; 22]

Artificial intelligence and machine learning constitute a key toolkit for real-time analytics of data streams originating directly from the disaster area. Algorithms in real time assess damage to infrastructure, model the dynamics of a fire front or the drift of a toxic plume, and synthesize optimal routes for rescue units, effectively functioning as an intelligent advisor to the operations commander [19].

Unmanned platforms become remote receptors for rescuers. UAVs are important for rapid reconnaissance under non-line-of-sight (NLOS) conditions, for deploying temporary communications, and for high-precision indoor positioning when GPS is unavailable [4; 7]. Complementary deployment of aerial and ground robots (UAV–UGV) addresses complex tasks: the UAV provides overhead coordination from the air, whereas the ground robot (UGV) performs operations directly in the hazardous zone [9; 18].

However, technologization also engenders a critical risk — cognitive overload of the operations commander. Multichannel streams of telemetry and video data from dozens of drones, robots, and sensors can, rather than accelerating, block decision-making [19]. Under extreme stress and stringent time constraints, the human brain tends to switch to heuristics, in particular to the recognition-primed decision model (RPD) [24], whereby complex analytics may be ignored. Empirical data show: under high cognitive load, teams less often follow the recommendations of an AI assistant, even when they are objectively correct [20].

Therefore, the implementation strategy should shift not toward maximizing data collection but toward designing human-centered interfaces and decision support systems. These systems must automatically filter out informational noise, highlight critically important signals, and present them in an intuitively readable form, reducing — not increasing — the cognitive load on the commander (figure. 1).

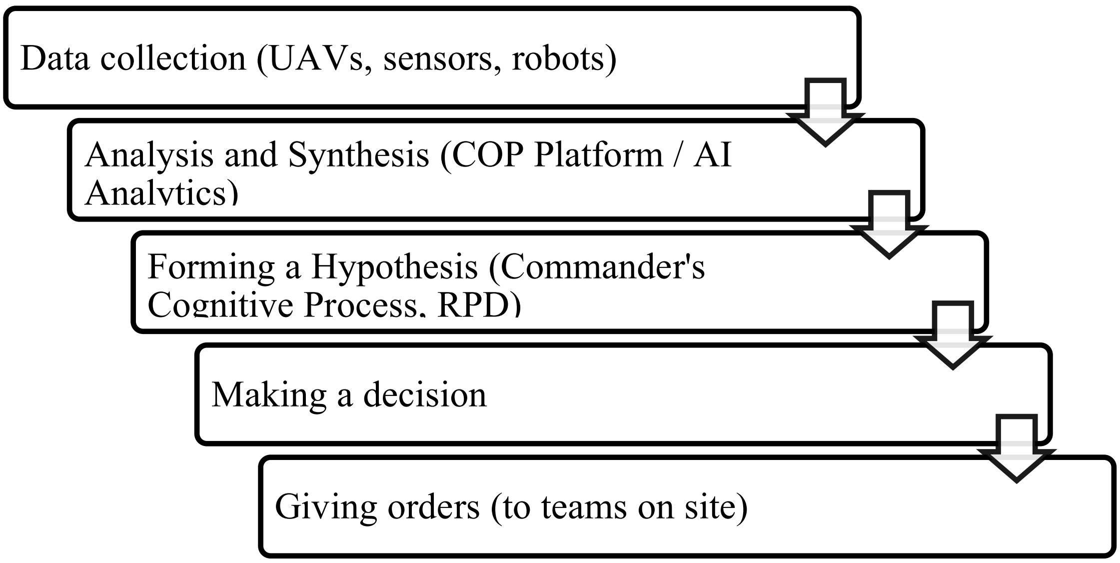

Fig. 1. The decision-making cycle in a technologically saturated environment

Source: compiled by the author based on [15; 19; 20; 24]

General strategic principles require contextual adaptation to specific restricted-access scenarios. Thus, in the case of high-rise buildings, during fires and other emergencies the main difficulties are associated with the mass movement of people along a small number of evacuation routes and with maintaining the safety and coordination of the rescuers' actions within a complex three-dimensional spatial configuration [3]. Conventional navigation and communication means often prove inadequate due to the absence of GPS and the shielding of radio signals by building structures [4; 16]. For evacuation management, the ACP approach (Artificial systems, Computational experiments, Parallel execution) is promising: a digital twin of the facility is created based on agent-based modeling, which makes it possible to compute optimal and safe routes in real time, taking into account the dynamics of hazardous factors and the current load on exits [3]. For accurate positioning of rescuers, it is advisable to employ swarms of UAVs that autonomously deploy a temporary local navigation network inside the building, for example based on ultra-wideband (UWB) technology, providing accuracy up to one meter [4; 21].

Confined spaces are characterized by high risk due to hazardous atmospheres (asphyxia, intoxication), sudden collapses, explosions, and limited maneuvering space [5]. Statistical data indicate that a substantial share of fatalities occurs among rescuers who attempted to provide assistance without adequate training and equipment. To reduce risks, the standardized five-stage REALE procedure is used — a clear sequence of actions [5]:

1. Reconnaissance: prior to any operations, detailed information is collected about the site, the nature of threats, and the condition of the casualty.

2. Elimination: isolation of energy sources is performed, forced ventilation is organized, atmospheric monitoring and stabilization of structures are carried out.

3. Access: access to the casualty is ensured via the safest possible route with the involvement of the minimum necessary number of rescuers.

4. Life-saving first aid: on-site stabilization is performed, with priority given to airway management in confined spaces (CSAM).

5. Extrication: safe transport of the casualty out of the confined space is carried out.

The application of REALE relies on strict adherence to two hierarchies: the hierarchy of protection (safety priorities: 1) rescuers, 2) bystanders, 3) the casualty) and the hierarchy of rescue methods (preferred: 1) self-rescue, 2) rescue without entry into the hazard zone, 3) rescue with entry). Detailed pre-planning and risk assessment prior to entry are critically important [10; 17; 23]. The matrix specifying the application of the REALE model is presented in Table 2.

Table 2

Risk matrix and response strategies in confined spaces based on the REALE model

REALE stage	Key tasks	Potential risks	Mitigation and control measures	Required equipment
Reconnaissance	Collection of information about the site, casualties, hazards	Incomplete or inaccurate information	Study of plans, interviewing witnesses, use of technical reconnaissance tools	Technical documentation, cameras, UAVs
Elimination	Isolation of energy sources, ventilation, stabilization of structures	Atmospheric (gases, O2), electrical, mechanical (collapse)	Lockout/tagout , forced ventilation, installation of supports	Gas analyzers, fans, self-contained breathing apparatus
Access	Reaching the casualty with minimal risk	Injuries during entry, worsening of the casualty's condition	Selection of the optimal route, use of the minimum necessary number of rescuers	Mountaineering gear, cutting tools, RPE
Life-saving aid	Stabilization of the casualty on site	Limited working space, time deficit	Priority on maintaining breathing and stopping hemorrhage (CSAM)	Medical kit for confined spaces, immobilization devices

Extrication	Safe extrication of the casualty	Injury during transport, entrapment	Use of special stretchers, block and tackle systems, vertical/horizontal lift	Flexible stretchers, winches, full-body safety system (harness)

Source: compiled by the author based on [5; 10; 17; 23]

Despite technological progress, the human being — the bearer of responsibility and meaning — invariably remains at the center of any rescue operation. A team's effectiveness is determined less by its equipment than by the level of training, resilience to stress, and the ability to make rapid and accurate decisions under extreme conditions.

Cognitive studies provide compelling evidence: in crises characterized by high stress and time pressure, experienced leaders (for example, shift commanders) do not resort to slow, exhaustive comparison of alternatives but rely on an intuitive pattern-recognition model — Recognition-Primed Decision (RPD) [24]. In essence, they instantly match the current configuration of events with a repertoire of familiar patterns and select the first sufficiently workable course of action. The effectiveness of RPD is directly proportional to the volume and relevance of the leader's prior experience. At the same time, pronounced stress, fatigue, and cognitive overload can distort recognition of the situation and trigger erroneous, sometimes catastrophic decisions [24].

Practice shows that personnel training is often insufficient. Surveys among healthcare workers and rescuers record a critical deficit: up to 65,6% of respondents had no prior training for mass-casualty incidents. The absence of joint interdisciplinary drills among services (firefighters, medical personnel, police) leads to blurred roles, communication failures, and organizational chaos at the scene of an emergency. At the same time, the effectiveness of simulation-based training has been repeatedly confirmed: in a safe and controlled environment it enables refinement of technical skills and team coordination, strengthening staff confidence and stress resilience [17; 19; 24].

A representative model of the required synthesis of competencies is the author's profile, combining experience in operational leadership, engineering training, and practical skills. A case analysis (18 years of service in ГСЧС as a shift commander, engineering education, 17 years of high-altitude work) demonstrates the archetype of the specialist of the future: such a professional does not limit themselves to following protocols but conducts a holistic assessment of the situation — thinking strategically as a leader; as an engineer, understanding the behavior of structures and systems; and as a practitioner of high-altitude work, accounting for the nuances of operating under extremely demanding conditions.

This logic leads to the concept of the T-shaped specialist as a staffing benchmark for modern rescue services. Depth in the core domain (the vertical of the T) is combined with a broad spectrum of adjacent competencies (the horizontal), enabling such integrators to operate effectively at disciplinary boundaries, connect heterogeneous teams, and make unconventional yet uniquely correct decisions in unique and complex emergencies. Formation of such a personnel core requires rethinking learning trajectories and career development, encouraging the acquisition of adjacent qualifications and the accumulation of diverse experience.

Conclusion. The conducted study provided a coherent systematization and in-depth analysis of strategies for organizing emergency rescue operations under access-constrained conditions, thereby empirically confirming the initial premise of the need to shift from fragmented practices to a single integrative paradigm.

The main results can be formulated as follows:

1) Hierarchical management models, including ICS, while sufficient for regulated scenarios, exhibit significant limitations in highly variable, nonlinear, and multi-agent contexts typical of contemporary disasters. A promising development vector is hybrid adaptive architectures that combine a regulated vertical with distributed network plasticity.

2) Breakthrough-class technologies (AI, UAVs, robotics, sensor networks)

cease to play the role of auxiliary means and become a structure-forming core that shifts practice from a centralized Unified Operational Picture to a model of Distributed Situational Awareness. Their deployment should be accompanied by human-centered interface design in order to minimize cognitive load on the staff and commanders.

3) The human factor retains the status of a determining element. The final effectiveness is defined not only by the level of technological equipment but also by the preparedness of personnel to make decisions under time pressure and stress (the RPD model), as well as by the degree of coherence of interdisciplinary interaction. The personnel strategy of rescue services should purposefully cultivate T-shaped specialist-integrators.

Consequently, the stated goal has been achieved: a conceptual integrative model has been substantiated that synthesizes three mutually complementary components — adaptive management, a technological platform, and the human factor. Their coordinated coupling establishes the basis for designing effective and safe emergency response strategies precisely in the most challenging — access-constrained — conditions.

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