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Reconstruction of Critical Industrial Complexes After Artillery Fire in Wartime Conditions

Obnova kritických průmyslových komplexů po dělostřelecké palbě v podmínkách války

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Abstract: The study focuses on the methodologies and strategic implications of restoring industrial complexes in post-conflict environments. Drawing on empirical evidence from the war in Eastern Europe, it links NATO engineering doctrine with approaches to damage assessment and stability classification. It proposes damage categorisation and prioritisation of reconstruction based on structural degradation and external system dependencies. Key strategies include mobile engineering teams, improvised materials, and limited documentation. The study also highlights the need to protect sensitive information generated during recovery. A combined approach ensures efficient reconstruction and national defence resilience.

Abstrakt: Studie se zaměřuje na metodiky a strategické dopady obnovy průmyslových komplexů po ozbrojeném konfliktu. Vychází z empirických poznatků z války ve východní Evropě a propojuje doktrínu NATO s přístupy k hodnocení poškození a klasifikaci stability. Navrhuje kategorizaci destrukce a stanovení priorit obnovy dle míry konstrukční degradace a závislosti na vnějších systémech. Klíčové strategie zahrnují mobilní inženýrské týmy, improvizované materiály a redukci technické dokumentace. Studie dále zdůrazňuje potřebu ochrany citlivých informací vzniklých během obnovy. Kombinovaný přístup zajišťuje efektivní rekonstrukci i obrannou bezpečnost státu.

Keywords: Critical Infrastructure; Demining; IED; Post-war Reconstruction; Pyrotechnic operations.

Klíčová slova: kritická infrastruktura; odminování; improvizovaný výbušný prostředek; poválečná obnova; Pyrotechnické činnosti.

INTRODUCTION

The ongoing large-scale ground combat operations in Ukraine have resulted in severe and widespread damage to critical infrastructure. This destruction has been predominantly caused by sustained artillery bombardments, unguided missile strikes, and the deployment of unmanned aerial vehicles (UAVs), all of which have contributed to the extensive degradation of both industrial and civilian facilities.

In order to facilitate rapid post-conflict recovery, it is essential to develop two distinct restoration strategies, each tailored to the level of structural damage incurred. The first applies to facilities affected by minor damage, while the second addresses scenarios involving moderate to severe destruction. Such damage is typically observed in industrial zones subjected to overpressure values ranging from 0.1 to 0.8 bar. Minor impairments are most often associated with overpressures below 0.2 bar, whereas moderate structural degradation tends to occur between 0.2 and 0.5 bar. The assessment of damage levels is carried out using UAV reconnaissance, which provides real-time surveillance and situational awareness in densely built environments (Stodola et al., 2019).



Figure 1: Ruins in the area of Mariupol Harbour with destroyed Ukrainian multiple rocket launcher VERBA of the 122 mm caliber [May 2022, digi24.ro]

A clear example of this destruction can be seen in the city of Mariupol, where entire industrial zones were subjected to repeated high-intensity shelling (Ivan et al., 2025). Figure 1 depicts a Ukrainian 122 mm multiple rocket launcher (MRL) system that was destroyed in situ amidst the ruins of a targeted industrial facility. The image highlights the operational environment in which emergency engineering units are required to function during the early stages of recovery, and illustrates the extent of structural collapse and technical complexity that must be addressed during reconstruction.

The timeline for repair and renewal operations (RMR) varies significantly depending on the extent of the damage. Empirical studies and wartime operational assessments have established timeframes of up to 30 days for facilities suffering minor damage, and up to 90 days for those affected by moderate destruction. During this period, the primary objective is the rapid reactivation of production capabilities, often through the use of temporary or simplified technical configurations. These include the refurbishment of critical assets such as machining tools, assembly lines, and industrial control systems across both heavy and light industries. Without restoring the functionality of these systems, enterprises cannot resume designated production outputs.

Repair and renewal efforts are typically conducted using a combination of established technical protocols and improvised, field-engineered solutions. These solutions are often developed on-site following detailed assessments of the damage profile. Operations rely heavily on emergency stocks and locally available building materials, replacement components, and spare parts.

1 MATERIALS AND METHODS

The reconstruction of industrial complexes in post-conflict scenarios constitutes a highly complex engineering and logistical operation. Its objective is not only the physical restoration of damaged structures but also the rapid reinstatement of industrial production capabilities under constrained timeframes and limited resources. Accordingly, the methodological framework is grounded in a systematic classification of damage levels, technical condition assessments, and the selection of context-specific construction strategies and organisational procedures. Reconstruction interventions are categorised according to the extent of structural degradation and the operational objectives into two principal levels: partial reconstruction and comprehensive reconstruction.

Partial reconstruction is applicable when the physical wear of the facility does not exceed 45%. Typical actions include:

- Spatial reconfiguration without significant alterations to load-bearing elements;
- Localised replacement or repair of façade elements, enclosure components, and surface finishes;
- Targeted interventions in structural or roofing subsystems that remain functionally intact.

Comprehensive reconstruction is mandated in cases of major structural impairment or when the facility is functionally obsolete in relation to the current production requirements, with structural degradation ranging from 45% to 50%. Representative tasks include:

- Full replacement of structural systems such as frames, columns, or trusses;
- Vertical and lateral expansion of the facility (e.g., the addition of one to five floors depending on subsurface and superstructure integrity);
- Reconstruction of intermediate floors, envelope systems, and integrated utility conduits.

Reconstruction is not merely a process of restoration but also an opportunity for optimisation of spatial and structural design in industrial layouts. Advanced transformation methods may include:

- Vertical extension of usable volume through column elongation or additional storeys;
- Span modification via removal or realignment of intermediate supports;
- Load capacity enhancement through reinforcement of slabs, foundations, and support beams;
- Prefabricated modular expansion to achieve rapid coverage of functional space;
- Integration of modern HVAC and lighting systems to meet contemporary environmental and occupational standards.

A central component of the methodological approach is the diagnostic assessment of physical and moral deterioration, which determines the viability and nature of reconstruction.

Physical deterioration encompasses structural and material degradation, identified through:

- Cracking, excessive deformation, and discontinuities in load-bearing elements;
- Moisture infiltration and loss of protective coatings in concrete and steel elements;
- Foundation instability and subsidence in core load-transmitting systems.

Moral (functional) deterioration refers to the mismatch between the existing facility configuration and current production demands, including:

- Inflexible spatial layouts due to excessive internal supports;
- Undersized crane systems and limited technical infrastructure;
- Insufficient environmental control (e.g., poor lighting, ventilation, thermal regulation).

Further decision-making incorporates the condition of technological systems, connectivity to external infrastructure (power, water, transport), and compatibility with production flow and logistics.

To ensure prioritisation and cost-effectiveness, buildings are evaluated using capital classification models, considering:

- Structural typology (e.g., steel framing, reinforced concrete skeletons, masonry-bearing systems);
- Envelope technology (e.g., composite sandwich panels, traditional infill walls, lightweight prefabricated modules);
- Dynamic and static resistance under operational and wartime loading conditions.

This classification enables the estimation of both normative and real service life, which is influenced by:

- The quality and frequency of preventive maintenance;
- The intensity and variability of industrial load cycles;
- Environmental exposure to humidity, aggressive chemicals, and vibration.

Such assessments form the basis for predictive decision-making models, supporting strategic selection between restoration, replacement, or adaptive re-use within the broader context of defence infrastructure planning and crisis resilience. One practical application of this methodology is the simulation-based evaluation of artillery unit survivability and operational continuity in contested environments, using platforms such as MASA SWORD to quantify the impact of enemy activity on task execution and resource allocation requirements (Havlík et al., 2024).

1.1 Clearance of mined areas

Available as-built documentation for existing buildings, structures, and equipment is utilised in the preparation of drafts, technical diagrams, and engineering solutions for the execution of malfunction repairs and infrastructure renewal. These technical documents should incorporate basic structural schematics, estimated requirements for building materials, components, structural assemblies, critical mechanisms, and a detailed work schedule including a bill of quantities.



Figure 2: Rescue operations following bombing: Left – Borodyanka, April 2022 (Verkhovna Rada of Ukraine); Right – Toretsk, July 2022 (State Emergency Service of Ukraine)

Restorative and repair operations should commence only after search and rescue procedures (see Figure 2) and emergency stabilization efforts have been completed. These initial actions, carried out after the safe evacuation of personnel, typically include:

1. Erection of support pillars and clearance of access routes through rubble and potentially contaminated zones;
2. Structural reinforcement and controlled demolition of unstable elements posing a collapse risk, thereby enabling the safe movement of personnel and continued rescue operations;
3. Localisation and containment of functional malfunctions, with the reactivation of energy networks essential to operate water supply and filtration systems in shelters;
4. Repair and restoration of damaged water mains, gas conduits, electrical systems, and industrial utility networks;
5. Temporary reestablishment of disrupted communication infrastructure;
6. Repairs to damaged protective structures, aimed at ensuring the safety of personnel in the event of repeated enemy fire.

Although the primary objective of rescue and emergency restoration work is not the immediate reactivation of full production, the timeliness and technical execution of these interventions significantly influence the duration and success of subsequent industrial recovery. In complex operational environments where infrastructure is degraded or rendered unusable, maintaining key technical functions often depends on the use of simplified and resilient procedures that are independent of automated systems and function without support from digital platforms (Blaha & Brabcová, 2012; Drábek et al., 2025).

A critical prerequisite for any repair activity in war-damaged areas is the clearance of mined zones and unexploded ordnance (UXO). In theatres of large-scale ground operations, mine clearance becomes significantly more complex due to the destructive means typically employed—such as explosive breaching, mechanical demining (Švehlík et al., 2023).

When such methods are deployed in densely built-up areas, they often cause extensive collateral damage and may contaminate the operational zone with unexploded submunitions. While the use of modern fire control systems can reduce unintended consequences, the complete elimination of secondary effects remains unachievable (Šilinger & Blaha, 2017; Šustr et al., 2022; Blaha & Brabcová, 2010).

Unexploded ordnance poses dual threats: it may detonate unpredictably, and it can be reappropriated for improvised explosive devices (IEDs). Ammunition that functions as landmines—whether industrially produced or makeshift—may be intentionally deployed and strategically masked to hinder detection. The process of removing such hazards is referred to as demining (Hryhorczuk et al., 2024), a task characterised by high risk, long duration, and operational uncertainty.

Recent analyses of the ongoing conflict in Eastern Ukraine highlight a procedural focus on the visual inspection of interior spaces for early threat identification. Visual inspection represents the first and most crucial step in the assessment of structures for potential explosive contamination. This phase enables specialists to detect anomalies or objects indicative of hidden ordnance. However, due to the advanced concealment

techniques used—where explosive devices are often disguised as everyday items—this process demands a high degree of technical training and situational awareness.

In addition to visual assessment, advanced detection technologies such as metal detectors, gas analysers, and multispectral sensors are employed. A multi-layered methodological approach—integrating manual reconnaissance with instrumentation-supported diagnostics—substantially reduces the risk to field teams and protects adjacent urban infrastructure during explosive ordnance disposal (EOD) activities.

This approach, adapted to the conditions in Eastern Europe, highlights the critical importance of combining visual inspection with advanced detection technologies for accurate identification and safe neutralisation of explosive threats. The methodology forms the foundation of urban security protocols and supports effective risk management (Cimr et al., 2018).

At a broader operational level, the process transitions from individual inspections to systematic (blanket) area clearance, a task that necessitates close cooperation between engineers and explosives disposal specialists. Each role carries a distinct mandate and set of competencies:

1. The explosives expert is responsible for determining the technically appropriate and safe procedure for ordnance removal and neutralisation.
2. The military or field engineer focuses on the localisation and spatial analysis necessary to define the ordnance's position within the physical and structural context.

Despite clear procedural guidelines, the success of the operation heavily depends on the degree of cooperation and coordination between both specialists, especially under combat or post-combat conditions (Ivan et al. 2018).

Guarantees and formal task assignments constitute a key component of operational accountability. The unit tasked with clearing a designated area assumes full responsibility for ensuring that all clearance activities meet predefined safety and operational standards. Prior to commencement of operations, two mandatory procedural steps are completed between the issuing authority (commander) and the executing unit:

1. The unit commander submits a formal work methodology (technological procedure), which reflects and satisfies all requirements stipulated by the assigned guarantees.
2. The ordering authority defines the acceptance protocol, specifying how the cleared area will be inspected and validated to confirm compliance—or identify non-compliance—with the stated safety and clearance criteria.

These steps establish a contractual and procedural framework for accountability, ensuring that all activities are aligned with international standards and doctrinal best practices in Explosive Ordnance Clearance (EOC).

The operational tasks assigned to the aforementioned unit must be carried out in accordance with the methodology of EOC.

EOC encompasses all activities aimed at locating, identifying, removing, and neutralising hazardous remnants of military operations, including those arising from armed conflict and military training exercises (Pekař et al., 2022). The purpose of these activities is to minimise the risk of accidental detonation and the end goal is to reduce the residual hazard to a level comparable to non-militarised areas. In this context, all unexploded

ordnance, weapon systems, and military-related hazardous waste are considered dangerous remnants of armed forces operations (Palasiewicz et al., 2023).

The EOC methodology is defined in two key NATO doctrinal sources – STANAG 2394: Land Force Combat Engineer Doctrine (ATP-52) and AAP-6: NATO Glossary of Terms and Definitions. Both documents refer to these activities under the broader term Explosive Ordnance Disposal (EOD), although they approach the concept with slight terminological and procedural distinctions. These can be compared and aligned with the procedures outlined in the Czech national military regulation Vševojsk-16-20.

In ATP-52, the term “reconnaissance” refers to a specialised activity not explicitly defined in Czech doctrine. It is carried out by an Explosive Ordnance Reconnaissance (EOR) Scout, a trained soldier whose primary task is to evaluate whether a reported object constitutes dangerous ordnance requiring the intervention of an EOD specialist. This role serves as an important filtering mechanism, conserving the time and resources of the highly specialised and limited EOD personnel (NATO, ATP-52, 2008).

In contrast, AAP-6 uses the term “localisation”, which broadly corresponds to the Czech concept of průzkum výbušnin as described in Vševojsk-16-20. In both contexts, this refers to the process of identifying and spatially locating ordnance within areas previously affected by hostilities (NATO, AAP-6, 2021; Vševojsk-16-20, 2013).

The AAP-6 glossary explicitly defines the term “detection” as the process of searching for hidden ordnance based on physical indicators and environmental anomalies (NATO, AAP-06, 2021). This concept is conceptually aligned with geophysical survey principles, where detection relies on magnetic, thermal, or material contrast signals. In this context, the requirement for engineering support is minimal, as the task is more closely linked to technical reconnaissance.

However, ATP-52 expands this concept by specifying a required detection depth of up to 6 metres, reflecting the operational need to locate deeply buried ordnance—most notably, large-calibre aerial bombs and penetrating munitions. Detecting and excavating them safely, often requires vertical access shafts and sophisticated retrieval methods, which necessitate full engineering support, particularly under urban or collapsed-structure conditions.

The task of “finding and exposing”, which is defined solely in ATP-52 (NATO, ATP-52, 2008), is particularly relevant in scenarios involving electronic, non-contact fuzes. These fuzes may be sensitive to electromagnetic fields or physical proximity, meaning that the mere physical presence of an explosives specialist could inadvertently activate the device. AAP-6 does not clearly isolate this phase and appears to subsume it under “identification,” potentially underestimating its operational significance.

In AAP-6, the activity of “identification” is formally described as a specialised component of explosive ordnance disposal. While ATP-52 and Vševojsk-16-20 also reference this step, only AAP-6 presents it explicitly as a stand-alone disposal activity. According to AAP-6, proper identification requires more than visual classification. It includes:

1. Precise determination of the type, variant, and calibre of the munition;
2. Assessment of fuse condition, including functionality and trigger mechanism;
3. Evaluation of the active agent’s status (with radiography noted as the preferred method);

4. Sampling of chemical or biological payloads, where applicable, with stringent containment to prevent agent leakage.

Both ATP-52 and AAP-6 define “on-site evaluation” as the final analytical phase before mitigation. It involves confirmation of the calibre, structural integrity, and fuse condition of the exposed ordnance. This step plays a decisive role in selecting the appropriate course of action—be it render-safe procedures, relocation, or on-site destruction.



Figure 3: Artillery shells (projectiles) and mines ready for destruction [East Ukraine, August 2022, REUTERS]



Figure 4: Destruction of mines and artillery shells (projectiles) [Mariupol, June 2022, La edaction avec AFP]

The activity of sorting is defined exclusively in the Czech military regulation Vševojsk-16-20 and is not explicitly addressed in NATO documents ATP-52 or AAP-6. It primarily concerns unidentified, defective, or failed ammunition that has already been secured and classified as non-threatening.

The purpose of sorting is to determine the most appropriate subsequent handling method, typically based on the technical condition, content, and potential utility of the munition. The main outcomes include:

1. Destruction – complete neutralisation and disposal (see Figures 4 and 5);
2. Delaboration – dismantling and extraction of usable components or energetic materials;
3. Reintegration into further use – under strict safety and quality control protocols.

It is important to note that this sorting process does not apply to unexploded, deliberately masked, or planted ammunition, as these types are treated as high-risk ordnance requiring immediate EOD intervention and their handling is governed by different procedural rules.

1.2 Explosive Ordnance Disposal in NATO Operations

In the context of NATO-led multinational operations, the role of the EOD specialist is particularly sensitive, as their activities are frequently conducted under observation. Any decision or action taken by the EOD operator may have significant implications for the local population's perception of international forces and overall mission legitimacy. In today's operational environments, military units alone no longer possess sufficient capacity to ensure comprehensive EOD assurance without coordinated, multidisciplinary support.



Figure 5: Robotic mine sweeping system Uran-6 in Cherson [June 2022, RIA Novosti]

Figure 5 illustrates a Uran-6 multifunctional robotic demining system deployed during clearance operations in the Kherson region (June 2022). Similar robotic systems have played a pivotal role in the demining of high-risk zones such as the Azovstal steelworks complex in Mariupol, during the Russian military campaign in Ukraine. Over the past two decades, remotely operated mine clearance systems (e.g., MV-4 flails, robotic plows, and sensor platforms) have become standard assets across virtually all major military engagements involving NATO.

The assurance of EOD operations is doctrinally governed by several NATO Standardization Agreements, including STANAG 2143, STANAG 2389, and STANAG 2370 (AEODP-3). These standards define the functional relationships, responsibilities, and operational limits of EOD personnel:

1. The explosives disposal expert functions in a purely technical capacity and does not act as the incident commander.
2. Prior to the commencement of intervention, the EOD expert remains subordinate to the organic (unit) commander.

3. The EOD expert holds the authority to postpone intervention until all necessary technical and safety requirements are fulfilled.
4. Upon initiating the disposal procedure, the expert acts on behalf of the requesting entity or commander.
5. The responsibility for overall mission assurance lies with the officer who authorised the intervention.

To effectively execute their role, the EOD specialist depends on area security, medical services, fire prevention teams, and dedicated engineering assets. EOD specialist is functionally and logistically subordinated to a senior engineer officer, who coordinates the broader support framework and ensures safe operational conditions (Šustr et al., 2025)

1.3 Particularities of Industrial Complex Restoration in Wartime Conditions

The restoration of damaged industrial facilities differs significantly from new construction, particularly in the structure of work tasks. General construction activities represent only a minor portion, while equipment assembly, roof repairs, steel reinforcement, and the installation of various systems dominate. This necessitates adjustments to construction sequencing and organisational procedures. For example, repair and reconstruction work carried out at the Mariupol Harbour industrial zone under the supervision of the occupying administration was characterised by the following structure of labour force utilisation:

1. Active employment of locally recruited workers loyal to the new administration, organised into renovation brigades attached to area-specific command centres;
2. Deployment of contractual construction and assembly units from adjacent regions of Russia;
3. Involvement of specialised emergency response teams from national ministries (e.g. Ministry of Emergency Situations, Ministry of Defence);
4. Reliance on repurposed Soviet-era Civil Defence headquarters, which continued to operate in the occupied regions under modified classifications.

Partial Results

The restoration of critical infrastructure and defence-oriented industrial facilities during wartime requires extremely rapid execution under conditions of limited workforce availability, reduced technical expertise, and shortages of standardised materials. These challenges are further exacerbated by the enemy's targeted use of precision-guided munitions against production and logistics hubs. As a result, conventional construction and engineering practices must be significantly adapted. In a broader operational context, similar challenges apply to the use of military assets—such as artillery systems—in support of crisis response operations including wildfire suppression, where military technologies have been evaluated as effective alternatives to conventional methods (Korec et al., 2025).

In such contexts, the restoration effort often allows for the abandonment of original architectural parameters, including the aesthetic or spatial layout of the structure. Instead, new materials, simplified construction systems, and altered structural elements may be adopted, enabling faster execution and reduced labour costs.

Upon ministerial approval of the restoration effort, a technical committee is appointed to manage all engineering, design, and technical planning associated with the damaged site. The committee consists of representatives from the contracting authority, project design bodies, construction and assembly organisations, and other relevant institutions. The structure of this committee varies depending on the functional nature of the facility and typically includes experts in civil construction, technical equipment, internal transport, and production technologies.

This committee operates directly on-site and produces the core documentation necessary to initiate restoration, including:

- Detailed work assignments for the reconstruction teams;
- Materials for expert evaluation of structural integrity;
- A list of required technical documentation and resource inputs.

The restoration brief must also include a survey of available construction, assembly, and specialist teams, a breakdown of accessible materials, plant and machinery, as well as a catalogue of materials for centralised supply. Additionally, data regarding workforce qualifications and the feasibility of producing simplified structural elements locally is required.

A comprehensive technical inspection is conducted to determine the nature and scale of destruction. This includes an objective assessment of both the structure as a whole and its individual components. For instance, the 16 July 2022 airstrike on the Yuzhmash (YuMZ) complex in Dnipro destroyed manufacturing and repair workshops for Tochka-U ballistic missiles and multi-launch rocket systems. Given that Ukraine's current operational inventory of such systems is estimated at only 10–15 % of the required force level, the restoration of these facilities is of high strategic value. Based on these conditions, the main tasks of technical assessment are as follows:

- Documentation of emergency repair works performed without project oversight, such as rubble removal and corridor clearance;
- Analysis of spatial-planning configurations and structural schematics, including key load-bearing and perimeter components;
- Evaluation of the level of damage and remaining load capacity of key structural elements;
- Identification and cataloguing of reusable materials or components.

As part of this process, all available project and implementation documentation is reviewed. Laboratory testing and analytical calculations are carried out to determine the strength properties of damaged and intact structural materials, along with their potential reuse. Preliminary engineering recommendations are formulated (see: Procházka et al., 2011).

Structures identified as critically damaged or at risk of sudden collapse are addressed immediately—either through reinforcement or controlled demolition under expert

supervision. The technical committee determines the extent of required documentation; in simpler cases, sketches and recommendations may suffice. For more complex interventions, full technical documentation is prepared by mobile interdisciplinary teams operating directly on-site. This approach accelerates planning and maximises the use of local and improvised materials—essential in devastated or contested environments.

In order to accelerate reconstruction efforts under conditions of ongoing or imminent hostile activity, it is highly advisable to implement joint support coordination measures. These measures serve primarily to clearly delineate the responsibilities, areas of operation, and security guarantees for friendly forces within the reconstruction zone, thereby minimising the risk of operational interference and ensuring the protection of units assigned to recovery operations (Korec, 2022).

2 CRITERIA OF STABILITY

In the event of a pre-emptive strike against NATO allies, it is essential to implement resilience-enhancing measures for critical infrastructure and ensure rapid recovery capabilities. Effective planning of repairs, resource mobilisation, and damage forecasting requires identifying factors that influence infrastructure stability.

These measures must also be aligned with rational models of defence spending that account for threat probability and national capacity, as demonstrated in risk-based budgetary frameworks developed for the B9 countries (Pekar et al., 2025).

To support this, a methodology for the objective quantitative assessment of key industrial complexes, particularly those intended for military and dual-use applications, must be developed. This approach evaluates both the baseline resilience and the effectiveness of adopted technical and organisational measures. Such assessments are crucial for adaptive defence planning and efficient resource allocation in crisis situations.

Stability Criteria

Industrial complexes, as considered in this study, refer to individual or interconnected groups of facilities typically associated with the engineering and heavy manufacturing sectors. From the perspective of economic systems theory and managerial cybernetics, such complexes represent probabilistic and structurally interdependent systems functioning under the influence of stochastic disruptions—namely, destructive factors generated by adversarial military action.

The functional reliability of these systems is statistically determined and correlates with the concept of operational stability—defined here as the facility's ability to sustain production activities under hostile conditions, including rocket strikes, artillery bombardment, and associated cascading effects (Ivan et al., 2021). In this context, stability reflects the capacity of an industrial enterprise to continue the manufacture of essential products despite sustained external attacks. This framework is not theoretical but grounded in recent empirical evidence. During the full-scale invasion of Ukraine by the Russian Federation, numerous defence-related industrial assets were severely disrupted or neutralised by continuous strikes. The resulting degradation of national industrial capabilities led Ukraine to become increasingly reliant on external supplies of obsolete Soviet-era

weaponry provided by partner nations. The operational instability also undermined the country's ability to recondition equipment from its reserves or conduct timely repairs of assets damaged in combat.

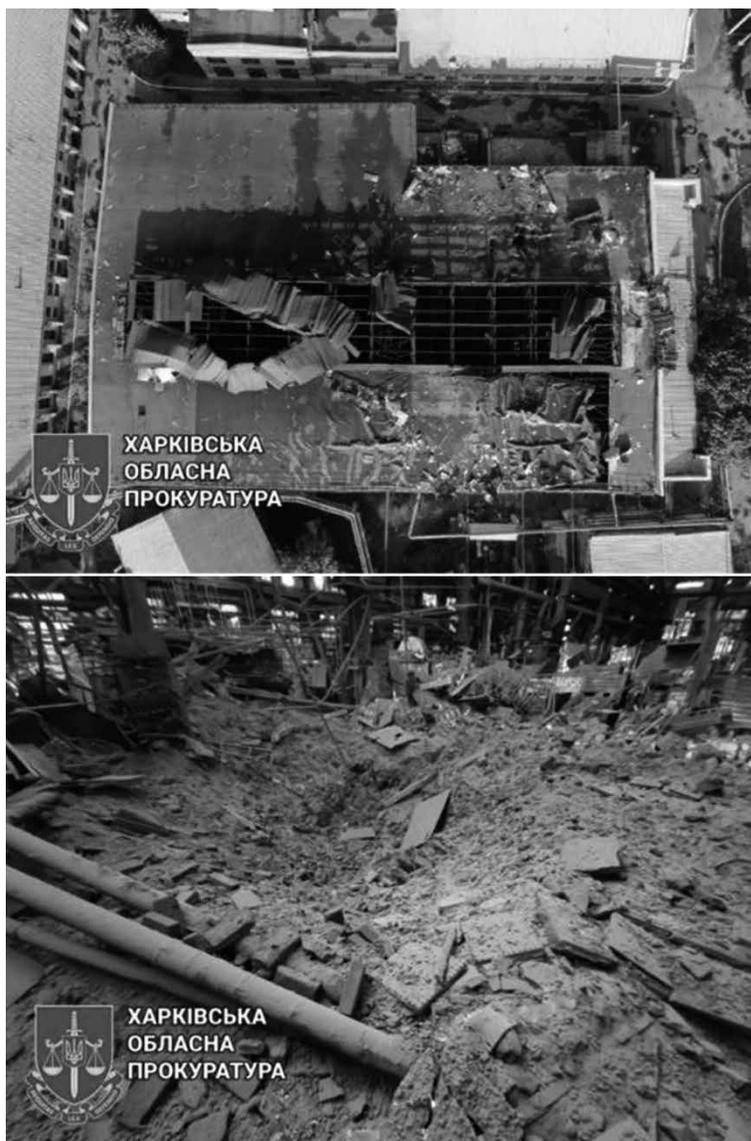


Figure 6: Rocket attack on the Mechanical Plant with the S-300 missile systems on 3rd of August 2022 [the Report of the Nowobowarska Prosecutor's Office of Kharkov].

Figure 6 illustrates the aftermath of a precision-guided missile strike on a mechanical plant associated with the S-300 long-range surface-to-air missile system, carried out on 3 August 2022, as documented in the report by the Nowobowarska Prosecutor's Office in Kharkiv.

Each large-scale industrial enterprise typically functions as a nodal component. This implies continuous interdependence with external subsystems that supply energy, raw materials, semi-finished products, spare parts, and other critical inputs.

For this reason, the stability of an industrial complex must be assessed not only based on the internal condition of the facility but also in relation to the functionality of the surrounding infrastructure, including transportation routes, energy networks, and communication systems. In analysing the resilience of industrial infrastructure under wartime conditions, it is essential to distinguish between two fundamental concepts of stability:

1. Structural (internal) stability, which presumes that the destructive effects impact only the engineering and technological systems of the facility itself. External systems are treated as quasi-stationary, meaning their operational parameters are assumed to remain unchanged during the disruption period.
2. Operational stability, in which destructive effects compromise both the internal functionality of the facility and the performance of its external connections. This model more accurately reflects real-world wartime conditions, where enemy strikes often target infrastructure in an integrated and systemic fashion.

While these models focus on physical and technical parameters, it is important to note that operational output also depends on human productivity, which is strongly influenced by the psychological and moral state of personnel.

To assess stability and design mitigation strategies, relevant influences must be categorised as either internal or external:

1. Internal factors include the availability of production facilities, technological equipment, trained personnel, and local material reserves.
2. External factors encompass energy supply, transport and logistics networks, and communication systems, along with the influence of harmful (destructive) factors, which should be considered separately due to their dominant effect.

All relevant factors can be described through measurable physical parameters. While internal parameters can be adjusted through technical or organisational measures, external ones—particularly destructive forces—remain largely beyond the facility's control. Therefore, improving stability depends on optimising internal conditions to maintain operational functionality under changing external environments.

Quantitative stability assessment is based on the premise that an industrial facility's resilience is proportional to the share of material and operational resources that survive the destructive event. Two primary indicators are used:

1. Percentage of residual production capacity, measured according to either production nomenclature or total output. Gross production is preferred, as it accounts not only for finished goods but also for intermediate and unfinished products across workshops and sections.

2. Proportion of surviving tangible assets, such as production areas, technological systems, and mechanical equipment—evaluated at the level of the entire facility or within selected critical sections.

These criteria are shaped by stochastic variables such as facility layout, intensity and direction of destructive forces, and random energy distribution. Due to their probabilistic nature, a single stability metric is insufficient. A set of parallel indicators is needed to assess both resilience levels and the effectiveness of stabilisation measures.

DISCUSSION AND CONCLUSIONS

Although the reconstruction of industrial complexes may appear to be a technical or logistical matter, it carries significant strategic, informational, and security implications. In post-conflict environments, even minor data points—such as timelines for debris removal or the scale of demining efforts—may be exploited by adversaries as indicators of the effectiveness and impact of their strikes. As such, information related to post-war reconstruction must be treated with the same level of sensitivity as tactical intelligence.

The duration and resource intensity of recovery operations, particularly those involving unexploded ordnance disposal, provide insight into the precision and consequences of kinetic attacks. Interestingly, a high incidence of unexploded munitions—while potentially indicating inaccuracy—can result in greater secondary burdens for the defending side. In strategically important areas, this tactic may be deliberately employed by attackers to impose disproportionate long-term recovery costs (Jeffrey, 2020).

Moreover, new construction activities unintentionally reveal valuable intelligence. The location, material composition, and structural design of rebuilt facilities may indicate their function, strategic importance, and inherent vulnerabilities (Kašpar et al., 2023). Therefore, critical infrastructure should be sited, where feasible, in areas with natural protective advantages—such as subterranean environments or rock formations (Pavelcová et al., 2022). This must be coupled with targeted investment strategies that weigh both the defensive value and the cost-efficiency of reconstruction efforts (Šlouf et al., 2023; Hujer et al., 2021).

Further vulnerabilities emerge during public procurement processes, where open tenders may unintentionally disclose technical specifications for construction, equipment, communication systems, and protective technologies. This underlines the need for a robust information protection framework, extending even into civilian-led phases of post-conflict recovery.

From a technical standpoint, the methods and volumes of industrial restoration must be directly linked to an accurate assessment of destruction levels. To support preliminary planning and facilitate approximate technical-economic calculations, it is essential to categorise affected buildings and infrastructure components into defined damage typologies. Each category should be associated with specific restoration metrics, enabling more structured and data-informed decision-making.

While state-of-the-art numerical modelling tools for simulating multi-hazard impacts are indispensable, they must be complemented by empirically grounded classification systems developed through decades of post-conflict reconstruction—particularly following conflicts in Iraq and other theatres of war (Varecha and Majchút, 2019).

In light of these insights, it is imperative that all data acquired during the post-war recovery process be critically assessed not only for its technical utility, but also for its potential strategic sensitivity. Where necessary, such information should be classified and handled within protected frameworks to prevent exploitation by hostile actors, ensure operational security, and safeguard national resilience planning.

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