Large-Scale Combat Operations and the Subterranean Dilemma

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The Department of Defense (DOD) must formalize a subterranean domain, build response capabilities, and capitalize on transferrable investments to complicate adversary decision-making and compel favorable action in alignment with U.S. objectives.

Introduction

The ongoing Israel-Hamas war continues to underscore the immense challenges of conducting operations in contested subterranean environments. Underground warfare is not an emergent threat.[1] In recent conflicts, Islamic State fighters utilized tunnels for concealment and cover in the Battle of Mosul, ambushing coalition forces as they approached the city.[2] In Fallujah, tunnels with full dormitories and kitchens were used so extensively that Iraqi Colonel Falah al-Obaidi described it as "fighting two wars in two cities... where there was a war on the streets, and there is a whole city underground where they are hiding. Now it's hard to consider an area liberated because though we control the surface, ISIS will appear from under the ground."[3]

The ability to fight, survive, and win underground is essential for U.S. and partner forces during Large Scale Combat Operations (LSCO). Forces will not only continue to face challenges posed by subterranean facilities designed to protect critical non-state and nation-state assets, but LSCO will undoubtedly involve combat in cities and densely populated urban terrain. These operations will present other subterranean challenges, such as underground parking garages, transportation corridors, sewage systems, and even "vertical tunnels" effectively formed by high-rise buildings. The U.S. Army is unprepared for these challenges due to its reliance on equipment, force structures, tactics, techniques, and procedures primarily intended for terrestrial operations.[4]

According to joint publications, physical and non-physical warfighting domains are identified as land, air, sea, space, and cyberspace (including the electromagnetic spectrum). However, subterranean operations are distinctly different than land operations. The Department of Defense should establish the subterranean environment as a separate domain managed by the Army. This is necessary to develop the training, response capabilities, and resource management needed to ensure U.S. military success during LSCO. This focus will enhance the Army's preparedness for subterranean operations while producing investments that can benefit operations across other domains. Moreover, improved Army capabilities to fight and win underground is a credible threat to the perceived security of subterranean assets and may compel adversary actions favorable to the United States and its partners. This paper explains these foundational arguments and presents the case for a domain composed of subterranean environments.

Rapidly Advancing Technology is Driving Adversaries Underground

When it comes to holding diverse and challenging targets at risk, the U.S. and its partners are victims of technological and operational success. Echoing this sentiment, scholars Keir A. Lieber and Daryl G. Press note that when it comes to nation-state nuclear arsenals, a fundamental "pillar of survivability—concealment—is being eroded by the revolution in remote sensing."[5] Similarly, in his comprehensive paper, "Bedrock Prime," Michael Dudas observes that, "globally potential adversaries such as China, Russia, Iran, North Korea, and Pakistan are building ever more complex, stronger, and deeper fortifications which are largely immune to U.S. non-nuclear weapons inventory."[6]Advances in persistent overhead technical observation alongside the rapid proliferation of diverse Intelligence, Surveillance, and Reconnaissance (ISR) assets, precision strike capabilities, Artificial Intelligence, and Aided Target Recognition (AiTR) systems necessitate investment in protecting their critical assets in subterranean and hard and deeply buried sites. U.S. and partner detection dominance has forced adversaries to invest in subterranean facilities to avoid detection and protect critical logistics operations, production capabilities, and strategic assets in the event of LSCO.

A subterranean environment constitutes "any space or structure located below ground."[7] This definition includes traditional subterranean structures that are natural or man-made, such as the tunnel systems used by Hamas in Gaza, mountain cave complexes used by the Taliban in Afghanistan, and massive hard and deeply buried facilities built by nation-states. While the conventional Army has faced limited subterranean challenges over the past two decades during combat operations in Iraq, Syria, and Afghanistan, LSCO against peer or near-peer competitors will result in immense subterranean challenges for land forces.

As of 2019, the Army estimated that "…over 10,000 known subterranean facilities exist around the world."[8] In its 2023 report on China to the U.S. Congress, the DOD publicly acknowledged Chinese investment in developing and expanding underground and subterranean facilities to "conceal and protect all aspects of its military forces."[9] Similarly, in 2020, Russia openly announced the development of a "new hardened strategic command post, possibly a deeply buried underground bunker."[10] These protective structures are not limited to protecting weapons of mass destruction (WMDs) or providing continuity of government. Even Iran has moved its strategic uncrewed aircraft systems into a bunker that is reportedly several hundred meters beneath the surface.[11] Collectively, these investments affirm adversary interest in subterranean facilities as they seek to mitigate technological disadvantages and protect "vital assets and capabilities."[12]

Large-Scale Combat Operations and the Increasing Subterranean Challenge

The Army is not the sole DOD entity that has a vested interest in subterranean facility defeat during LSCO, however, it is best designated as the ground forces service primarily responsible for the leadership and management of the subterranean domain. Transferable investments and positive capability ripples across manning, training, and equipping that will not only increase survivability in subterranean operations at echelon, but also enhance the Army's overall effectiveness during LSCO. Additionally, improving technologies with cross-domain dependencies such as communications, positioning, navigation, and timing (PNT), and ISR, emphasizes that technologies can be leveraged across multiple domains to ensure a more integrated and effective military strategy.

In October 2022, the Army published Field Manual 3-0 *Operations* which defines Large-Scale Combat Operations as "extensive joint combat operations in terms of scope and size of forces committed, conducted as a campaign aimed at achieving operational and strategic objectives."[13] The LSCO definition demonstrates the Army's transition from a two-decade focus on counterterrorism operations, mainly in the Middle East, to a global era of great power competition and multidomain operations. In multi-domain operations, commanders must leverage and interweave effects from multiple domains to support complex objectives. Terrain dominance during LSCO cannot be established without multi-domain operations to seize and control underground facilities. The Army is poorly postured for this scenario during LSCO, with only a few units specializing in subterranean operations. Additionally, very little capability exists to perform accurate Battle Damage Assessment (BDA) for air attacks on underground structures, further driving the need to seize, assess, and exploit subterranean facilities during LSCO to determine their true nature and the effects of an attack.

These uniquely subterranean challenges for land forces cannot be overcome with a "mark and bypass" mindset. Forces must be specially trained and equipped for surface *and* subterranean operations, where the benefit of Combined Arms Maneuver is not fully realized due to an inherent lack of armor, artillery, and air support. The Army must be able to survive, fight, and win underground by properly educating, training, and equipping its forces for subterranean operations. While unlikely to deter adversaries from relocating their assets underground, deliberately increasing Army capabilities for subterranean operations by establishing a subterranean domain could compel favorable actions and diplomatic policy for the U.S. and its partners.

Framing the Problem Through an Operational Vignette

Consider a future scenario where the Army is engaged in protracted LSCO within the U.S. Indo-Pacific Command Area of Responsibility. Due to the complex nature of combat operations, a cross-functional element from an infantry division is tasked with assaulting, clearing, and defeating a subterranean facility that intelligence indicates is primarily a vehicle repair depot.

After seizing the above-ground area (Figure 1), the cross-functional infantry element works to gain access to the facility—even if somewhat limited—utilizing specialized entry techniques and equipment developed for uniquely difficult subterranean breaching requirements.

Once the element has access to the facility (Figure 2), a team member places a vehicle with GPS-denied mapping technology into the breach point. At the above-ground portal, the element commander and assault elements begin to see a two-dimensional map developing over a communications network. As the mapping vehicle conducts reconnaissance of the subterranean facility, AI models running within the mapping software assess risks and opportunities for the operations team. The use of advanced mapping technology on robotic systems helps minimize the cognitive load on warfighters and accelerate mission execution by identifying critical infrastructure and labeling key facility features on the map.

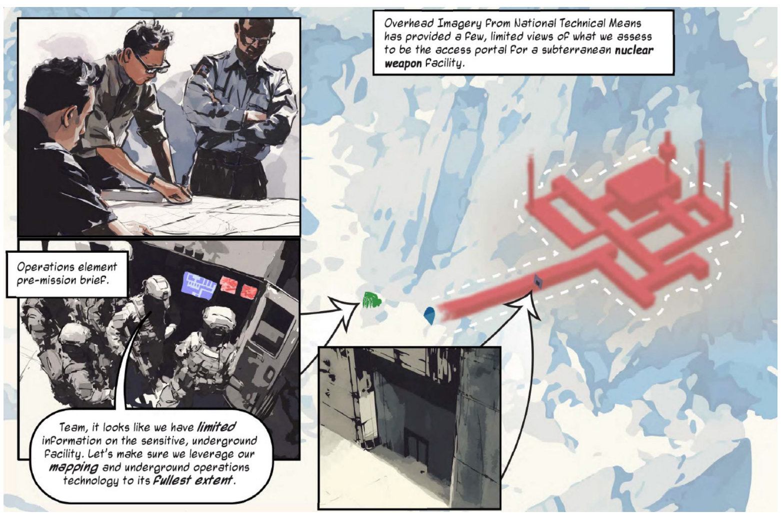

FIGURE 1: Mission planning for a massive subterranean facility.[14]

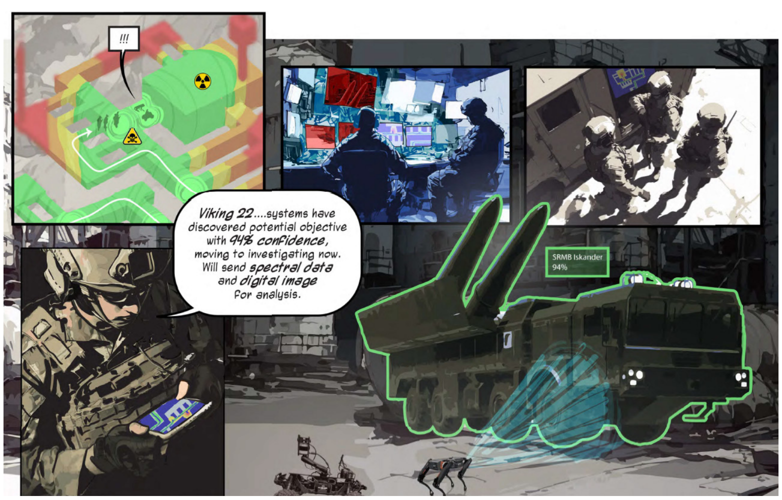

FIGURE 2: Robotic systems detect threats, that may include weapons of mass destruction, and alert operators.[15]

Throughout operations (Figure 3), mission leaders underground, mission planners above ground, and decision-makers over the horizon at multiple operations centers intuitively interact with the virtual environment in 3D thanks to specialized compression techniques that distill complex 3D datasets into optimized facility models, allowing them to be shared over bandwidth-constrained tactical networks. Although subterranean operations are incredibly complex, the infantry element is successful in assaulting, clearing, and defeating the adversary vehicle repair depot. This success is a direct product of Army senior leadership's emphasis on subterranean training and investment in transferable technologies that support subterranean operations and enable more effective land warfare.

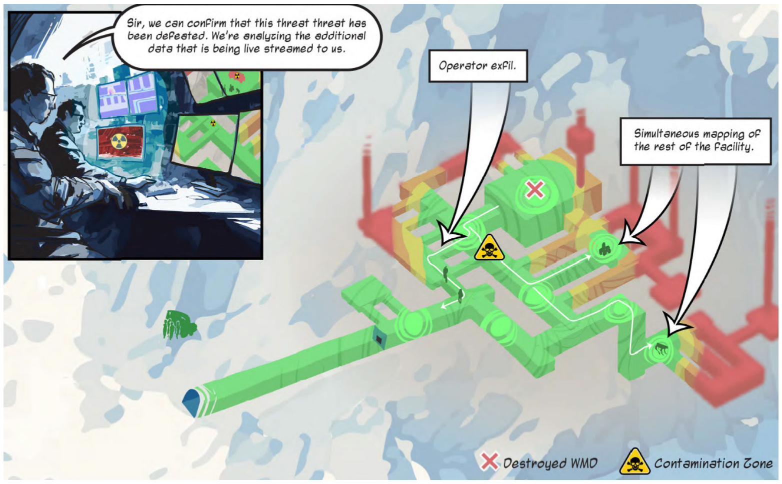

FIGURE 3: Common operating picture for a subterranean facility and breaching mission.[16]

This brief vignette demonstrates how deliberate investment in training and transferable technologies could enhance an infantry element's ability to access, understand, navigate, and communicate in a subterranean environment. These subterranean-focused investments will result from formalizing the subterranean environment as a unique domain. Additionally, many of these same investments are highly transferable across the land warfare domain, increasing mission speed and success on the earth's surface.

Transferable Investments and Capability Development Ripples

Even the most rudimentary subterranean environments challenge conventional communication methods, defeat conventional PNT technologies, complicate *ad hoc* planning considerations, and require life support equipment with a compounding logistics tail. Direct application of conventional technologies, when possible, often runs into second-order problems not encountered during land operations, and individuals are implicitly expected to "make it work." For instance, self-contained breathing equipment in inventory is not integrated with ballistic plates and plate carriers. This causes stress and limits the range of motion because the air tanks are cantilevered and improperly positioned on the user's back.

Another example is driving uncrewed ground vehicles (UGVs) via remote control. Some UGVs currently in inventory may be well suited to subterranean operations but may be effectively useless because of the sheer volume of solid rock that UGV radios encounter as soon as the vehicle goes around a corner. Vehicles must either drop communications nodes or communication links must be able to penetrate rock or reflect around corners, all while providing a high-bandwidth conduit for video and command and control signals—something that UGV designers do not typically consider.

During their day-to-day work, the authors spend much of their time considering the broader problem set of Subterranean Situational Awareness (SubT-SA), which is the ability to perceive, understand, and predict environmental elements and events that contribute to an underground mission. Situational awareness is key to success in the subterranean mission space because it creates a distinct advantage for friendly and partner forces and reduces adversary benefits. The U.S. Army's operational philosophy is to shoot, move, and communicate underground; with current subterranean capabilities, this ability is at risk or severely degraded.

During current subterranean operations, situational awareness is provided to personnel via voice communications and standalone sensors over terrestrial radios, with limited application of teleoperated vehicles and human-machine teaming. Investment in a baseline and evolving technology ecosystem focused on subterranean operations would reduce risk to force, reduce support equipment requirements, conserve resources, and leverage machines and autonomy in hostile and complex environments. Moreover, these investments would result in transferable technologies that will ripple across all domains during LSCO, adding new capabilities to fielded equipment and strengthening interdependent links between existing technologies.[17]

The following sections will explore key transferable technologies and capabilities to increase the Army's ability to survive, fight, and win when required to conduct LSCO in environments where subterranean facilities exist. The tactical, operational, and strategic levels of war provide useful lenses to depict transferable investments and capability ripples across both the subterranean and land domains.

Tactical Subterranean Transferable Investments

Technologies and Areas of Emphasis: Breaching and New Energetic Materials; Alternate Position, Navigation, and Timing; Communications; Robotics; Blue Force Tracking; Chemical, Biological, Radiological, and Nuclear (CBRN) Sensing; Novel Wearable Materials

TRANSFERABLE INVESTMENT: BREACHING TECHNOLOGIES AND EMPLOYMENT OF ENERGETICS

Challenge: Before entering a subterranean facility, Army and partner forces will often face adversary defensive measures, including large, solid metal doors, reinforced concrete walls, and other impediments to entry. The Army lacks broad capabilities to conduct extensive breaching operations or employ tailored explosives and other energetic materials outside of a few specialized units. Similarly, during LSCO in dense and populated urban environments like cities, the Army will need increased capabilities for quicker breaching. The Army will likely benefit from subterranean breaching investment across the land domain if tasked to gain and hold terrain in an urban environment. Current operations can take hours, and they must be done faster to remain effective at scale.

Vault doors and blast doors will be present in most strategic subterranean facilities. Designed for high security and protection against blast effects, these doors are made of thick gauge metal and high-strength concrete and have complex locking mechanisms. Governments use this type of access point to protect national-level assets, and they require a high level of training to properly assess before attempting a breach. Failed breaches of these types of doors can easily result in a permanent barricade.

Solution: Novel energetic materials with a smaller form factor but which yield a larger controlled detonation should be developed. Similar products should be considered transferable investments as they apply to air-delivered munitions, ground munitions, and naval mines, benefiting all services. High-fidelity facility models generated in real-time based on operational data enable the simulation of weapons effects to support mission execution and simulation of shock propagation to limit individual exposure to hazardous overpressures.

TRANSFERABLE INVESTMENT: GPS-DENIED MAPPING AND SITUATIONAL AWARENESS

Challenge: Currently, if the Army and its partner elements were to enter a subterranean facility, they would face rapidly degraded communications and a loss of situational awareness provided by persistent ISR. Unaware of what lies ahead, leaders rely on antiquated and inefficient methods such as hand-drawn maps, with only the light sources they bring with them. Split into initial entry and deliberate mapping teams/elements, human mappers often rely on spray paint or other markers left by the initial entry team to develop cohesive maps of a facility for commanders. Different personnel may draw these maps in the vast expanses of a subterranean facility, generating significant errors between measurement methods such as pace counts, pedometers, and laser range finders. Thus, even after mapping is complete, navigation within the facility remains challenging.

Solution: The key to subterranean situational awareness is the presentation of actionable data to the force in a usable and easily understood manner. The future of how personnel enter and explore complex subterranean spaces requires agencies and services to possess, train with, and operate a completely interoperable family of systems that is capable of not only sensing in subterranean environments but also presenting information in a way that is immediately useful for awareness and planning. The foundation of this awareness is two-dimensional and three-dimensional map data that can be processed and stored on uncrewed systems and distributed across a network. This data will be pivotal to informing autonomy and guidance software and provides the building blocks that tailorable sensor data can be overlaid upon.

Overlaid on the map is a human-centered presentation of data that fuses all the requisite elements for individuals and leaders to make informed, data-driven decisions on target. Additionally, the map data allows the interagency to solve problems ahead of the force before individuals physically observe it themselves.[18]

TRANSFERABLE INVESTMENT: COMMUNICATIONS (INCREASED BANDWIDTH AND PROPAGATION COVERAGE)

Challenge: Within subterranean facilities and hard and deeply buried sites, communications are constrained and reduced due to natural and manmade phenomena. The facility's depth, wall thickness, and overhead protective materials severely restrict the ability to transmit and receive radio frequency (RF) signals inside the environment and externally to teams providing overwatch or to a local Tactical Operations Center (TOC).

While conducting operations in subterranean facilities, commanders and their units will experience numerous challenges as they coordinate activities. Limited communications can make it difficult for leaders to reposition their forces to respond to a dynamic environment without sending runners, dropping intermediate relay nodes, or using other delayed communication techniques. Additionally, bandwidth constraints prohibit streaming live video, persistent VoIP (voice over IP), and other large files such as CBRN sensors and their corresponding spectra when transmitting data-heavy information. These communication limitations are commonplace in subterranean operations and affect casualty evacuation, logistical support, and operational tempo. Often, forces only discover that they are overextended by physically approaching that point and basing that decision on human-generated estimates of distance and complexity.[19]

Solution: As novel RF waveforms continue to be developed and employed on software-defined radios, the hardware also continues to improve. Today, newer, more powerful chipsets are being miniaturized and utilized in form factors that are a better fit for military kits. Some technologies can be transitioned from the mining industry, which has worked in that environment for decades. Still, many pre-existing commercial off-the-shelf (COTS) solutions will not work without significant mission planning and staging. Technologies such as low-frequency communications (used for submarines) can be used but are often bandwidth-constrained. Non-RF approaches such as free-space optical and magnetic communications should be developed considering subterranean use cases.

Additionally, efforts should be made to maximize the use of edge computing to reduce the amount of data that needs to be transmitted in the first place. This area is likely rich ground for AI research, where a data-heavy, computer-based view of the world can be significantly simplified while communicating more information by pushing technology to provide a human understanding of the subterranean environment.

This two-fold "meet in the middle" approach—exploring alternate communication modalities while reducing the amount of data that needs to be transmitted—improves the chances of fielding practical solutions through technology convergence.

TRANSFERABLE INVESTMENT: ATTRITABLE, LOW COST, AND INTELLIGENT ROBOTICS FOR HUMAN-MACHINE TEAMING

Challenge: Operations in subterranean environments primarily rely on humans to identify threats and make sense of a chaotic and complex environment. Often, as in Gaza, these tunnels are booby-trapped with IEDs, contain dangerous breathing conditions, and are rigged with other hazards designed to injure, kill, or further delay an operation.[20] Some robotic solutions are designed to be "one way" and have a specific mission where they are only used once and then disposed of or destroyed at the target. While this might be acceptable in some scenarios, individuals will demand more from technology to ensure that they can transport equipment and sensors into subterranean environments.

Currently, robotic solutions face numerous challenges when used in subterranean facilities since these facilities are often GPS-denied spaces with multiple levels and corridors that can quickly overwhelm small robotic vehicles. Further research and development is necessary to employ multiple teamed robotic solutions that can rapidly collect and share information for efficient application.

Solution: Increased human-machine teaming will result in safer, more efficient operations in subterranean facilities. Utilizing robotic systems, the Army element deploys machine systems and sensors ahead of them into the environment, enabling them to explore while solving the challenge directly in front of them. If direct or kinetic action is required, the intuitive mapping and situational awareness information is sent to the assaulting force via a robust mobile ad hoc network (MANET).

Additionally, we envision an enhanced suite of robotic systems that can perform predictive logistics requests and autonomously navigate subterranean facilities to bring requested resupply to forces operating underground. Advanced modular sensor arrays on robotic systems could overlay hazard data on the map and broadcast that data to personnel, ensuring that all know the protective equipment and other requirements needed to approach the objective.[21] Furthermore, using autonomous systems mitigates communications risks because the systems can explore outside of the communications range, performing tasks in support of a larger goal before returning to a communications node, much as a human scout would do. This is yet another example of technology convergence that is useful across multiple domains but driven by challenging subterranean requirements.

TRANSFERABLE INVESTMENT: PERSONNEL ACCOUNTABILITY

Challenge: Personnel accountability is another significant challenge to operations in subterranean spaces. Currently, limited technical capabilities require that accountability be maintained by using a "release point" to track personnel and equipment entering or leaving the facility.

ABOVE: U.S. Army Soldiers assigned to 5th Battalion, 20th Infantry Regiment, 1st Brigade Combat Team, 2nd Infantry Division, secure an enemy tunnel complex during Decisive Action Rotation 18-06 at the National Training Center in Fort Irwin, Calif., April 15, 2018. (U.S. Army photo by Spc. Daniel Parrott, Operations Group, National Training Center)

What of the personnel inside of the facility? Mission leaders at the TOC do not know Blue Force positions with any certainty beyond manual reporting. Navigating the subterranean facility is arduous as personnel follow rudimentary maps, possibly laden with errors, to their destinations. When wearing personal protective equipment (PPE), critical attributes of the facility might not be noticed and individuals may overheat under the increased strain. In an emergency, personnel may rely on pace counts and markings to maneuver to a known exit, potentially bypassing other safe areas or exits.[22] Casualty evacuation adds further risk, as personnel may not be able to report their current location, and those performing recovery are left to deal with the same factors that likely contributed to the casualty in the first place. Additionally, risk assessment after encountering CBRN hazards is also encumbered because prior exposures can only be estimated, and no one knows exactly who was where or for how long.

Solution: Research and deliver products that replicate time-proven technologies such as Blue Force Tracking, Joint Battle Command Platform (JBC-P), and other platforms that geolocate personnel in reference to a locally rendered map data file and update in near real-time. GPS-denied simultaneous localization and mapping (SLAM)[23] technologies may use visual, lidar, thermal, radar, and other sensing modalities to enable compact, accurate mapping solutions for squads or individuals. Alternate position, navigation, and timing (Alt-PNT) solutions leveraging advancements in areas such as radio ranging, RFID, inertial navigation, magnetometry, signal processing, and computer vision are already making advancements that can precisely track personnel in GPS-denied environments. Many of these technologies passively sense the environment, enabling them to transfer quickly to surface-based applications with the potential to have a Low Probability of Intercept/ Low Probability of Detection assets that operate independently of GPS for personnel localization.

Once again, technology convergence proves that needed subterranean capabilities are critical across multiple domains, this time in the form of autonomous casualty evacuation. Autonomous systems that can localize themselves within a mapped facility can perform autonomous casualty evacuation by navigating to the known position of a team member in distress. There are cascading effects too—other personnel are freed up to focus their limited energy and breathable air on the primary objective.

TRANSFERABLE INVESTMENT: CBRN DETECTION, RESPONSE, AND TRACKING EXPOSURE

Challenge: Due to the nature of nation-state subterranean facilities, there are valid concerns that some facilities may contain and hazardous, WMD materials. Personnel must be aware of the presence of any hazardous materials and take precautions to avoid spreading contamination... Current technology allows limited personnel status to be tracked and monitored using wearable sensors that detect and monitor risks, including CBRN threats and poor air quality. However, as with other technology, these wearable sensors rely on limited communication capabilities in subterranean facilities. As a result, personnel don the most restrictive PPE for longer durations than necessary, consuming valuable logistical resources such as compressed breathing air and chemical filtration, all while fatiguing the force with bulky and cumbersome equipment.[24]

Solution: To provide robust and efficient capabilities, transferable investment in subterranean technologies can improve threat awareness and monitoring. With increased research and development, personnel can access force protection data such as air quality and hazard sensor data, spatial data, opposition personnel data, and critical facility attributes. This data increases threat awareness and significantly mitigating risk.

If used effectively, radiation dosing and chemical sensors mounted on robotic platforms can provide individuals with information that proactively influences personnel protection postures. Chemically contaminated areas can be revealed by unmanned platforms and marked long before personnel encounter them. Similarly, collecting and communicating this information could provide operational-level context for leaders to focus on the more significant requirements of multiple maneuver elements.[25]

TRANSFERABLE INVESTMENT: ENHANCED MATERIALS FOR PERSONNEL PROTECTION AND PHYSICAL RESILIENCE

Challenge: Several unique support requirements exist for conducting operations in subterranean environments and close-confined spaces. Multiple levels of PPE, including Mission-Oriented Protective Posture Equipment, replacements for expendable items, and the ability to refill high-pressure breathing air cylinders are all necessary to conduct and sustain operations in subterranean environments. Current equipment suffers from a variety of limitations including a lack of ruggedization necessary to protect wearers in extreme conditions.

Solution: A ruggedized suit designed to protect wearers conducting a full range of activities in subterranean environments is needed. Additionally, the ability to produce breathable air under pressure in a contaminated environment will shorten the logistics tail required to sustain operations for longer durations.

Finally, the use of uncrewed systems and robotics, especially autonomous systems, for the exploration of the most dangerous spaces conserves compressed breathing air and other life support materials, reduces the possibility for personnel contamination, reduces physical strain on individuals, and generally shortens the logistics tail by preserving resources required by humans.

Operational Subterranean Transferable Investments

Technologies and Areas of Emphasis:
Sensitive Site Exploitation (SSE);
Data-Driven Decision-Making;
Reachback and Virtual Subject Matter Expert Support

TRANSFERABLE INVESTMENT: SENSITIVE SITE EXPLOITATION CAPABILITIES AND ANALYSIS

Challenge: In the current subterranean environment, SSE relies on human-provided data, measurements, and documentation, creating the potential for error caused by imprecision in the location of materials in the facility, the layout and equipment characteristics, or the simple absence of documentation. The lack of laboratory-grade equipment and sensors at the edge may require transporting hazardous materials from the objective. Personnel exposure limits will restrict time on target and inhibit the measurement and recording of secondary facility information. Invaluable facility data related to construction, layout, equipment, materials, infrastructure, and other facets of sensitive sites is collected in a time-consuming and manual way, if at all, limiting the utility of post-mission intelligence activities.[26]

Solution: The intelligence community is constantly working to identify and characterize WMD facilities and surrounding activities based on their priority and importance. Higher resolution products fed by high-precision facility scans with forensic-level cataloging of equipment, materials, and infrastructure and their inferred relationships will let analysts make higher confidence assessments with actionable, mineable intelligence for the counter-WMD community. Digital models, anchored to actual facility blueprints, can also provide mission planners and individuals insight into what may lie behind the initial breach. A shared geographic information system (GIS) that can extract, transform, and load 3D data will allow known ground truth to be fused into analysis models as new information is obtained. Individuals, mission planners, analysts, and subject matter experts will all work from the same central model, each seeing their own curated view, enhanced with information from each other.

TRANSFERABLE INVESTMENT: DATA-DRIVEN DECISION-MAKING

Challenge: During subterranean operations, operational-level leaders must manage the deployment and activities of personnel operating in complex underground environments. This involves brokering the right information to the right individual at the right time. Operational-level leaders wholly rely on information from the Tactical Operations Center (TOC) during subterranean operations, while the TOC itself has limited insight into the ground truth of the operations.

Solution: Using advanced situational awareness tools, leaders can leverage sharable mapping data to anticipate force requirements and preposition personnel for the best outcome. Using data, decision-makers can ensure that the right personnel are dispatched to key target areas to deliver their expertise promptly. Using map overlays, leaders can depict where WMD materials are located, allowing leaders to prepare the right personnel and equipment for deployment once the area is secured. The ability to geolocate all personnel in the subterranean facility three-dimensionally informs accountability requirements and enables a level of subterranean understanding well beyond current capabilities.

Individuals should be able to use edge technology and advanced communications, to leverage critical data that is collectively fused onto a single pane of glass for multiple users. This level of data-driven decision-making eliminates the potential for confusion and provides additional capabilities across the subterranean and land domains.[27] Transparent information sharing relies on robust networking, which was mentioned previously in the “Tactical Communications” section. Utilizing over-the-horizon communications, enabled by AI-driven data reduction, allows for even greater data-fueled decision-making.

TRANSFERABLE INVESTMENT: SUBJECT MATTER EXPERT REACHBACK AND INTELLIGENCE ANALYSIS

Challenge: A critical aspect of subterranean operations is transmitting information from lead warfighters conducting subterranean operations back to subject matter experts (SMEs) awaiting entry to a subterranean facility. Current technology limits the discovery and transmission of challenges in a limited, essentially linear fashion. This often does not make the best use of valuable time and slows down situational understanding and the reduction of challenges and obstacles.

Similarly, any hazardous materials within a facility require high-level SMEs to evaluate and render them safe. Current technological limitations require that reachback be reactive, with SMEs reliant on a discoverer’s description of what they see. Often, the description of the threat or hazard has been relayed through second- and third-hand channels, creating the opportunity for confusion. Only after the expert arrives at the hazardous material do they get a clear, first-hand look at what is required for the appropriate action.[28]

Solution: Real-time environment data, fused and processed at the edge to minimize bandwidth while maximizing information content, will allow complete scene reconstruction for SMEs to operate as effective virtual scientists. Whether implemented in a 2D interface or virtual reality, investments that provide these capabilities for subterranean operations are transferable investments that can benefit multiple domains. Nowhere else is this more apparent than in the space domain, where astronauts are often asked to perform tasks and experiments outside their training and expertise. Using voice communications and video links, experts often talk astronauts through scientific processes analogous to what needs to occur in a subterranean environment for the identification of materials and operations in a suspected WMD facility.[29] Similarly, investment in increased subterranean capabilities will continue to ripple positively across other domains.

Strategic Subterranean Transferable Investments

Technologies and Areas of Emphasis:
Command & Control; Interagency SME support;
Intelligence Exploitation; Predictive Logistics

ABOVE: U.S. Soldiers assigned to the 3rd Infantry Division conduct a Radiological Evaluation Exercise during Combined Resolve 24-01 at the Joint Multinational Readiness Center near Hohenfels, Germany, Oct. 24, 2023. (U.S. Army Photo by Pfc. Jaimee Perez)

TRANSFERABLE INVESTMENT: JOINT ALL-DOMAIN COMMAND & CONTROL VIA SUBTERRANEAN MISSION DATA STORAGE

Challenge: As discussed previously, managing subterranean operations requires brokering the correct information to the right individual at the proper time. Currently, this involves personnel manually collecting information and then manually sharing it as best they can. Often, personnel are burdened with competing demands placed on them by the mission, the environment, and their technologies. Currently, some mission information can be brokered via the Android Tactical Assault Kit (ATAK), which offers a modular, open development environment but relies on government developers to develop and maintain mission solutions.

Solution: A Subterranean Mission Data Storage (SMDS) solution is a collaborative, cloud-based environment supporting subterranean transferable investments across several domains. This capability supports Army leaders at the strategic level who will likely use situational awareness technologies before, during, and after subterranean operations.

The value of fusing sensor information with detailed mapping data in the subterranean space, coupled with georeferenced data, provides intelligence analysts and chemical, biological, and nuclear subject matter experts a previously unobtainable understanding of the inner workings, design, and exploitability of complex underground spaces. This fundamental understanding can drive more efficient responses and safer subterranean operations.[30]

Establishing a dedicated, enduring data storage solution, such as a SMDS repository, allows senior leaders in operations, logistics, and acquisitions planning to make data-driven decisions on Operations Plans, Time Phased Force Deployment Models, Campaign Plans, and other vital requirements necessary to maintain capabilities ahead of potential threats. Intelligence analysts can access and exploit vast amounts of collected data and information about existing subterranean facilities and hard and deeply buried sites. Additionally, acquisition planners will possess first-hand, informative knowledge of the materials and personnel required to execute subterranean operations successfully.[31]

TRANSFERABLE INVESTMENT: PREDICTIVE LOGISTICS

Challenge: The logistical challenges of subterranean operations overlap with those faced by military operations in the land domain. However, degraded situational awareness during subterranean missions hinders a commander's ability to resupply operational forces efficiently. This is further aggravated by ineffective communications and the lack of a comprehensive map with accurate personnel locations.

Solution: In our envisioned future for operations in challenging and complex subterranean environments, predictive logistics are solved through a fusion of previously discussed transferable investments. For example, novel RF waveforms can be used to transmit location data in a more rapid and usable format, enabling precision navigation and timing and refining location information. This precise data could be used to create a robust digital map that allows for a both human-driven and eventually autonomous systems to deliver critical items to individuals before they need to request them.

Investment in Subterranean Capabilities to Compel Adversary Action

The previous sections argue that transferable investments in technologies enable the Army to survive, fight, and win across multiple domains during LSCO against subterranean facilities or subterranean areas of the city and urban environments. The rapid advancement of adversary subterranean facilities and hard and deeply buried sites continues to highlight the need for comprehensive U.S. and Allied focus.[32] As argued, adversary investment is primarily due to increased U.S. technological advancements and ubiquitous surveillance. However, U.S. adversaries likely continuously watch U.S. military investment, assess its capabilities, and weigh these factors against their own actions and investments. Thus, while developing subterranean capabilities is crucial for U.S. ability to survive, fight, and win during future conflicts across multiple domains, our investments may also serve U.S. strategic purposes and influence preferred U.S. outcomes.

1. Compellence is "direct action that persuades an opponent to give up something that is desired."[33] Creating a credible threat to the perceived security of subterranean assets, the U.S. could compel adversaries to reassess their strategies and alter their behavior in alignment with U.S. objectives. Similarly, demonstratable Army capabilities across subterranean missions may compel adversaries to drastically increase their economic investment into harder and more deeply buried sites as their perceived benefits diminish. This could force adversaries to reallocate their already limited funds away from other capability areas and toward subterranean facilities.

2. Diplomatic leverage will be increased during arms control discussions and negotiations due to increased subterranean capabilities. Robust subterranean capabilities will allow the U.S. to hold adversary strategic facilities and systems at risk. This increased capability may support more substantial U.S. positions during arms control negotiations and international agreements.

3. Intelligence collection and exploitation are improved by transferable investments in subterranean capabilities. Advanced U.S. subterranean capabilities not only enhance intelligence collection on site but may also ripple out and improve the ability to assess and monitor adversary underground activities without direct confrontation.

The Army can help shape the strategic landscape by deliberate investment in and showcasing subterranean capabilities. This approach potentially alters adversary behavior without resorting to direct conflict. Transferable investments in technologies that enable the American military to survive, fight, and win during subterranean operations and LSCO align with broader national security objectives to maintain our military-technological edge and enhance deterrence.[34]

Exploring the Nexus Between Subterranean and Other Domains

The establishment of a formalized U.S. Space Force focused on the space domain offers valuable insights and parallels for addressing challenges in the proposed subterranean domain.[35] Before the inception of the Space Force in 2019, the DOD's space mission lacked centralized governance, clear authorities, and cohesive defense and offensive architectures.[36] As military and civilian sectors grew increasingly reliant on space-based capabilities, particularly GPS, U.S. adversaries and competitors recognized and sought to exploit this dependence. This vulnerability drove the need for a defensive space posture, including surveillance of adversaries and protection of our assets.

In 2019, following numerous anti-satellite (ASAT) launches and tests by countries such as China and India, NATO announced space as a formal warfighting domain, joining the ranks of air, land, maritime, and cyberspace.[37] As adversaries develop capabilities that threaten our advanced systems, the U.S. must prioritize technological innovations and capabilities that maintain strategic advantage.

The DOD must acknowledge that adversarial activities and investments are occurring in the subterranean domain, just as it did with the space domain. Recognizing and understanding these actions is crucial for developing effective countermeasures, enhancing our ability to hold adversary subterranean facilities at risk, and improving our strategic position. This awareness is foundational for creating informed strategies that ensure operational readiness and resilience.

When the Space Force was created, and space was formally recognized as a warfighting domain, policymakers and budget analysts were critical components of the discussion. The Army should prepare and posture now for the possible future establishment of a subterranean domain to ensure its requirements are codified and captured for inclusion within future defense budgets. The Army and U.S. Special Operations Command (USSOCOM) should collaboratively lead the effort to capture requirements and investments needed for successful subterranean operations. With deliberate planning and forward-thinking, the Army and USSOCOM communities can lead engagement and galvanize defense industrial base investment focused on solving subterranean challenges.

Many subterranean capabilities and technologies currently fall under CBRN response or counter-WMD technology areas. We argue for a specific subterranean domain category that supports increased capability development for personnel and more investment opportunities for developers and industry. In the FY24 National Defense Budget (Green Book) and the FY24 National Defense Authorization Act, the terms space and cyber appear many times.[38] In contrast, terms associated with the proposed subterranean domain, such as tunnel, subterranean, below earth, and underground, were used very few times, if at all. This lack of inclusion in critical guiding documents indicates a lack of prioritization.

As the Space Force continues to expand its list of requirements, we are seeing an active surge within the commercial and consumer space domain, with the number of active satellites expected to triple in the next decade. Private investments in space communications, edge computing, artificial intelligence, and remote sensing are expected to directly benefit the national security sector. Private companies such as SpaceX have changed how small satellites are launched and increased Low Earth Orbit (LEO) architecture.

Establishing a unique subterranean domain will help concentrate complex problems from multiple domains into a focused area for investment, but if the example of the space domain is repeated, private investment and research and development would lead to accelerated advancement and greater overall outcomes.

Domain Dependency: Multiple Domains Support Subterranean Operations

The Army defines multidomain operations as “the combined arms employment of joint and Army capabilities to create and exploit relative advantages that achieve objectives, defeat enemy forces, and consolidate gains on behalf of joint force commanders.”[39] The multidomain approach focuses on coordinating the “use of Army capabilities and those from other service branches in more than one physical domain (land, sea, air, space or cyberspace) or dimension (physical, human or informational).”[40] Recognition of the subterranean environment as a separate domain is critical to future success in LSCO. To better connect our argument with the Army’s emphasis on multidomain operations, consider the following notional vignette set in 2040 that focuses on a subterranean operation where specific capabilities are summoned and other domains provide support.

“During LSCO in 2040, a cyber-enabled team exploits a zero-day vulnerability, reducing power to an electric grid in a target city that houses a subterranean facility of interest. Based on intelligence reporting, this subterranean facility is suspected of enriching nuclear material and having the capabilities to manufacture Advanced Conventional Weapons (ACW) capable of being a nuclear material delivery vehicle.

Simultaneously, space-based Signals Intelligence (SIGINT) detectors are focused on this location to provide operational overwatch. A collaborative fusion of government and commercial Geospatial Intelligence (GEOINT) spacecraft confirm that power has been disabled at the site and the lights are off. Upon confirmation, tactical assault teams depart a nearby vessel in adjacent littoral waters to enter the facility and conduct ground defeat operations.

Concurrently, an airborne asset provides sensitive missile warning and additional overwatch for the vessel and ground forces conducting operations. An intelligence analysis team in a remote, over-the-horizon location observes ground force operations and confirms the presence of WMD at the subterranean facility. During operations, air-based platforms use radio frequency jamming capabilities to disable adversary cell networks in that location only. Following the completion of ground force operations, a swarm of "one-way" attack drones is employed to reduce the ability to reuse the subterranean facility. Using AI-enabled change detection capabilities, intelligence personnel have an accurate battle damage assessment and can ensure that the cyber-enabled operations have permanently disabled facility servers."

While this is a notional and futuristic scenario, it highlights the importance of leveraging the full spectrum of multi-domain capabilities that can enable successful subterranean operations. In this scenario, subterranean operations are the primary "domain" but are closely supported by other domains, services, Interagency, and Combatant Commands.

The growing multidomain nature of LSCO and the need to interweave diverse cross-domain capabilities support our call to establish a subterranean domain and leverage transferable investments across all domains. A defined subterranean domain bridges capabilities across services and the Interagency and strengthens the Army's ability to survive, fight, and win during LSCO.

Conclusion

Others have recommended establishing the subterranean as its own unique domain owned by the Army and distinct from the land domain. While we have thus far provided reasons supporting our argument, we also wanted to address a few important arguments against a separate subterranean domain.

Critics argue that subterranean operations do not warrant designation as a separate domain but should remain part of the broader land domain. They contend that subterranean environments, while challenging, are fundamentally extensions of land warfare. Opponents argue that because people live and work underground, the subterranean environment can be connected to the land rather than other domains. The unique aspects of subterranean operations, such as isolation and hazards, are viewed as analogous to specialized operations in the land domain and specialized subsurface diving in the maritime domain. Additionally, some argue that subterranean capabilities are closely tied to urban warfare skills and that investing in urban operations would broadly address subterranean needs with only minor additional focus required.

Opponents also question whether the benefits of establishing a separate subterranean domain outweigh the costs. They often suggest that instead of creating a new domain, the focus should be on developing transferable technologies and capabilities that enhance subterranean and broader land warfare operations. There are concerns about funding and resource allocations, with some arguing it would be prohibitively expensive to outfit and train entire divisions for subterranean operations. Critics sometimes propose that specially trained forces, specifically those under USSOCOM rather than the broader Army, are a more cost-effective way to handle the uniquely challenging subterranean missions. Critics would argue that conventional forces should remain focused on more general urban warfare capabilities and subsequently seek transferable investments that enable most subterranean environments.

Such counterarguments are compelling and merit serious consideration. However, designating subterranean environments as a separate domain is equally well-reasoned and supported when considering the likely scope and scale of subterranean operations during LSCO.

What is most important is to recognize that these arguments represent starting points for a solution, and neither argument advocates for nor endorses the status quo. The foundational premise is that the DOD must provide its personnel with the best possible support when ordering them into the uniquely challenging realm of subterranean operations. Similarly, opponents of subterranean as a domain would likely agree that specialized, no-fail counter-WMD operations, possibly in subterranean environments, do not have the luxury of a learning curve.

During high-stakes and high-risk subterranean operations, technologies, capabilities, and tactics should not be fielded or trained on demand. To ensure an effective and measured response, truly capable technologies cannot be created after a crisis. Instead, these technologies, many of which are transferable to other domains, must be developed in anticipation of the expected operating environment. This is especially true considering the deliberate process of integrating technologies into existing architectures or possibly developing new architectures that can function within the challenges unique to subterranean operations.

The U.S. military must shift its perspective. Instead of questioning the potential drawbacks of establishing a subterranean domain, the DOD should urgently consider the grave risks and missed opportunities inherent in failing to do so. A subterranean domain that prioritizes response capabilities and capitalizes on transferrable investments may complicate adversary decision-making and compel favorable action in alignment with U.S. objectives. ■

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Notes

1. Daphné Richemond-Barak and Stefan Voiculescu-Holvad, "The Rise of Tunnel Warfare as a Tactical, Operational, and Strategic Issue," *Studies in Conflict & Terrorism*, August 23, 2023, https://doi.org/10.1080/1057610X.2023.2244191.

2. Kristina Hummel, "Defeat by Annihilation: Mobility and Attrition in the Islamic State's Defense of Mosul – Combating Terrorism Center at West Point." Combating Terrorism Center at West Point, April 14, 2017, https://ctc.westpoint.edu/defeat-by-annihilation-mobility-and-attrition-in-the-islamic-states-defense-of-mosul/.

3. Ishaan Tharoor, "The Islamic State Has Tunnels Everywhere. It's Making Them Much Harder to Defeat," *Washington Post*, April 14, 2017, https://www.washingtonpost.com/news/worldviews/wp/2017/04/14/the-islamic-state-has-tunnels-everywhere-its-making-them-much-harder-to-defeat/.

4. Heard by one of the authors from a trained subterranean operator in 2023: "None of this [equipment] is designed to work together—it's all just stuff."

5. Keir A. Lieber and Daryl G. Press, "The New Era of Counterforce: Technological Change and the Future of Nuclear Deterrence," *International Security* 41, no. 4 (April 2017): 9–49, https://doi.org/10.1162/isec_a_00273.

6. Michael G. Dudas, "Bedrock Prime: How Can the United States Best Address the Need to Achieve Dominance within the Subterranean Domain?," *Defense Technical Information Center*, December 14, 2012, https://apps.dtic.mil/sti/citations/ADA569345.

7. U.S. Department of the Army, *ATP 3-21.51 Subterranean Operations*, Army Publishing Directorate, November 2019, https://armypubs.army.mil/epubs/DR_pubs/DR_a/ARN19656-ATP_3-21.51-000-WEB-1.pdf.

8. U.S. Department of the Army, *ATP 3-21.51*.

9. U.S. Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2023, https://media.defense.gov/2023/Oct/19/2003323409/-1/-1/1/2023-MILITARY-AND-SECURITY-DEVELOPMENTS-INVOLVING-THE-PEOPLES-REPUBLIC-OF-CHINA.PDF.

10. Joseph Trevithick, "Putin Reveals Existence of New Nuclear Command Bunker," *The War Zone*, November 11, 2020, https://www.twz.com/37569/putin-reveals-existence-of-new-nuclear-command-bunker-and-says-its-almost-complete.

11. Reuters, "Iran shows off underground drone base, but not its location, state media report," *Reuters*, May 28, 2022, https://www.reuters.com/world/middle-east/iran-shows-off-underground-drone-base-not-its-location-state-media-2022-05-28/.

12. U.S. Department of the Army, *ATP 3-21.51*.

13. U.S. Department of the Army, *FM 3-0 Operations*, Army Publishing Directorate, October 2022, https://armypubs.army.mil/epubs/DR_pubs/DR_a/ARN36290-FM_3-0-000-WEB-2.pdf.

14. Matt Crotts, Rich Van Voorst, Gordon Banks, and Jason Arnott, *SubT-SA, Subterranean Situational Awareness Envisioned Future*, Liberty Alliance for Defense Threat Reduction Agency, July 2024, 2. Approved For Public Release.

15. Crotts, Van Voorse, Banks, and Arnott, *SubT-SA*, 8.

16. Crotts, Van Voorse, Banks, and Arnott, *SubT-SA*, 10.

17. RD-CXR, Mapping Awareness for Counter-WMD Operations (MACO) Team, "Internal Document: Subterranean Situational Awareness Envisioned Future," (Defense Threat Reduction Agency, December 1, 2023).

18. RD-CXR, MACO Team, "Internal Document."

19. RD-CXR, MACO Team, "Internal Document."

20. William Booth, Itay Stern, and Hazem Baloush, "Hamas Booby Traps, Ambushes Challenge Israeli Military in Gaza," *Washington Post*, December 22, 2023, https://www.washingtonpost.com/world/2023/12/22/hamas-booby-traps-gaza/.

21. RD-CXR, MACO Team, "Internal Document."

22. RD-CXR, MACO Team, "Internal Document."

23. Kamak Ebadi et al., "Present and Future of SLAM in Extreme Underground Environments," arXiv, August 2, 2022, https://arxiv.org/abs/2208.01787.

24. RD-CXR, MACO Team, "Internal Document."

25. RD-CXR, MACO Team, "Internal Document."

26. RD-CXR, MACO Team, "Internal Document."

27. RD-CXR, MACO Team, “Internal Document.”

28. RD-CXR, MACO Team, “Internal Document.”

29. Molly Kearns, “NASA Develops Advanced Space Communications Process,” NASA, March 1, 2023, https://www.nasa.gov/humans-in-space/nasa-develops-advanced-space-communications-process/.

30. RD-CXR, MACO Team, “Internal Document.”

31. RD-CXR, MACO Team, “Internal Document.”

32. U.S. Department of Defense, “2023 Strategy for Countering Weapons of Mass Destruction,” September 28, 2023, https://media.defense.gov/2023/Sep/28/2003310413/-1/-1/1/2023_STRATEGY_FOR_COUNTERING_WEAPONS_OF_MASS_DESTRUCTION.PDF.

33. John Rafferty, “Compellence | International Relations,” Britannica, 2019, https://www.britannica.com/topic/compellence.

34. The White House, “National Security Strategy” (The White House, October 12, 2022), https://www.whitehouse.gov/wp-content/uploads/2022/10/Biden-Harris-Administrations-National-Security-Strategy-10.2022.pdf.

35. Space Training and Readiness Command (STARCOM), “STARCOM Releases Space Domain Awareness Doctrine Publication,” STARCOM, November 16, 2023, https://www.starcom.spaceforce.mil/News/Article-Display/Article/3589828/starcom-releases-space-domain-awareness-doctrine-publication/.

36. U.S. Department of Defense, “DOD Space Strategy,” U.S. Department of Defense, September 16, 2024, https://www.defense.gov/Spotlights/DOD-Space-Strategy/.

37. Ashley Tellis, “India’s ASAT Test: An Incomplete Success,” *Carnegie Endowment for International Peace*, April 15, 2019. https://carnegieendowment.org/2019/04/15/india-s-asat-test-incomplete-success-pub-78884; “NATO’s Approach to Space.” NATO-What We Do, last modified March 21, 2024, https://www.nato.int/cps/en/natohq/topics_175419.htm.

38. U.S. Department of Defense, “NATIONAL DEFENSE BUDGET ESTIMATES FOR FY 2024 OFFICE OF THE UNDER SECRETARY OF DEFENSE (COMPTROLLER),” May 2023, https://comptroller.defense.gov/Portals/45/Documents/defbudget/FY2024/FY24_Green_Book.pdf; National Defense Authorization Act for Fiscal Year 2024, H.R.2670, 118th Cong. (2023-2024), https://www.congress.gov/bill/118th-congress/house-bill/2670.

39. U.S. Department of the Army, *FM 3-0 Operations*.

40. International Institute for Strategic Studies (IISS), “The US Army’s Multi-Domain-Operations Doctrine,” *IISS*, 2019, https://www.iiss.org/en/publications/strategic-comments/2022/the-us-armys-multi-domain-operations-doctrine/.