# **Mastering the Invisible Battlespace: An Analysis of Modern EMSO Planning and Command & Control Applications**

### **Executive Summary**

The increasing complexity of the Electromagnetic Operational Environment (EMOE) has rendered traditional, stove-piped approaches to Electronic Warfare (EW) and Spectrum Management (SM) obsolete. This has driven a strategic and doctrinal shift within the U.S. Department of Defense (DoD) toward integrated Electromagnetic Spectrum Operations (EMSO). This report provides an exhaustive analysis of the modern EMSO planning and Command and Control (C2) applications that are the critical enablers for this strategic pivot. These applications provide commanders with the necessary tools to plan, visualize, execute, and assess military operations within the contested, congested, constrained, and dynamic electromagnetic spectrum (EMS).

The analysis begins by establishing the foundational context, defining the EMS as a physical warfighting domain and detailing the strategic imperatives, such as the 2020 DoD Electromagnetic Spectrum Superiority Strategy, that drive the need for these advanced C2 tools. It examines the evolution of military doctrine from separate EW and SM disciplines to the unified concept of EMSO, as codified in Joint Publication 3-85 and various service-level manuals.

The report then dissects the anatomy of a modern EMSO C2 application, exploring its core architectural principles—data-centricity, cloud-to-edge computing, and a Modular Open Systems Approach (MOSA)—which are designed to overcome historical challenges of interoperability and slow acquisition cycles. A detailed functional workflow is presented, organized into four key modules: Mission Planning and Analysis, Situational Awareness and Visualization, Execution and Deconfliction, and Assessment and Reprogramming. This workflow demonstrates how these applications are designed to accelerate the commander's decision cycle, or OODA loop, within the EMS.

An overview of the current ecosystem, including the joint-level Electromagnetic Battle Management-Joint (EMBM-J) system and service-specific tools like the Army's Electronic Warfare Planning and Management Tool (EWPMT), reveals a complex "system of systems" approach fraught with both promise and significant integration challenges.

Finally, the report looks to the technological frontier, detailing the revolutionary impact of Artificial Intelligence (AI) and Machine Learning (ML). The progression from AI-assisted signal classification to predictive analytics and ultimately to Cognitive Electronic Warfare (CEW) illustrates a clear roadmap toward increasing operational autonomy. The integration of these capabilities into the broader Joint All-Domain Command and Control (JADC2) construct is identified as the ultimate goal. EMSO is shown to be both a critical enabler of JADC2, by protecting the data networks, and a key effector within it, by delivering non-kinetic attacks.

The report concludes that mastering the invisible battlespace requires a concerted effort to accelerate the transition to AI-enabled autonomous C2, mandate a unified joint data architecture, and invest in the human enterprise. The development and fielding of sophisticated EMSO C2 applications are not merely a technical upgrade but a strategic necessity for achieving and maintaining decision advantage over peer adversaries in future conflicts.

## **Part I: The Foundation for EMSO Command and Control**

### **Section 1: Defining the Operational Domain: The Electromagnetic Spectrum**

The effective command and control of modern military operations is predicated on a thorough understanding of the environments in which those operations occur. While the domains of land, sea, air, and space are readily conceptualized, the electromagnetic spectrum (EMS) has emerged as a co-equal, and arguably the most critical, physical domain of warfare. Its unique characteristics and the contemporary challenges within it form the foundational rationale for the development of specialized planning and C2 applications.

#### **1.1 The EMS as a Physical Maneuver Space**

Doctrinally, the EMS is now recognized as a physical domain that exists regardless of human interaction, possessing properties that can be leveraged and controlled for military advantage.1 It is not merely a medium for communication but a maneuver space with physical characteristics of frequency, waveform, power, and time that can be managed, occupied, and selectively controlled like any other domain.1 The EMS comprises all manmade and naturally occurring electromagnetic energy, arranged by wavelength and frequency from zero to infinity.1 This vast range includes everything from the extremely low-frequency (ELF) radio waves used to communicate with submerged submarines to the X-band microwave frequencies used for deep space communications, as well as infrared, visible light, ultraviolet, X-rays, and gamma rays.1 Nearly every modern weapons system—including aircraft, satellites, tanks, ships, and radios—depends on the spectrum to function, making control of this domain essential for achieving strategic and operational objectives.1

#### **1.2 The Modern Electromagnetic Operational Environment (EMOE)**

The contemporary EMOE, the operational context for EMSO, is defined by four intersecting characteristics that create unprecedented complexity and drive the requirement for advanced C2 tools.1 The characterization of the EMOE as congested, contested, constrained, and dynamic is not merely descriptive; it is the fundamental problem statement that dictates the necessary attributes of any viable EMSO C2 solution. A C2 application must be agile enough to handle the dynamic nature of the EMOE, intelligent enough to deconflict the congested environment, compliant enough to operate within its constraints, and resilient enough to function when contested.

* **Congested:** The EMS has experienced an exponential increase in the number and density of emitters due to the proliferation of both military and non-military systems.1 The global explosion in commercial wireless technology, including 5G networks and the Internet of Things (IoT), has saturated the spectrum.3 Sixty years ago, the EME was used by perhaps 100,000 people; today, it is used by over 6 billion, with a projection of 7.5 billion users averaging 10 devices each by 2030.4 This has created what is termed a "large-scale collective action problem," where the sheer volume of users, not just adversaries, can deny access to critical spectrum, making assured electromagnetic protection a significant challenge.4
* **Contested:** Peer and near-peer adversaries, particularly China and Russia, have meticulously studied the U.S. military's deep reliance on the EMS and have invested heavily in sophisticated capabilities to challenge this dependence.1 These adversaries have demonstrated the ability to deny, degrade, and disrupt U.S. operations through advanced jamming, spoofing, and other forms of electronic attack.8 This direct contestation means that U.S. forces can no longer assume unimpeded access to the spectrum; spectrum degradation must be considered the norm rather than the exception in future conflicts.11
* **Constrained:** The use of the EMS is not limitless; it is framed by the unyielding laws of physics, national and international policies, and technological limitations.1 Physics dictates the propagation characteristics of different frequencies, making certain bands more desirable for specific applications.13 Furthermore, spectrum use is governed by a complex web of regulations from bodies like the International Telecommunication Union (ITU), the National Telecommunications and Information Administration (NTIA), and the Federal Communications Commission (FCC).14 This regulatory framework, coupled with the need to share spectrum with commercial partners, means the DoD cannot treat the EMS as its own private domain and must operate with consideration for all users.3
* **Dynamic:** The state of the EMOE is not static; it is subject to rapid and varying fluctuation due to the constant interplay of congestion, contestation, and constraints.1 Maintaining accurate, real-time EMS awareness is therefore critical for achieving a position of advantage, enabling commanders to make decisions and create effects more rapidly than an adversary.1

#### **1.3 The Strategic Imperative: The Pursuit of EMS Superiority**

In response to the challenges of the modern EMOE, the DoD has formally articulated a new strategic vision. The 2020 DoD Electromagnetic Spectrum Superiority Strategy codifies the department's primary goal: to achieve "freedom of action in the electromagnetic spectrum, at the time, place, and parameters of our choosing".12 This document represents a significant evolution in strategic thinking, unifying the previously separate 2013 EMS Strategy and 2017 Electronic Warfare Strategy into a single, cohesive approach.17 This unification acknowledges that spectrum management and electronic warfare are two sides of the same coin and must be treated as integrated operations.

The strategy establishes five strategic goals 12:

1. Develop Superior EMS Capabilities.
2. Evolve to an Agile, Fully Integrated EMS Infrastructure.
3. Pursue Total Force EMS Readiness.
4. Secure Enduring Partnerships for EMS Advantage.
5. Establish Effective EMS Governance.

This strategic framework directly addresses documented past failures to implement EMS-related strategies, which were largely due to a lack of senior leadership with appropriate authorities and established oversight processes.8 The new strategy explicitly assigns oversight to senior leaders, including the DoD Chief Information Officer (CIO) and the EMSO Cross-Functional Team (CFT), to ensure accountability.12

The very term "EMS Superiority" marks an important and nuanced strategic shift. It is an implicit admission that "EMS dominance," a term often used in the past, is no longer a feasible objective in a globally congested and contested environment. Doctrinal publications acknowledge that global superiority is not achievable.21 Instead, like air superiority, EMS superiority is the goal of achieving a localized and temporary degree of control in a specific portion of the spectrum, at a specific time, to enable a specific mission or operation.3 This reframes the entire problem for military planners and the C2 systems they use. The objective is no longer to achieve total, persistent control of the EMS, but to skillfully identify and create temporary "windows of advantage" that allow friendly forces to act while denying the same to the enemy.6 This makes the planning, modeling, and real-time execution capabilities of an EMSO C2 application paramount. The tool must be able to predict where and when a window of superiority can be opened and orchestrate the necessary assets to achieve it—a far more complex task than simply executing a broad jamming plan.

### **Section 2: The Evolution of Doctrine: From EW to Integrated EMSO**

The strategic imperatives for operating in the modern EMOE have been mirrored by a significant evolution in military doctrine. The U.S. military has moved away from viewing Electronic Warfare (EW) and Spectrum Management (SM) as separate, loosely coordinated activities. Instead, it has embraced the integrated concept of Electromagnetic Spectrum Operations (EMSO), a holistic approach to managing and fighting in the spectrum. This doctrinal shift, codified in joint and service-level publications, provides the formal framework upon which modern EMSO C2 applications are built.

#### **2.1 Defining Electromagnetic Spectrum Operations (EMSO)**

Joint doctrine defines EMSO as military actions undertaken to exploit, attack, protect, and manage the EMOE.1 The concept represents the formal unification of two traditionally distinct disciplines: Electronic Warfare and Spectrum Management.1 This integration is a core tenet of modern military thought, reflecting the reality that one cannot effectively conduct electronic attacks without managing the spectrum to prevent fratricide, nor can one manage the spectrum for friendly forces without protecting it from enemy attack. This unified approach is reflected in the formal replacement of older terminology, such as Joint Electromagnetic Spectrum Management Operations (JEMSMO), with the broader term EMS Management within the EMSO construct.23 The formula is simple yet profound:

EMSO=EW+SM.4

This doctrinal evolution from separate disciplines to an integrated whole reveals a deeper realization: the EMS is the physical transport layer for cyberspace operations.4 An action in one domain has direct and immediate effects in the other. For instance, a jamming attack (an EW action) can sever a satellite datalink, denying a critical cyber capability. Conversely, a cyber intrusion into the software of a network-enabled radio can manipulate its spectral output, creating a potent EW effect. This convergence means that controlling the spectrum is a prerequisite for effective cyber operations, and that an EMSO C2 application must be inherently a cyber-aware tool. It cannot operate in a "spectrum-only" vacuum; it must be able to ingest data from and provide data to cyber C2 platforms, modeling the dependencies between network nodes and the spectral links that connect them. This doctrinal shift has also driven organizational changes, breaking down the traditional staff silos of intelligence (J-2), operations (J-3), and communications/cyber (J-6) and leading to the creation of integrated bodies like the Joint EMSO Cell (JEMSOC) and the Army's Cyberspace Electromagnetic Activities (CEMA) sections.6 The EMSO C2 application is the digital workbench for this new, integrated staff element.

#### **2.2 The Pillars of Electronic Warfare (EW)**

The traditional subdivisions of EW remain the functional core of the "attack" and "protect" elements within the broader EMSO concept. An EMSO C2 application must be ableto plan and manage actions across all three pillars.1

* **Electronic Attack (EA):** EA is the offensive component, involving the use of electromagnetic energy, directed energy, or anti-radiation weapons to attack personnel, facilities, or equipment with the intent of degrading, neutralizing, or destroying enemy combat capability.9 EA is doctrinally considered a form of non-kinetic fires and is integrated into the joint targeting process.9 Examples range from jamming enemy radar and communication systems to using high-power microwaves to disable electronics or anti-radiation missiles that home in on enemy emitters.10
* **Electronic Protection (EP):** EP consists of actions taken to protect friendly personnel, facilities, and equipment from any effects of friendly or enemy use of the EMS that might degrade or destroy friendly combat capability.9 This includes a wide array of techniques, such as frequency-hopping radios, spread-spectrum technologies, emissions control (EMCON) procedures to reduce a unit's electromagnetic signature, low-observable (stealth) technologies, and physical countermeasures like deploying chaff and flares to decoy missiles.1 The elevation of EP to the "linchpin" of EMSO signifies a critical shift from an offense-dominated mindset to one that prioritizes operational resilience.4 It is a tacit acknowledgment that in a contested environment, the ability to  
  *continue operating* despite enemy action is often more critical than the ability to completely silence the enemy. This reframes the primary purpose of an EMSO C2 application: it is less of a "sword" for planning attacks and more of a "shield and brain" for orchestrating a resilient friendly posture.
* **Electronic Support (ES):** Formerly known as Electronic Support Measures (ESM), ES involves actions tasked by a commander to search for, intercept, identify, and locate or localize sources of radiated electromagnetic energy.9 This is the "sensing" function that provides the foundational intelligence for all other EMSO activities. ES provides the situational awareness and data needed for immediate threat recognition, targeting, and the planning of future EA and EP actions.24

#### **2.3 The Doctrinal Framework**

The principles of integrated EMSO are formally captured in a hierarchy of doctrinal publications that guide the development of TTPs (tactics, techniques, and procedures) and the requirements for C2 systems.

* **Joint Publication (JP) 3-85, *Joint Electromagnetic Spectrum Operations*:** Published in May 2020, JP 3-85 is the authoritative joint doctrine for EMSO.22 It provides the fundamental principles and guidance for planning, executing, and assessing JEMSO across the full spectrum of competition and conflict.22 It establishes the requirement for integrated planning processes and designates the JEMSOC as the JFC's primary staff element for coordinating and controlling EMS operations.22
* **Service-Level Doctrine:** The joint concepts from JP 3-85 are further refined and implemented through service-specific doctrine, which tailors the principles to each service's unique operational context.
  + **Air Force Doctrine Publication (AFDP) 3-85, *Electromagnetic Spectrum Operations*:** The Air Force doctrine emphasizes an "overmatching, offensive approach to EMSO" designed to create multiple dilemmas for adversaries.1 It frames EMSO as one of the six principal capabilities of Air Force Information Warfare, highlighting its role in enabling effects across all domains.1
  + **Army Field Manual (FM) 3-12, *Cyberspace and Electronic Warfare Operations*:** The Army has taken the concept of integration a step further with its doctrine on Cyberspace Electromagnetic Activities (CEMA).9 CEMA is the process of planning, integrating, and synchronizing cyberspace operations, EW, and spectrum management operations in support of unified land operations.6 This doctrine formally recognizes the deep interdependence of the cyber and electromagnetic domains and provides the framework for Army commanders to employ physical and virtual, kinetic and non-kinetic capabilities in a synchronized manner.6

## **Part II: The EMSO C2 Application: Architecture and Functionality**

Building on the strategic and doctrinal foundations, the modern EMSO C2 application emerges as the tangible tool through which commanders and their staffs can implement the principles of integrated spectrum operations. These applications are complex systems of systems, defined by a new set of architectural principles and a comprehensive suite of functionalities designed to manage the entire operational workflow, from initial planning to post-mission assessment.

### **Section 3: The Command and Control Construct for EMSO**

The development of a dedicated C2 application for the EMS reflects the domain's maturation into a primary arena of military operations. While the principles of C2 are universal, their application to the invisible and dynamic electromagnetic environment requires a specialized construct and a new technological architecture.

#### **3.1 Principles of Military Command and Control (C2)**

At its core, military C2 is defined as "The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission".30 This exercise of authority is performed through an arrangement of personnel, equipment, communications, facilities, and procedures that a commander employs to execute the core functions of planning, directing, coordinating, and controlling forces and operations.31 C2 can be analyzed through five key variables:

*who* commands the forces (authority), *what* forces are being commanded, *when* (the temporal aspect), *where* (the geographic aspect), and *how* the command is technically enabled through systems and hardware.32 EMSO C2 applications are the primary answer to the "how" variable for this specific domain.

#### **3.2 Electromagnetic Battle Management (EMBM): The C2 for the EMS**

Electromagnetic Battle Management (EMBM) is the formally recognized C2 capability for the EMS domain.16 It is the designated materiel solution and operational process for JEMSOCs at the Combatant Command (CCMD) and Joint Task Force (JTF) levels to plan, direct, monitor, and assess military activities within the EMOE.16 EMBM systems are designed to provide commanders with user-defined operational pictures, fuse relevant data from disparate sources, and provide the supporting software tools necessary to synchronize and deconflict all joint force operations in the EMOE.16

The formalization of EMBM as a distinct capability is a landmark development. It institutionalizes C2 for a non-physical domain, signaling that the DoD now views the EMS as a co-equal arena of warfare requiring its own dedicated C2 infrastructure, analogous to an Air Operations Center (AOC) for the air domain or a Maritime Operations Center (MOC) for the maritime domain. Historically, the EMS was seen merely as a medium *through which* C2 was exercised (e.g., via radio). The modern contested environment has forced a paradigm shift where the EMS is now a domain *in which* C2 must be actively exercised. The EMSO C2 application is therefore not just another battlefield tool; it is the central nervous system for the command and control of an entire warfighting domain, tasked with orchestrating maneuver, fires (EA), and protection within that domain.

#### **3.3 Foundational Architectural Principles**

To meet the challenges of the modern EMOE, EMSO C2 applications are being developed based on a set of architectural principles that represent a significant departure from traditional defense acquisition. These principles are not merely technical buzzwords; they are a direct response to the institutional problems of stove-piped systems, slow development cycles, and a lack of interoperability that have plagued DoD modernization efforts for decades.8

* **Data-Centricity:** A fundamental shift is occurring from a platform-centric view of EW to a data-centric, enterprise-wide construct.38 The objective is to "weaponize data" by creating a mesh network of sensors and effectors that can observe, orient, decide, and act (OODA) on new information faster than the adversary.38 This requires the C2 application to be architected around the data, capable of ingesting, fusing, analyzing, and disseminating vast amounts of information from a multitude of sources in real-time.39
* **Cloud-to-Edge Architecture:** Modern applications leverage a hybrid cloud-connected architecture. This model brings the immense power of centralized cloud computing—for large-scale data storage, processing, and AI/ML model training—to the enterprise level, while pushing tactical decision-making, analytics, and execution to ruggedized "edge" nodes in the battlespace.37 This architecture provides the flexibility, scalability, and resilience necessary to operate in environments with disconnected, intermittent, and latent (DIL) connectivity.38
* **Modular Open Systems Approach (MOSA):** To combat the problem of proprietary, "stove-piped" systems, EMSO C2 applications are increasingly built using a MOSA philosophy.37 This involves using open standards, common interfaces, and a modular, "plug-in" software architecture. This approach prevents vendor lock-in and allows for the rapid and incremental integration of new capabilities, services, and third-party applications, creating a "marketplace of open EMSO applications".37 This software-defined approach directly addresses the historically slow acquisition cycle by allowing new capabilities to be fielded as software updates rather than requiring the development of entirely new hardware systems.

### **Section 4: Anatomy of an EMSO C2 Application: Core Modules and Workflow**

A modern EMSO C2 application is a comprehensive software suite designed to guide an operational commander and staff through the entire military decision-making and execution cycle as it pertains to the electromagnetic spectrum. Its functionality can be understood by examining a composite workflow organized into four core modules, which directly mirror the OODA Loop (Observe, Orient, Decide, Act) and the military's plan-execute-assess process. This model, synthesized from the capabilities of systems like the Army's EWPMT and the joint EMBM, demonstrates how these applications aim to accelerate the commander's EMS-specific decision cycle to a speed that outpaces any adversary.

#### **4.1 Module 1: Mission Planning and Analysis (Orient)**

This module provides the tools for the pre-execution "orient" phase, where planners make sense of the environment and develop courses of action. The extensive modeling and simulation (M&S) features within this module are critical for managing the inherent uncertainty of EMSO; because the effects of non-kinetic actions are often invisible, these tools must make their potential impact as tangible and predictable as possible to give commanders the confidence to employ them.

* **EMOE Characterization:** The planning process begins with building a deep understanding of the operational environment. The application ingests and fuses data from national intelligence databases, tactical sensor feeds, and allied partners to construct a detailed Electronic Order of Battle (EOB). This EOB identifies and characterizes friendly (blue), adversary (red), and neutral (gray) systems operating in the spectrum.1
* **Course of Action (COA) Development:** The application provides planners with a digital workspace to develop and wargame multiple COAs, consistent with the doctrinal Joint Military Appreciation Process (JMAP).37 Users can define mission objectives, assign specific EW assets, and create time-phased plans for execution.37
* **Modeling and Simulation (M&S):** A cornerstone of the planning module is the ability to model and simulate the potential effects of planned actions. Using advanced radio frequency propagation models and system performance data, planners can run simulations to visualize the likely effectiveness of an electronic attack (EA) against a specific target, a capability known as an Electronic Attack Effects Simulator (EAES).47 This allows them to assess friendly vulnerabilities, optimize the placement and tasking of EW assets, and evaluate the risks and benefits of different COAs before committing forces.44

#### **4.2 Module 2: Situational Awareness and Visualization (Observe)**

This module is the primary "observe" function, focused on providing the user with an intuitive, real-time, and actionable understanding of the live EMOE.

* **The EMS Common Operating Picture (COP):** The central output of this module is a single, unified operational picture of the EMS.37 The application serves as a fusion engine, ingesting live data from a distributed network of sensors, EW platforms, and intelligence systems. It then correlates and visualizes this information, creating a comprehensive picture that can be viewed within the application and also pushed as a data layer to the overall joint or service-level COP (e.g., the Army's Command Post Computing Environment, CPCE).39
* **Geospatial and Spectral Visualization:** Making the invisible visible is the primary challenge of the user interface (UI). The application must present complex RF data in an intuitive manner. This is achieved through a multi-layered display that includes geospatial visualization of friendly and enemy assets on a map using standard military symbology (MIL-STD-2525D).37 Critically, this is overlaid with spectral displays (e.g., waterfall plots) and visualizations of RF energy, showing commanders their own unit's "electromagnetic footprint" to help manage emissions and avoid detection.47 Advanced tools like graph analytics can be used to map the complex web of interconnected signals, turning raw data into a contextualized network map.52
* **Real-time Anomaly and Threat Detection:** The application actively monitors the EMOE in real-time. Using AI-driven algorithms, it can automatically detect anomalies, such as the appearance of a previously unknown emitter or a signal exhibiting threatening behavior, and provide immediate alerts to the operator.52 It can also discriminate between friendly, adversary, and unauthorized emitters by comparing detected signals against an authoritative database like the Joint Spectrum Data Repository (JSDR).47

#### **4.3 Module 3: Execution and Deconfliction (Decide/Act)**

This module facilitates the "decide" and "act" phases, enabling active C2 of EMSO assets during a mission.

* **Dynamic Tasking and Remote Control:** The application functions as the command interface for the entire network of friendly EW assets. Through an intuitive graphical user interface (GUI), an authorized operator can remotely control networked EW systems like the Army's Terrestrial Layer System (TLS).44 This includes issuing discrete commands, such as "Buzzer On / Buzzer Off" to initiate or terminate jamming, and dynamically re-tasking sensors and effectors as the mission evolves.42
* **Automated Spectrum Deconfliction:** A core C2 function is the prevention of electromagnetic interference (EMI), a problem known as deconfliction. This includes preventing "friendly fire" where one friendly system interferes with another, as well as mitigating the "collateral interference" that friendly EA actions can cause to other friendly systems.55 The application provides tools for automatic detection and notification of overlapping or conflicting frequency assignments.37 It can manage complex frequency and time-sharing schemes, such as those used by the Link 16 tactical data link, to ensure all systems can operate effectively without mutual interference.57 This is the critical "management" component of EMSO.
* **Integration with Fires and Targeting:** Since EA is doctrinally considered a form of non-kinetic fires, the EMSO C2 application is deeply integrated with the joint targeting cycle. The ES capabilities of networked sensors generate precise geolocation data on enemy emitters. The C2 application can then format this data as a target nomination and pass it to fires and maneuver elements, supporting both the deliberate targeting of scheduled targets and the dynamic targeting of pop-up threats.22

#### **4.4 Module 4: Assessment and Reprogramming (Learn/Act)**

This module closes the loop, providing tools to assess the results of actions and adapt for future operations.

* **Battle Damage Assessment (BDA):** The application provides capabilities for non-kinetic BDA. By analyzing post-attack sensor data and intelligence reporting, it helps operators assess whether an EA action achieved its desired effect (e.g., deny, disrupt, degrade) on a targeted enemy system. This assessment is critical for determining if a target needs to be re-attacked, perhaps with a different technique or a kinetic weapon.44
* **Mission Effectiveness Analysis:** On a broader scale, the system collects and collates performance data and operator feedback from the mission. This information is used to conduct post-mission analysis to evaluate the overall effectiveness of the EMSO plan, identify shortfalls in TTPs or equipment, and generate lessons learned to inform future planning cycles.22
* **Dynamic Reprogramming:** The ultimate goal of the modern EMSO architecture is to achieve a rapid, adaptive "move-countermove" cycle.1 The C2 application, as part of a cloud-to-edge ecosystem, is designed to support the dynamic, in-mission reprogramming of EW systems. Threat data collected at the edge can be sent back to a central processing node, where a new countermeasure can be developed and pushed back out to the entire force as a software update, all in near-real-time. This shortens the reprogramming cycle from months or weeks to mere minutes, a critical advantage against an agile adversary.38

### **Section 5: The Ecosystem of EMSO Applications**

The DoD's approach to fielding EMSO C2 capabilities is not monolithic. It is a complex "system of systems" ecosystem, comprising a joint-level integrating platform supported by several mature, service-specific applications. This structure is both a strength, allowing services to tailor solutions to their specific needs, and a significant challenge, creating technical and bureaucratic hurdles that must be overcome to achieve a truly unified joint enterprise.

#### **5.1 Joint Systems: Electromagnetic Battle Management-Joint (EMBM-J)**

Electromagnetic Battle Management-Joint (EMBM-J) is the DoD's designated joint program of record designed to provide a C2 and situational awareness capability specifically for the JEMSOCs operating at the CCMD and JTF echelons.16 Released by the Defense Information Systems Agency (DISA), EMBM-J is a cloud-based visualization tool that functions as an EMS-centric component of the broader Combined Joint All Domain Command and Control (CJADC2) effort.39 Its primary purpose is to ingest data feeds from multiple service-specific systems and foundational databases, fuse them together, and provide a single, unified picture of the EMS to the joint force commander.39 A core design principle of EMBM-J is its interoperability with the service systems, which is achieved through the implementation of a common data layer and standardized interfaces, allowing it to serve as the authoritative joint visualization and C2 tool without replacing the tactical functionality of the service programs.39

#### **5.2 Service-Specific Implementations**

Each military service has developed its own EMSO C2 applications to meet its unique operational requirements. These systems are the primary sources of tactical data and control that feed into the joint EMBM-J architecture.

* **U.S. Army: Electronic Warfare Planning and Management Tool (EWPMT):** EWPMT is arguably the most mature and widely fielded of the service-level systems. It is a comprehensive software application providing Army Electronic Warfare Officers (EWOs) and Electromagnetic Spectrum Managers (ESMs) with the tools to plan, manage, and execute C2 of EW activities from the brigade to corps level.42 It integrates directly with Army EW and signals intelligence (SIGINT) sensors, such as the dismounted VMAX and vehicle-mounted Sabre Fury systems, via ruggedized laptops known as Raven Claw, which serve as the forward edge of the system.42 The development of EWPMT was accelerated in response to an urgent operational needs statement from U.S. Army Europe (USAREUR), forcing it to mature rapidly through real-world feedback and exercises.42 As a result, it has become a de facto pathfinder for the entire DoD EMSO C2 effort, with its capabilities and lessons learned heavily influencing the development of the joint EMBM-J system.16 The Army is now pursuing the next generation of the system, EWPMT-X, which is a software modernization effort focused on a more advanced architecture to support future multi-domain operations.49
* **U.S. Navy: Real-Time Spectrum Operations (RTSO):** The Navy's primary contribution to the ecosystem is its RTSO capability.24 While less is publicly detailed about its specific interface, RTSO is focused on the unique challenges of the maritime environment, where a single vessel hosts a dense concentration of powerful radars, communication systems, and EW emitters. RTSO's goal is to provide real-time spectrum awareness and management to deconflict these systems and support naval operations, from self-protection to information warfare.24 It is a required data provider to the EMBM-J system.39
* **U.S. Marine Corps: Spectrum Services Framework (SSF):** The SSF is the Marine Corps' counterpart system, designed to provide spectrum management, planning, and deconfliction capabilities in support of the Marine Air-Ground Task Force (MAGTF).24 Like its Army and Navy counterparts, it is a key component that must interface with and provide data to the overarching EMBM-J framework to ensure a complete joint picture.39

#### **5.3 Commercial and Allied Systems**

The DoD ecosystem is complemented by a growing market of commercial and allied EMSO C2 systems. Companies like ATDI (with its HTZ Warfare tool) and Consunet (with its EMBM platform) offer sophisticated solutions for battlespace spectrum management, planning, and simulation.37 Furthermore, allied partners, particularly within NATO, are developing their own C2 of EW capabilities and working toward common standards to ensure interoperability in coalition operations.5 This highlights the importance of the DoD's strategic goal of securing enduring partnerships and leveraging commercial innovation to maintain an advantage.12

The existence of this complex ecosystem presents a significant integration challenge. The success of the entire joint vision for EMSO hinges on the ability to overcome the technical and bureaucratic friction inherent in a "system of systems" approach. If data from a Marine Corps SSF cannot flow seamlessly through the joint EMBM-J to inform a targeting decision being made in an Army EWPMT, the promise of agile, all-domain C2 remains unfulfilled. This makes the development of, and strict adherence to, the common data layer, open APIs, and MOSA principles the single most critical technical task for the entire enterprise.

**Table 1: Comparison of Key DoD EMSO C2 Systems**

| Feature | Electromagnetic Battle Management-Joint (EMBM-J) | Electronic Warfare Planning & Management Tool (EWPMT)-X | Real-Time Spectrum Operations (RTSO) | Spectrum Services Framework (SSF) |
| --- | --- | --- | --- | --- |
| **Primary User/Echelon** | Joint Staff, Combatant Commands (CCMDs), Joint Task Forces (JTFs), Joint EMSO Cell (JEMSOC) 16 | U.S. Army Brigade, Division, Corps; Electronic Warfare Officer (EWO), Spectrum Manager (ESM) 42 | U.S. Navy Fleet, Task Force, individual platforms 24 | U.S. Marine Corps Air-Ground Task Force (MAGTF) 24 |
| **Architectural Approach** | Cloud-native, visualization service, built on a joint common data layer, designed for interoperability 39 | Server-client architecture evolving to a modernized, joint-capable framework; MOSA-based, software-defined 44 | Focused on real-time data processing and deconfliction for dense shipboard environments 24 | Framework designed for spectrum management services and deconfliction within expeditionary operations 24 |
| **Key Planning & Analysis Features** | Ingests and visualizes service-level COAs; provides high-level EMS situational awareness for joint planning 36 | Detailed M&S of EW effects (EAES); COA development and wargaming; EOB creation; vulnerability analysis 44 | Real-time analysis of onboard and environmental spectrum usage to support mission planning 24 | Planning and deconfliction of MAGTF communications and spectrum-dependent systems 24 |
| **Execution & Control Features** | Provides the joint EMS Common Operating Picture (COP); enables high-level C2 and synchronization of joint EMSO 39 | Direct remote control of Army EW assets (e.g., TLS); dynamic targeting integration with Army fires networks (AFATDS) 44 | Real-time interference monitoring and resolution; supports dynamic management of shipboard emitters 24 | Provides tactical spectrum deconfliction and interference resolution for deployed Marine units 24 |
| **JADC2 Integration Role** | Designed as the primary EMS-centric component of the CJADC2 architecture; acts as the joint integration and visualization hub 16 | Key tactical data provider to EMBM-J; integrates with the Army's Command Post Computing Environment (CPCE) 16 | Required data provider to the EMBM-J common data layer to inform the joint maritime picture 39 | Required data provider to the EMBM-J common data layer to inform the joint amphibious/expeditionary picture 39 |

## **Part III: The Technological Frontier and Future Outlook**

The development of EMSO C2 applications is not a static endpoint but a dynamic, ongoing process driven by rapid technological advancement. The future of command and control in the electromagnetic spectrum will be defined by the integration of artificial intelligence, the pursuit of operational autonomy, and the seamless incorporation of EMSO into the broader vision of all-domain military operations.

### **Section 6: The AI/ML Revolution in EMSO C2**

Operating at the speed and scale required by the modern EMOE is beyond human cognitive capacity. The sheer volume of signals, the agility of adaptive threats, and the complexity of deconflicting thousands of friendly emitters make Artificial Intelligence (AI) and Machine Learning (ML) not just an enhancement, but an essential, transformative technology for effective EMSO C2.64 The progression from basic AI assistance to full cognitive autonomy represents a clear roadmap for systematically removing the human from time-critical decision loops where they are the weakest link.

#### **6.1 AI for Signal Intelligence and Situational Awareness**

The foundational layer of AI integration involves using ML algorithms to bring clarity to the chaos of the EMOE. Traditional EW systems rely on vast libraries of known threat signatures; if a signal is not in the library, it cannot be identified.64 Modern adversaries employ agile radars and communications systems that can change their characteristics on the fly, rendering these static libraries obsolete.66 AI, particularly deep learning algorithms like Convolutional Neural Networks (CNNs), can be trained to recognize the underlying features of signal types, allowing them to rapidly classify and identify novel or unknown waveforms in real-time.68 This capability allows an EMSO C2 system to automatically sift through the spectrum, differentiate between friendly, neutral, and potential threat signals, and provide operators with a far more accurate and timely EOB.47 This is a critical enhancement of the "Observe" and "Orient" phases of the decision cycle.

#### **6.2 Predictive Analytics for Proactive Battle Management**

The next level of AI integration moves from reactive identification to proactive prediction. By applying predictive analytics models to vast datasets—including historical intelligence, real-time EOB, geographic data, and even social media or news feeds—an EMSO C2 system can begin to forecast adversary actions and optimize friendly resource allocation.65 For example, a system could predict the most likely avenues of approach for an enemy electronic attack or identify which friendly communication nodes are most vulnerable based on current force posture. Bayesian inference techniques can be used to automatically weigh multiple competing hypotheses about adversary intent at machine speed, allowing the system to recommend the most effective COAs to human commanders, such as repositioning a jammer or shifting communications to a more resilient waveform.66 This capability directly supports the "Decide" phase of the OODA loop.

#### **6.3 Cognitive Electronic Warfare: The Path to Autonomous Response**

The technological frontier of AI in this domain is Cognitive Electronic Warfare (CEW). CEW is a bio-inspired approach that seeks to imbue EW systems with the ability to observe, orient, decide, and act autonomously, learning from their environment and adapting their behavior in real-time without direct human intervention.73 A true CEW system, integrated into an EMSO C2 framework, could detect a novel threat radar, analyze its characteristics, synthesize a unique and optimized jamming waveform, and execute the countermeasure, all within milliseconds—a timescale far beyond human capability.66 This represents a paradigm shift from pre-programmed, library-based responses to intelligent, adaptive, and autonomous action.71 This level of automation is seen as essential for achieving spectrum dominance, optimizing the use of EW resources, and effectively countering the complex, networked threats of the future.73

The successful implementation of this entire AI/ML roadmap, however, is critically dependent on a factor that is often overlooked: the availability of massive, high-quality, and correctly labeled training data. The most sophisticated ML algorithms are useless without the right data to learn from.68 Collecting a comprehensive library of adversary RF signals is an immense intelligence challenge. This reality has led to significant research into developing synthetic RF data for training purposes 71, but it also reveals a critical vulnerability. The datasets used to train these AI systems become a high-value target for adversaries, who could attempt to conduct "data poisoning" attacks to corrupt the AI's learning process and degrade its performance.40 Therefore, a massive, ongoing effort to collect, curate, and secure RF training data is a necessary precondition for the success of the entire AI-enabled EMSO vision.

**Table 2: AI/ML Applications Across the EMSO C2 Workflow**

| EMSO Workflow Phase | AI/ML Application | Function / Purpose | Key Technologies |
| --- | --- | --- | --- |
| **Planning & Analysis (Orient)** | Predictive Threat/Vulnerability Analysis | Forecasts likely enemy EA COAs and friendly vulnerabilities based on historical data, EOB, and environmental factors. 65 | Predictive Models, Bayesian Inference, Game Theory 66 |
|  | AI-Enabled Wargaming | Rapidly simulates outcomes of complex EMSO plans against intelligent, adaptive adversary models to refine COAs. 40 | Reinforcement Learning, Generative Adversarial Networks (GANs) 68 |
| **Situational Awareness (Observe)** | Cognitive Signal Classification & ID | Rapidly identifies and categorizes known, novel, and agile RF signals without relying on pre-existing library entries. 64 | Deep Learning, Convolutional Neural Networks (CNNs) 68 |
|  | Anomaly Detection | Continuously monitors the EMOE to detect and alert operators to unusual patterns, such as unexpected emitters or changes in signal behavior. 52 | Graph Analytics, Unsupervised Learning 52 |
| **Execution (Act/Decide)** | Dynamic Spectrum Access (DSA) | Autonomously senses the spectrum to find and utilize unoccupied or underutilized frequencies, increasing agility and resilience. 18 | Software-Defined Radio (SDR), AI Agents 40 |
|  | Cognitive Jamming / Adaptive EA | Devises and executes novel, optimized countermeasures against agile threats in real-time based on environmental feedback. 66 | Reinforcement Learning, Generative Models 66 |
|  | Automated Targeting Support | Analyzes sensor data to automatically generate Find-Fix-Target (F-F-T) information for non-kinetic targets and passes it to fires networks. 44 | Data Fusion Algorithms, Pattern Recognition |
| **Assessment (Learn)** | Automated BDA & Effectiveness Assessment | Analyzes post-action EMOE data to determine if non-kinetic effects were achieved, informing re-attack decisions and updating models. 54 | Machine Vision (for sensor data), Data Fusion Algorithms |

### **Section 7: Integration into All-Domain Operations**

EMSO C2 applications are not being developed in a vacuum. They are a critical and foundational component of the DoD's broader strategic shift toward fully integrated, all-domain operations. The ability to command and control the electromagnetic spectrum is both a prerequisite for and a key capability within the future warfighting concepts of Joint All-Domain Command and Control (JADC2) and Multi-Domain Operations (MDO).

#### **7.1 EMSO as a Cornerstone of JADC2**

The DoD's JADC2 strategy aims to create a warfighting capability that can "sense, make sense, and act at all levels and phases of war, across all domains, and with partners, to deliver information advantage at the speed of relevance".79 This vision is predicated on connecting sensors from all military services into a single, resilient network, enabling commanders to make better, faster decisions.32 EMSO, and by extension its C2 applications, plays a unique and indispensable dual role within this construct.

First, EMSO is a critical **enabler** of JADC2. The vast network of sensors, platforms, and decision-makers that JADC2 seeks to connect relies almost entirely on the electromagnetic spectrum for its data transport layer.2 If these wireless links are jammed, disrupted, or degraded, the entire JADC2 construct collapses. Therefore, the "protect" and "manage" functions of EMSO—orchestrated by an EMSO C2 application—are essential for ensuring the resilience of the JADC2 network itself.80

Second, EMSO is a primary **effector** within JADC2. One of the key all-domain effects a JADC2-empowered commander can employ is a non-kinetic electronic attack to paralyze an adversary's C2, ISR, and weapon systems.1 This makes the EMSO C2 application a critical node in the "act" portion of the JADC2 cycle. This dual role creates a profound C2 challenge: the EMSO C2 system must orchestrate the protection of friendly blue networks while simultaneously planning and executing attacks on enemy red networks, often using the same limited pool of EW assets and spectral resources. This inherent tension requires a level of sophisticated, AI-driven optimization and deconfliction that is arguably unparalleled in any other C2 domain.

#### **7.2 Enabling Multi-Domain Operations (MDO)**

Closely related to JADC2, the MDO concept focuses on the synchronized employment of capabilities from across all domains to present adversaries with multiple, simultaneous dilemmas and create temporary "windows of advantage".6 Achieving localized EMS superiority is one of the most effective ways to create such a window. By dominating the spectrum in a specific time and place, a commander can enable friendly freedom of maneuver while blinding adversary sensors, disrupting their C2, and rendering their precision weapons ineffective.1 The EMSO C2 application is the tool that allows a commander to plan, visualize, and execute these complex, synchronized, cross-domain schemes of maneuver that are the hallmark of MDO.

However, the very success of concepts like JADC2 and MDO paradoxically increases the military's vulnerability in the EMS. By networking every sensor and shooter, the DoD is creating a larger, more interconnected, and more lucrative attack surface for adversaries to target via the spectrum.32 The EMS can thus become a single point of failure for the entire joint force.20 This reality creates a positive feedback loop: the more connected and all-domain the force becomes, the more critical it is to protect those connections (EP) and attack the enemy's (EA). Consequently, the demand for and strategic importance of advanced EMSO C2 applications will only continue to grow as these future warfighting concepts mature.

#### **7.3 The Challenge of the Joint Enterprise**

Despite the clear vision for an integrated, all-domain force, significant challenges remain in its implementation. The DoD has a long history of struggling to move from service-centric, "stove-piped solutions to a highly connected, agile, and resilient system".80 Government Accountability Office (GAO) reports have highlighted past failures to fully implement EMS strategies due to dispersed governance and a lack of senior leaders with the necessary authority and resources.8 While the 2020 EMS Superiority Strategy and the JADC2 Implementation Plan aim to rectify this with reformed governance and clear leadership assignments, the risk remains.12 Achieving the vision of a seamlessly integrated EMSO C2 enterprise will require sustained, high-level focus to overcome the institutional inertia that favors service-specific solutions over a truly unified joint architecture.

### **Section 8: Strategic Recommendations and Conclusion**

The analysis of modern Electromagnetic Spectrum Operations (EMSO) planning and Command and Control (C2) applications reveals a domain undergoing a rapid and profound transformation. Driven by the realities of a contested and congested electromagnetic environment and the strategic imperative to compete with peer adversaries, the U.S. Department of Defense is fielding a new generation of tools designed to master this invisible battlespace. To ensure these efforts succeed and deliver a decisive military advantage, several strategic priorities must be pursued.

#### **8.1 Accelerate the Transition to AI-Enabled, Autonomous C2**

The speed and complexity of modern warfare in the EMS have already surpassed the limits of human cognition. To effectively counter agile, adaptive, and AI-driven adversary systems, the DoD must accelerate its transition toward C2 systems that are themselves AI-enabled and capable of autonomous action. The current generation of applications, which primarily serve as decision aids for human planners, is a necessary but insufficient step. The true advantage will come from fielding Cognitive Electronic Warfare (CEW) capabilities that can sense, learn, and act at machine speed, executing the full decision cycle in microseconds.66 This requires sustained investment in the research and development of reinforcement learning, intelligent algorithms, and the robust Test and Evaluation (T&E) infrastructure needed to validate and build trust in these autonomous systems.

#### **8.2 Mandate a Unified, Data-Centric Joint Architecture**

The greatest threat to achieving EMS superiority is not an adversary's capability, but the DoD's own institutional friction. The current "system of systems" approach, with separate joint and service-level applications, risks recreating the stovepipes of the past. The Department must rigorously enforce a truly data-centric approach, mandating adherence to a Modular Open Systems Approach (MOSA) and a common joint data enterprise.19 Success hinges not on attempting to bolt together disparate, fully-formed systems, but on building a common, resilient data and communications backbone upon which all services can plug in their capabilities. This requires strong governance from the highest levels of the DoD to ensure that service-level requirements do not compromise the integrity and interoperability of the joint architecture.

#### **8.3 Invest in the Human Enterprise**

Advanced technology alone is not a panacea. The most sophisticated AI-driven C2 application is useless without a cadre of skilled professionals to operate, manage, and lead it. The DoD must make a commensurate investment in the human enterprise.12 This involves creating new career paths and training pipelines for EMSO professionals who are fluent in the integrated disciplines of electronic warfare, spectrum management, and cyberspace operations. These warfighters will need to be trained not just as technicians, but as mission commanders capable of understanding and employing AI, managing risk, and exercising mission command over networks of autonomous and semi-autonomous systems.73

#### **8.4 Concluding Thoughts: Decision Advantage in the Invisible Battlespace**

The contest for military advantage in the 21st century will increasingly be decided in the electromagnetic spectrum. It is a domain that underpins all other military operations, from tactical communications to strategic deterrence. The fight for EMS superiority is, at its heart, a fight for information and decision advantage. The side that can more effectively and rapidly sense the environment, make sense of the complexity, and act decisively will hold an insurmountable edge. Modern EMSO planning and C2 applications, powered by artificial intelligence and integrated across all warfighting domains, are the indispensable key to securing that advantage and ensuring success in any future conflict.

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