78-94

ADVANCING C4ISR CAPABILITY: LEVERAGING EMERGING TECHNOLOGIES AND COMMERCIAL ADVANCES

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Modern military operations are expected to involve increasingly diverse and intricate operational scenarios requiring missions to be conducted across multiple domains and effects. The expanded battle spaces have increased the breadth and depth of information desired in real time. Commanders have to plan for a wider range of missions, from those involving high tempo of operations that mandate prompt responses, to long drawn face-offs that depend on force capability, deployment and sustenance for deterrence. Complexity has been further added by the introduction of newer domains of space and cyber and of novel technologies and weapon systems. Military strategies as well as compulsions of resource constraints, of both equipment and manpower, are compelling the precise use of combat elements, achieving the desired results while ensuring economy of effort. The increased dynamism of manoeuvre in an expanded battlefield space has reduced the decision-making timelines, with the advantage going to the side that can stay ahead in these processes.

It has been evident for some time now that enhancing operational efficiency requires a shift from the platform-centric approach to one that leverages technology for optimum employment of combat elements. Command and Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) systems are labelled as the "nervous system" of the military. They enhance situational awareness (SA) and knowledge of the adversary and environment, provide support in planning, offer decision advantages to the commanders, allow novel concepts of operations and assist in the synchronised management of combat related operations. They are thus force enhancers that depend on technological solutions to provide a competitive edge against the adversary.

C4ISR is an amalgamation of various subsystems, each contributing to the overall efficacy of the system. There is a heavy dependence of these on information and communication technologies (ICT) and an asymmetric advantage would be gained by the side that could better apply developments in these as well as exploit emerging technologies and innovative technological applications towards capability enhancement. Traditionally, militaries have depended on government funded R&D and a lot of new age technologies have emerged from these programs. This has changed in recent years as the necessity of quick, innovative and resilient solutions in an increasingly competitive and contested civil and commercial space is becoming as essential as in the military domain. This has incentivised private investments in technology development, especially those related to ICT.

Artificial Intelligence (AI) is a technological tool that has applications across domains to improve efficiencies, accuracies and help in decision making. Machine Learning (ML) is a subset of AI that allows the system to operate more autonomously, adapting to the dynamic environment and progressively improving their responses. Both are finding important applications in the modern military operational environment, especially among C4ISR systems, that are highly dependent on IT enabled applications and services. The article would cover a few of the envisaged advances in technology and assess the leveraging of developments in the civil domain to achieve information superiority and stay ahead in the decision making and execution cycle.

Intelligence, Surveillance and Reconnaissance (ISR)

The ISR process involves information acquisition through multiple sensors, having the necessary communication capability to ensure timely transmission of information, adequate storage and processing capability for the huge amount of assorted data, and the ability to provide actionable intelligence to decision makers, where required, in a format that is easily comprehensible.

Sensors. The wide expanse of operational areas and the accelerated rate of operations dictates increasing the numbers and diversity of distributed sensors across multiple domains, including those of space and cyber, to address the spatial, spectral and temporal gaps. Space offers resilient and secure multi-spectral capability, mainly from Low Earth Orbit. Digitisation and miniaturisation have enabled the production of smaller satellites with comparable capabilities. Private entities are now fielding imaging constellations with advanced capabilities that reduce the time between scans through numbers and provide multi-spectral imagery at affordable costs. Pixxel, an Indian start-up, launched the first of its satellites, Shakuntala, claimed to host the 'world's highest resolution hyper spectral commercial cameras that has ever been flown to space', on SpaceX's Falcon-9 rocket. There is also a proliferation of Unmanned Aerial Systems (UAS) that could be equipped with varied sensor payloads. Capabilities of both platforms and payloads are being developed by private players for a variety of civilian roles that have applicability to military ISR too. An agile and resilient sensor architecture that connects sensors and weapons across mission areas would greatly enhance the efficacy of operations.

The complex battlefield necessitates real time information across vast areas and domains, even as the sensors of requisite capabilities remain scarce. AI could be gainfully applied to automatically prioritise, cue and optimise ISR platform and sensor use to maximize the probability of target detection and identification. An appropriately designed closed loop system would enable dynamic resource allotment to cater to the evolving operations and the command intent.

AI capability onboard distributed platforms would help optimise the use of interlinked machines by improving the decision-making capabilities and contextual awareness of robots towards working cooperatively towards common mission achievement with minimal human interaction. Swarm UAV demonstrations, involving autonomous formations of scalable machine-to-machine teams, are already demonstrating their prowess and could be programmed for various C4ISR related functions. U.S. DoD's Defense Advanced Research Projects Agency's (DARPA) Context Reasoning for Autonomous Teaming (CREATE) program seeks to develop the theoretical foundations of autonomous AI teaming to enable a system of heterogeneous, contextually-aware agents to act in a decentralized manner and satisfy multiple, simultaneous and unplanned missions' goals.[1] This technology would greatly enhance the functionality and capability of unmanned swarms in support of ISR missions.

Geospatial Systems. Military operations are planned and executed in a geographical space and would benefit from georeferenced data. Besides reducing the processing requirements, it would provide context to the information. Space enabled Position, Navigation and Timing services contribute immensely to these efforts. Geospatial tools also enable digital terrain modelling and projection of geographical and military data onto digital maps for better appreciation of threats, patterns and trends. Georeferenced projections allow more synergised planning and execution of operations, optimising support missions and reducing chances of fratricide. Additional applications and map products could be developed to provide enhanced capabilities for decision-making.

Communication and Network Technologies. Information assurance would require communication networks' infrastructure that is robust, agile, secure, resilient and adaptable and has sufficient capacity to handle the large volume of data being generated by an increasing array of sensors. The highly dynamic battlefield environment consists of distributed and displaced mobile command posts and forces that need to be orchestrated in real time by timely conveying of command decisions. Redundancy can be achieved through a network of dispersed heterogeneous groups of communication equipment with expansive coverage. Last mile connectivity would require wireless connectivity.

Space Enabled Communications. Space is being revolutionised with the addition of LEO-based distributed communication capability that reduces latency, enhances coverage and greatly adds on the transmission capacities. This capability is supplementing the already increasing communication capabilities through deployment of High Throughput Satellites in the conventional GEO and Optical Communication. LEO-based communication constellations are being developed by private entrepreneurs like SpaceX and OneWeb and provide options in terms of technology and capabilities that the military systems could exploit. A pertinent example is of the ongoing Russian-Ukrainian War, where access to open internet has been resorted to for transmission of information and C2 by both sides to overcome electronic disruption. A significant event of the conflict was the continued provision of internet to Ukrainian soldiers through the private Starlink LEO-based satellite internet network, when Russian EW and cyber efforts were able to achieve disruption of SATCOM services from the American Viasat network. Interestingly, the private company was able to counter similar Russian disruption against its own systems, ensuring continued last mile connectivity through hundreds of terminals provided to the Ukrainian forces.

5G Networks. These are already being progressed for commercial services that would provide higher data transfer capacity at significantly higher speeds. It has applicability for military networks, especially for last mile connectivity. China has already deployed 5G networks for information flow in border areas of Eastern Ladakh. Indian Armed Forces have also actively followed up on the introduction of 5G for civil networks by conducting a Joint Services Study that has deliberated upon and recommended a roadmap for the induction of 5G. An MoU has been signed between MCTE and IIT Madras for the setting up of a test bed that would facilitate the validation of military use cases of 5G.[2]

Software Defined Communication. Software defined communication devices that would be capable of hosting multiple waveforms and operating over multiple orbits and frequencies is vital for communicating in a dense electromagnetic environment susceptible to jamming, interference and outages. These would be portable and easy to reconfigure and could even employ AI for more autonomous functioning.[3]

The armed forces are already assessing the network-centric potential of both legacy and developing systems and work is afoot on different sets of multimodal communication networks to enable the coordinated use of forces and collaborative targeting. Communication technologies involving satellite enabled networks, wireless communications, including 5G networks and software defined radios, would have to be leveraged to provide multi-layered architecture for enhanced capacities, lower latencies and redundancy. AI also has applications for Electromagnetic Spectrum Operations (EMSO) – mission specific networking and dynamic bandwidth allocation for use in degraded communications conditions and for enabling proactive and responsive network protection (Electronic Warfare).

While commercial communication systems are not traditionally designed to function in contested environments, collaborative efforts could help exploit advances in civil networks towards upgrading existing military systems or could assist in developing enterprise communication architectures to meet military standards. Commercial private networks could also be exploited for emergent military operations, when organic communication capability has not been deployed or has been degraded. In the U.S., its Army is pursuing an Integrated Tactical Network that incorporates a Secure but Unclassified (SBU) communications architecture into the network. This allows soldiers to leverage commercial cellular networks—such as 4G, LTE and WiFi, along with other commercial wavelengths—to communicate. This is expected to enable the forces to be more expeditionary and mobile.[4] Its DoD is also focussing on Joint All Domain Command and Control (JADC2) through open architectures and interoperability and these modernisation goals and objectives are being pursued through commercial solutions.[5]

Data Processing. Computers enhance the processing power of information and decision making and consequently of the timeliness and efficacy of Command and Control (C2). The proliferation of ISR sensors is resulting in a deluge of complex data from service specific sensors and from other diverse sources. These could be operating in different spectral bands of the electromagnetic spectrum, imaging from varied positions in terms of heights and angles and have diverse software standards. Leveraging data for information dominance would necessitate integration of the varied data, tested for its accuracy and processed for relevance to provide value addition to the decision making. This is a challenge considering that most of the sensing systems belong to differing legacies and domains and have evolved disparately, leading to incongruent formats. Innovative computing solutions are required to scale up the processing capability to address subsequent enlarged data handling functions.

Cloud Technology. This huge volume of intelligence data would have to be stored for future analysis and reference purposes in a format that could be easily shared, when required. Cloud technology allows the use of shared IT infrastructure and services that go beyond storage to cloud computing – through the flexible, scalable and on-demand IT environment.

Deployable Clouds. While server farms could be distributed for better network management and redundancy, another application offering options for military operations is deployable clouds. This would reduce the dependency on networks and latency in transmission of data, while enhancing the ability of the field commander to take decisions as part of more evolved decentralised execution.

Edge computing. It is a concept involving distributed, networked autonomous sensors, allowing data to be processed on the spot at the "edge" of the network, i.e., AI enabled processing at the level of sensors, or nearby. This helps in cutting down the processing time, speeding up the sensor to shooter cycle and lowering the exposure to network vulnerabilities and limitations. It also reduces the need for large processing centres that could be vulnerable to physical and virtual attacks.[6] The importance of cloud infrastructure has grown significantly in recent years, further accelerated due to challenges thrown up by the Covid-19 pandemic. Strategic cloud solutions being developed by companies for business applications could be applied to national security efforts. Thales is working on the world's first theatre-level deployable defence cloud capability for NATO's Deployable Communications and Information System (DCIS). This project will utilise private cloud architectural principles and functions like automation and orchestration to significantly reduce the time to configure, deploy and activate services to the soldier. The new project will be based on work previously done with the industry to develop an architecture for a new DCIS.[7]

Manual operations for fusing this data, spread across many different databases and stakeholders, is arduous and time consuming, even with the help of the high computational prowess of contemporary machines. AI and ML algorithms and processes would lead to automated sensor data fusion with ultra-low latency. Human resources are also limited in capacity and skills to analyse the data to accurately produce results of relevance. AI would enable high-speed autonomous scrutinizing of data, with appropriate algorithms turning the information into coherent, actionable intelligence to speed up the decision making. For example, on the basis of algorithms, convolutional neural networks (AI systems designed to process images) are able to pick out objects of interest automatically. Linking the system to diverse libraries of relevant data would enable next-level intelligence functions such as anomaly detection, automatic feature extraction for target identification and characterisation and automatic characterisation of operational areas.

Rafael Advanced Defence Systems Ltd has demonstrated a new Automatic Target Recognition (ATR) capability for its SPICE-250 air-to-ground, stand-off, autonomous weapon system which can utilise this capability to autonomously detect and recognise its individually assigned target.[8] Project MAVEN is a U.S. DoD's initiative that aims to use AI to decipher aerial surveillance footage to improve targeting for UCAVs.[9] The Indian Army has developed in-house algorithms to analyse in real-time the inputs coming from various sensors in the field. The system is capable of handling heterogeneous inputs from diverse sensors and an AI-based real time monitoring software has considerably reduced the requirement of human involvement. It is collaborating with DRDO and academia for this.[10] Private companies in the digital domain are already acquiring petabytes of data from multiple sources and devices, and sifting through it to provide personalised feed for its billions of users. This ICT capability could be harnessed for military systems.

Decision Making. Enhanced computing would also contribute to timeliness of decision cycles at all levels of command. AI has emerged as an important component of decision-making processes and algorithms could be suitably developed or modified for military applications.

Decision Options. As battlefield complexities continue to rise, AI could be employed to assist the commanders by offering courses of actions and their probable outcomes at exponentially faster speeds. For example, the system could offer target prioritisation options for a particular outcome over a given area. ML could be utilised to improve the computed responses of the C4ISR system over regular gaming of situations.

Predictive Analysis and Inputs. AI and ML could also be programmed to develop capability towards predictive analysis and inputs. This would greatly enhance the response options and timelines. This has relevance in all physical and virtual domains. For example, systems could be programmed to generate preconfigured responses to electronic warfare (EW) and information warfare (IW) attacks. Predictive threat analysis is already a part of cyber security efforts and could provide the foundations for similar efforts in other domains. An example of this concept is Project Kaiju, a U.S. Air Force Research Lab's effort which is exploring AI/ML-related technologies and resources to advance EW technology against emerging Integrated Air Defence System (IADS) capabilities.[11]

Visualisation

Common Operating Picture (COP). SA would be greatly enhanced through the projection of simple, intuitive, geo-referenced intelligence onto a common display. Task complexities could be reduced towards more efficient planning, decision making and battle management. Joint operations would ordain integrated information display covering multiple domains to consolidate all warfighting information onto a common operating picture (COP) that would also support multi-domain manoeuvres in real-time. Immersive technologies like Augmented Reality/ Virtual Reality, and now the evolving Metaverse being developed for multiple commercial applications, could have applications for enhancing SA and assist in decision making.

Tactical level SA could be enhanced through the provision of relevant information onto wearables or platform mounted screens. It is important to design these for easy assimilation and with minimal task complexity through user-friendly interfaces and optimised interlays for ease of use. Private companies consistently strive to enhance visualisations and interfaces and this experience should be exploited for military systems too. North Atlantic Treaty Organisation (NATO) has contracted with Thales to supply the new increment of the NATO Common Operational Picture (NCOP) programme. This is expected to be achieved through layers of maps and referenced information on battle space objects operating in all domains.[12] Information sharing and decision making could also be supported through apps for SA and C2. Applications based on social media and chat structures could be incorporated for more interactive processes towards information exchange and decision making.

AI would help ease the process of sharing of information to relevant decision-making nodes through ‘push’ rather than ‘pull’ processes, autonomously. The ‘pull’ principle works on data being queried from the system, whereas the ‘push’ principle involves predictive provision of appropriate data to the user, based on the mission and operational environments. The tools already exist in the social media platforms, wherein advertisements are forwarded to consumers based on their surfing history, without being queried.

Joint C4ISR

There is a growing emphasis on joint operations and Joint C4ISR would enable flexibility in composition, deployment and employment of force packages to meet their evolving objectives and enable the coordinated application of combat power. The aim for an integrated C4ISR architecture, although desirable for a long time now, has faced its challenges in terms of technology, service specific command and control practices, cognitive variations and budgetary limitations. A U.S. Navy Study had recommended the attributes of composability and adaptability in the service specific capabilities. Composability is a system design principle that deals with the inter-relationships of components, allowing components to be selected and assembled for mission specific combinations of platforms and sensors in each layer. They would depend on a local-area network for tasking and collection and processing of data to create a tactical picture that meets the commander’s needs for that mission area.[13] Adaptability is the longer-term goal of using military systems in missions for which they were not originally intended, in response to dynamically changing situations and/or real-time events.[14] Equipment adaptability should also facilitate future upgrades as advances in C4ISR technology mature and are implemented.

Interoperability

The key to effective joint C4ISR lies in optimising the functionality and interoperability of disparate domain/ service specific components and systems. Contemporary systems and technologies have been procured or developed in isolation, with little consideration to interoperability, even within the services. The same holds true for communication networks that have been developed for specific systems or functions, resulting in silos. They require manual processes and inputs to accomplish mission tasks, entailing time critical delays and affecting accuracy of data. Interoperability among systems would allow more autonomy to be enmeshed into the systems that would provide advantages in terms of data handling and processing.

Developing a Common Operating Environment (COE) would be achieved through integrating hardware and software systems, requiring standardisation of equipment and protocols. Development of futuristic C4ISR systems should be based on Enterprise Integration, which would involve creating an open digital ecosystem that would better enable connecting components and systems through adoption of these measures. Open architecture approaches would enable exploiting modern hardware and software solutions being developed commercially to achieve interoperability among digital devices. The armed forces could use the service-oriented architecture (SOA) approach, which has been developed in the commercial sector for enterprise software systems, to enable interoperability. SOA defines a way to make software components reusable via service interfaces that utilise common communication standards in such a way that they can be rapidly incorporated into new applications. This allows users to combine functionality from existing services without requiring deeper integration of existing systems.[15]

Acquisition process would have to be streamlined to acquire or develop sub-elements of planned C4ISR architecture that follow defined standards for interoperability, even when acquisition follows a multi-track or multi-vendor option. This would dictate smooth funding and streamlining of arduous bureaucratic procedures. Innovation would also be enabled by involving academia and laboratories through incentivised, time-bound funding of next-gen foundational technologies.

Private Participation

The military remains sceptical of the capabilities available in the civil domain and their applicability to its operations. Concerns relate to limited experience in applying commercial approaches to military applications, the ability of commercial products to address the scale of military operations and the adequacy of security protocols among these systems.

A lot of effort in the civil domain is aimed at seeking solutions for information handling and decision making towards maximizing the operational and business effectiveness; these have applicability to military C4ISR systems. Constant endeavour is also being made at enhancing technological prowess and refining protocols and processes, while exploring more emerging technologies and applications to constantly improve upon these capabilities, achieving rationalisation of the effort in terms of time and resources. Advanced technology, hitherto dominated by government institutes and large conglomerates, is seeing an increasing participation by medium enterprises and even small start-ups. The resultant increase in competitiveness is beneficial for technological developments, innovation and a higher diversification in offered products. Diverse strategies of the commercial domain that include partnerships and collaborations and mergers and acquisitions lead to faster technology maturation and operationalisation.

Military professionals would have to collaborate with experts with a greater understanding of technology to identify ways to bring those technologies and solutions into the operational environment, and for the collaborative development of futuristic systems and architectures. Adaptation of such solutions in the military will come with corresponding savings in terms of time and costs, but would have to emphasise on security of data.

Global Efforts

The U.S. is taking an integrated approach towards utilising AI for military applications. It established a Joint Artificial Intelligence Center (JAIC) in 2018, with a focus on C4ISR systems. The strategy included partnering with leading private sector technology companies, academia and global allies and addressing the Human Resource development issues.[16] It has now been placed, along with the Defense Digital Services (DDS), the Chief Data Officer, and the enterprise platform Advana into one organization, the Chief Digital and Artificial Intelligence Officer (CDAO), which became operational on 01 Jun 2022. The aim is to build a strong foundation for data, analytic, and AI-enabled capabilities to be developed and fielded at scale.[17] China's commitment to enhance the prowess of its C4ISR systems is evident in the reorganisation effort that centralised space, cyber and electronic warfare under the newly established PLA Strategic Support Force and its investments in cyber capabilities and futuristic technologies like AI. In the U.K., Joint Concept Note (JCN) 1/20 has spelt out Multi-Domain Integration (MDI), founded on the Integrated Operating Concept, aiming to integrate operations across the domains and levels of warfare, as also with other national entities and networks. It also provides a vision for the development of an integrated force out to 2030 and beyond.[18] There are similar efforts being pursued across the globe, many of them in collaboration with globally established private defence contractors. Consequently, the C4ISR market is projected to grow from USD 119.9 billion in 2021 to USD 147.1 billion by 2026, at a CAGR of 4.2%.[19]

Conclusion

Across the spectrum of military operations, it is clear that the advantage would lie with the commander who has better situational awareness and swift decision-making tools and capabilities at his disposal and can ensure that his plans are executed expeditiously. C4ISR best defines the interdependency between technology and military operations. Foundational C4ISR architectures have been put in place by most major militaries but the requirement is of constantly improving upon the sophistication of equipment and seamless integration across all warfighting domains and functions. Indigenisation is a necessity for economic as well as security considerations. As India intensifies its efforts at *Atmanirbharta*, IT related development is one of the strengths of its industry that could be judiciously utilised to reduce the reliance on defence imports. The pace of technology upgradation is so rapid that conventional acquisition processes need to be overhauled so that the technology remains relevant. Another challenge is the way this IT based technology would be shared or owned. This would require modification of existing budgetary and acquisition processes to keep up with the rapid pace of technology development and to cater to newer technological domains. For example, AI is a software-as-a-service (SaaS) model, which would require a different approach from the existing buying model.[20]More importantly, it necessitates a change of mindset towards collaborating with the private industry.

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