Frameworks for Assessing the Military Implications of Emerging and Disruptive Technologies

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ABSTRACT

Emerging and disruptive technologies continue to be of significant interest to technologists, military strategists, operators, planners, budgeters, and policy makers. An emphasis on "Threat-Informed, Concept-Driven, Capabilities Development" is emerging in the U.S. Department of Defense. This construct encompasses three primary vectors of effort but does not fully account for the role and impact of emerging technologies. This paper presents and discusses some key frameworks for assessing the military implications of emerging and disruptive technologies, through the phases of technology maturation, military utility, the use of catalysts, processes for military innovation and adaptation, offset strategies, and operational concepts. Multi-component and multi-level analysis frameworks are discussed - kill chains and mission engineering. In addition to technologies, corresponding efforts must also consider processes for transitions and adoption, links between echelons of analysis, enhanced interaction between Requirements & Concepts; Technologies; Acquisition; and Planning, Programming, Budgeting, and Execution (PPBE); as well as associated organizational design. As users develop greater awareness and understanding about emerging and disruptive technologies, they must be corresponding efforts for experimentation, implementation, and evolution of existing and additional alternative Operational Concepts. Despite various terminology and composition, nearly all contemporary Operational Concepts share the same underlying goal – trying to effectively conduct combined arms in the 21st Century while operating at machine speed. Advancements in Technology Intelligence must also continue and evolve. Despite popular concerns and pronouncements about "Black Swan" events or "technology surprise," for emerging and disruptive technologies, surprise only happens to those who are not paying attention. The military Operations Research and Analysis (ORA) community can serve as a crucial bridge among staekholders and assess the military utility of these various technologies and how they can be best employed for strategic, operational, and tactical advantages.

1.0 EMERGING AND DISRUPTIVE TECHNOLOGIES

Emerging and disruptive technologies continue to become increasingly important to the NATO Alliance. For the purposes of this paper, we define *emerging technologies* as militarily relevant technologies that are under development or will be operationally applicable within the next few years. *Disruptive technologies* are the subset of emerging technologies that drastically change the way systems, organizations, and industries function by making current modes of operation obsolete within a relatively short timeframe. These types of technologies have the potential for both transformative changes, enabling new advantages and ways of warfare, as well as eroding and negating previously cultivated and persistent advantages for deterrence and victory. Commonly cited contemporary examples include advances in robotics, autonomy, and next-generation communications and computing. Although not an exhaustive list, specific technologies with potential military applications include: self-reconfiguring robotic systems; self-directed autonomy; artificial intelligence; nanotechnology; molecular electronics; 6G communications; neuromorphic computing; quantum computing; quantum sensing; synthetic biology; metamaterial cloaking; and augmented reality.

A substantial factor in the growing interest in these types of technologies in the 21st century also stems from their inherent dual-use nature, for both military and civilian applications. Most of these new technologies are also disrupting established commercial industries and business practices, in addition to military applications. These technologies are also proliferating and diffusing across a broader section of nations and societies. As we discuss below, the First Offset involved nuclear weapons, with an inherently governmental focus; the Second Offset focused on precision-strike, which was government-led, but yielded technologies that also became widely useful in civilian applications (the most well-known example being GPS). Current technologies, focused around advanced computing, robotics, and autonomy, have simultaneous applications for military and civilian purposes, with significant parallel research efforts ongoing in both industry and government.

As a field of inquiry, Science of Science [1] continues to mature and enhance understanding of technology & innovation ecosystems [2]. Aspects address the emergence of new technologies, along with incubation, convergence, recombination, and diffusion processes, as well as the parallel processes of awareness, interest, and adoption of new technologies. This last category includes models such as "hype cycles" [3] or seasonal periods, such as Artificial Intelligence "summers" and "winters". New approaches, models, and tools for "technology watch"; "horizon scanning"; knowledge, network & investment mapping; and foresight increase understanding and enable better science and technology intelligence [4] [5]. These are used in combination to observe and cultivate the technology maturation process for advantage, and or keep a vigilant and watchful eye on potential adversary advancements and transitions, for the development and fielding of new military capabilities.

The emergence of technologies, through human effort, coupled with the organizational constructs and incentives can be understood as Complex Adaptive Systems (CAS). These CAS consist of an ecosystem of elements and actors, which respond, self-organize, and adapt to various stimuli and interactions within and external to the environment. For emerging and disruptive technologies, some have posited that organizational design, with specific mechanisms to be "safe-to-fail" instead of "fail safe" are crucial. A "safe-to-fail" CAS leverages features of flexibility, redundancy, and dynamic response to adapt to unpredictable environments and exploit emergent behaviors and characteristics. Especially for military organizations, there is an eternal emphasis to eliminate inefficiencies and redundancies. However, by avoiding excessive standardization, organizations will enable and ensure that probabilistic sets of possible options will have time to incubate and emerge, enhancing the organization's ability to tap the potential of unforeseen and unexploited opportunities. "They do this under the influence of constraints that enable self-organization and trigger the emergence of new, more sophisticated approaches" [6]. The U.S. Navy organization during the interwar period was a Complex Adaptive System, where the various organization, experimentation, and technologies all interacted to significantly advance naval warfare [6].

1.1 Phases of Technology Maturation

All modern technologies follow several key milestones, although the duration and pacing of these stages varies widely. Basic research, through discovery-based inquiry, obtains new knowledge and understanding, uncovering the elemental building blocks for future emerging and disruptive technologies. As this new knowledge is discovered or invented, efforts shift to applied research, where specific uses and applications are considered. Technology evolution through this applied research phase for military uses can be either "technology pull" or "technology push"- sometime colloquially known as "needs-based" vs "seeds-based" [7] [8]. Technology pull is the more common process of where technologies are used to close specific capability needs or achieve new characteristics to satisfy requirements gaps. Technology push is where a specific demand does not exist, but through the development and application of emerging technology, then a new or significant departure from existing operational concepts and capabilities may be realized. Technology push, or seeds-based research, also help to push the boundaries of the state-of-the-art of both technologies and capabilities, while inspiring both technologists and warfighting concept developers. Technology pull is more often perceived as incremental and evolutionary, compared to technology push which is more often perceived to be revolutionary and disruptive. Technology push is required because disruptive technologies are, by definition, not within the pre-existing imagination or experience of operational end users. Additionally, the process of technology push is more difficult because it must overcome and displace existing institutional preferences and inertia that have become less relevant.

A significant aspect during the later stages of both tech pull and tech push is prototyping, which is also usually coupled with experimentation. Subsequently, when the experience from prototyping for constructing and manufacturing a technology, as well as operational use from experimentation, then the technology proceeds to integration and fielding. For complex systems, comprised of many integrated systems and sub-systems, these individual stages are aggregated into system design efforts. Lastly, as technology is experimented with, or fielded, use-inspired change may consider how to repurpose or use the technology or systems in a different way than originally intended. While the technology itself may no longer be emerging, the novel use can be potentially disruptive. The overall maturation process, as well as the associated process at each phase, is not linear and sequential, but rather is comprised of many iterations, dead-ends, and re-combinations [Figure 1-1].

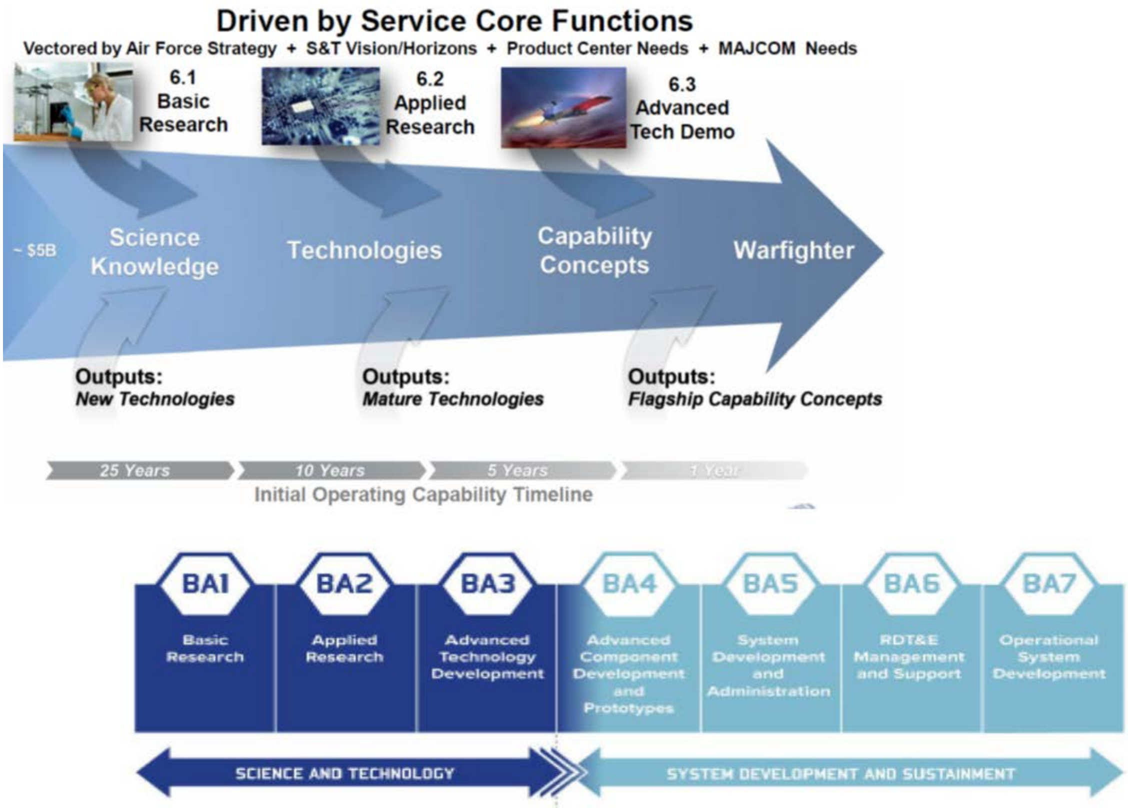


Figure 1-1: Technology Maturation Process (derived from models, such as [7] and [9]). This process highlights the relationship between knowledge, technologies, transition, and ultimate delivery; and also shows the timeline and funding activities associated with each phase. Innovators cannot be successful without at least acknowledging the framework for which technologies are matured in defense organizations.

Throughout the activities and outputs from these phases of technology maturation, awareness by external communities of the progress, or state-of-the-art, from varies widely. While scientists, engineers, designers, and technologists have been slowly progressing, especially in specialized communities and disciplines, warfighters, policymakers, and acquisition professionals often remain only tangentially aware and are more likely to have unrealistic (either overly optimistic or pessimistic) estimations or anticipations of the timelines. In particular, the Operations Research and Analysis (ORA) community can be a bridge between the research and technology community and the "user" community (including decision-makers, budgeteers, procurers, and operators) by placing emerging and disruptive technologies into a common framework. This will help to support analysis and comparisons for rational trade-offs of different possible investment options, counteracting the potential of senior leadership fascination with the "flashiness" of novel technologies over true potential use and impact.

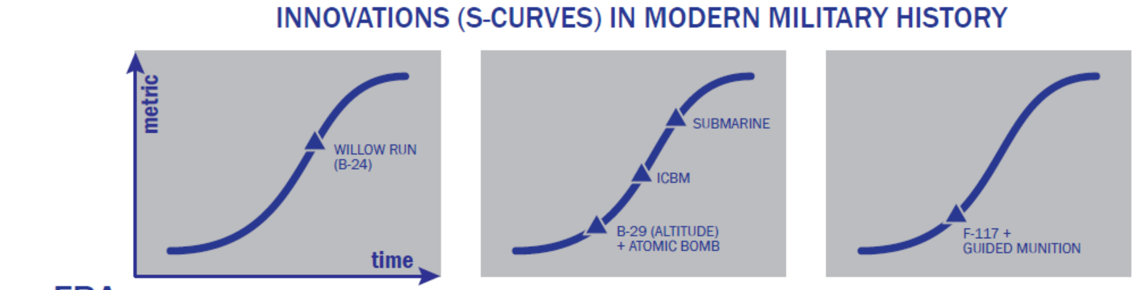
Successful prototyping frequently involves unsuccessful experiments, which are more commonly known as "failures." Counter to the perceptions of most military organizations, the correct type of failures are very productive. *Technical failure*, especially due to pushing the boundaries of the existing state-of-the-art and then diagnosing how and why a solution may fall short, is beneficial. Whereas, *management failure*, where the scope, timelines, and budgets for a specific effort are unrealistic and do not properly account for risk or uncertainty.

Despite constant calls for increasing the speed or acceleration of technology timelines, experience has shown that technology development timelines, beginning at "true" conception and discovery to fielding tend to occur on predictable 20 to 30-year cycles. Policymakers and senior leaders often conflate the need or desire to transition and field technologies faster with instead futilely calling for speeding up the earlier stages in the maturation process. A more productive focus that would accelerate the use of new technologies at scale, would be speeding up the processes for increased adoption, integration, and fielding opportunities. So that as these technologies mature and the potentials are more well understood and have been de-risked, there are more opportunities to insert and upgrade weapons systems with these new aspects.

1.2 Military Utility- Design and Engineering with Emerging and Disruptive Technologies

Beyond individual technologies is their contribution and impact to military effectiveness. The ORA community has a leading role in understanding the military utility of emerging and disruptive technologies and assessing how they can make the biggest difference to desired military capabilities, and ultimately outcomes. A technology's ability to improve specific key operational characteristics for a platform, weapon, or payload is the most important aspect. Examples include range, speed, maneuverability, and survivability. Additionally, emerging and disruptive technologies are becoming increasingly essential also enhancing linkages and information and data sharing between systems. This represents a significant paradigm shift- from platforms and payloads to instead designing and fielding integrated and re-composable force packages & networks, moving from a "systems" approach to a "systems-of-systems" approach.

A common model to understand technology evolution and maturation has been "S curves." For platforms and payloads, aspects such as unit size, function, and attributes/characteristics are interrogated in design trade-space, using systems architecting/design and systems engineering methods. But as the systems are aggregated into multiple, interacting components, using systems-of-systems architecting/design and systems-of-systems engineering methods, this "S curve" construct may be further applied to these systems, or systems of-systems [Figure 1-2]. As these technologies are aggregated, operational experimentation is critical. This enables feedback for designing concepts, testing in wargames and testing in exercises, and ultimately transition emerging technologies into key enablers for revised and enhanced military doctrine, and tactics, techniques, and procedures (TTPs). The key features of the technological S curve are found at the inflection points, and these also present risks for "technological surprise." At the beginning of the curve, the transition from concept to rapid adoption can find the non-adopters quickly left behind. During the steepest slope of the curve, which points up and to the right, there is a temptation for leaders to think that the technological advantage will last forever; forgetting that each new concept carries with it the seeds of its own obsolescence. This is the second opportunity for "surprise," because obsolescence initially happens slowly, then can rapidly accelerate.



ERA	INDUSTRIAL CAPACITY	NUCLEAR WEAPONS	INVISIBILITY & PRECISION
exemplary metrics	• quantity produced	• yield • number of launch options • prosecutable targets	• signature / detectability • collateral effect size • navigation precision
key technologies	• mass production	• fission • delivery mechanisms	• radio frequency stealth • electronic warfare • computer control
DoD institutional innovation	• effective relations with private industry	• strategic decision making	• performance-driven product development
counters	• centralized state control of industry	• equivalent capability creates stasis	• multi-mode detection • basing denial

Figure 1-2: System "S Curves" for Technology Enabled Innovation Across Three Historical Eras [10]. Each of these curves contains two opportunities for strategic surprise; first, at the beginning, when the capability provided by technology takes off and leaves adversaries vulnerable. Second, where the capability provided by the technology plateaus, leaving the innovators vulnerable to "catch up".

1.3 Challenge Problems as Catalysts

One of the key methods for catalyzing the virtuous feedback between technologies and design is the use of "Challenge Problems." These are sometimes also referred to as "moonshots," but are specific demonstrations and applications which appear to be just out of reach for the current state-of-the-art of technologies While these problems present an opportunity for technology refinement, their purpose is to galvanize technologists and designers to advance new designs and new technologies and creative combinations and integrations.

In the early 1960s, USAF General Bernard Schriever championed the idea of Zero Circular Error Probable (CEP), which had been conceived as part of the USAF Project Forecast [11]. The goal of the Zero CEP concept was to deliver weapons long distances and attempt to hit with exacting precision on target. Although true zero CEP is unachievable, this challenge goal was to reduce the CEP of long-range weapons to "functionally zero" to increase both tactical and strategic use, by reducing the required warhead explosive power without the issues associated with nuclear radiation or collateral damage. Then Director of Defense Research and Engineering (DDR&E) Harold Brown began working with the U.S. Air Force, and General Bernard Schriever on the idea for Zero CEP [Brown]. This became the catalyst for a portfolio of technologies ultimately used as part of the U.S.'s "Second Offset" strategy in the 1980s. This is detailed further in the next section.

As a specific demonstrator effort during the "Second Offset," against the Soviet Union, a system-of-systems project called "Assault Breaker" was a DARPA led effort to prototype and demonstrate a "system-of systems" architecture and suite of capabilities. This provided a network for deep attack against massed Soviet conventional forces, using integrated intelligence and surveillance, precision guided munitions, and ground-launched cruise missiles. The results from the Assault Breaker effort fed into acquisition programs of record, and in parallel, development and fielding of stealth aircraft and GPS satellites further enhance the effectiveness of employing these networks. In the words of then Secretary of Defense William Perry, this would enable the U.S. "to be able to see all of the high value targets on the battlefield at any time; to be able to make a direct hit on any target we can see, and to be able to destroy any target we can hit" [12].

Since 2000, the U.S. Defense Advanced Research Projects Agency (DARPA) has expanded and applied this model conducting several "Grand Challenges," which are critical catalysts to stimulating technology and industrial ecosystems, while also pushing the boundaries of the state-of-the-art, embracing competition and learning, and inspiring the wider technology community.The first set of DARPA Grand Challenges was a series in the mid-2000s, which helped to spawn the self-driving car industry and multiple associated technologies. In the mid-2010s, the DARPA Cyber Grand Challenge pushed the state-of-the-art for detecting, patching and exploiting software vulnerabilities - healing friendly systems while also attacking adversary systems. Most recently, the DARPA AlphaDogFightTrials matched a human fighter pilot against A.I. in virtual aerial dogfighting. However, the implications for the use of emerging technology in these warfighting scenarios are not yet fully realized [13].

1.4 Military Innovation and Adaptation

When discussing military innovation, it is important to determine which kind of innovation is of interest. There are at least five major categories of innovation: (1) Operational innovation (including Operational Concepts, CONOPS, CONEMPS, etc); (2) Capabilities and Technologies; (3) Processes; (4) Organizations; and (5) Analysis/Understanding. Innovation can also be either formal or informal.

Of primary interest for this discussion is the characterization of military innovation can be determined as both a combination of technology, whether sustaining or disruptive, and operational concepts, whether evolutionary or revolutionary [Figure 1-3]. A common posterchild for military innovation during peacetime is the U.S. Navy's Fleet Problems during the interwar period, where twenty-one major full-scale exercises were conducted from 1923 to 1940. These Fleet Problems were devised to work on developing and testing solutions to specific strategic problems, while also helping naval officers to understand how to best employ emerging technology [6] [14].

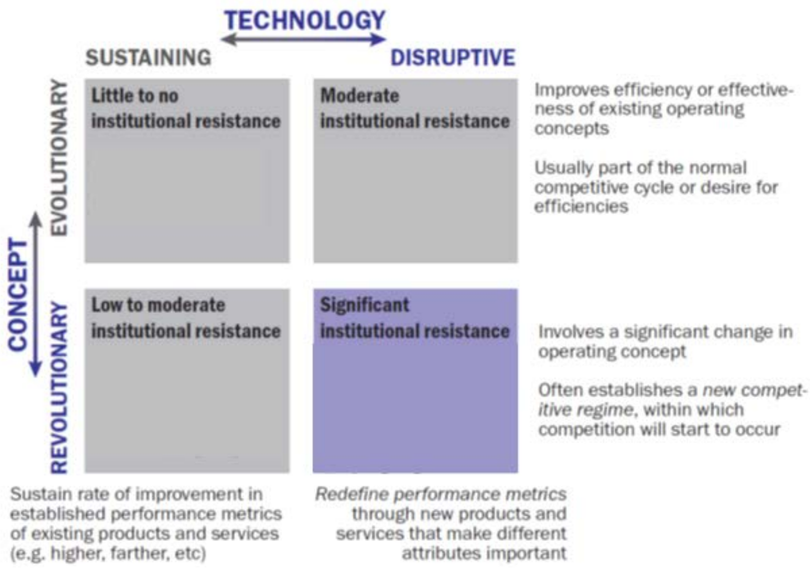


Figure 1-3: Innovation Typology as a Function of Technology and Operational Concept [10]. Innovators need to understand the context of where a particular concept-technology combination resides, and understand both the technological and institutional barriers they are breaking. Most revolutionary technologies and concepts fail due to institutional resistance and policy issues.

New, or significantly enhanced, military capabilities occur as a result of the outcome of the interaction between technical and operational innovation. "What matters for innovation and adaptation is how well new technologies are incorporated into effective and intelligent concepts of fighting; it is not the technological sophistication that matters, it is the larger framework" [15]. For the "American way of war", advanced technology in support of operational and tactical overmatch has been the key strategy since World War II:

> "No nation in recent history has placed a greater emphasis upon the role of technology in planning and waging war than the United States. Although the U.S. military as a whole favors technology, such a view has not gone unchallenged. To the contrary, civilian and military leaders and defense analysts have repeatedly debated the merits of the U.S. military's reliance on advanced technology" [16].

Along with this emphasis on technology, supporting conceptual constructs such as the "Revolution in Military Affairs" (RMA) have also been developed, especially during the 1990s and 2000s. The RMA debate occurred among two primary camps. On one side were those who determined precision guided munitions technology was accelerating and would fundamentally change the character and conduct of war. RMA proponents thought emerging and disruptive technologies such as these could give advantages to the U.S. and allies over any potential adversary. RMA skeptics asserted that technology often failed to deliver as originally envisioned and on much longer-timelines than anticipated, while also being overemphasized compared to other aspects of military effectiveness. However, much of the RMA debate only considered simplistic views about technology, and how it is developed and used in the military:

> "Enthusiasts overstate both the magnitude of change wrought by technology, as well as the rate which new technology can be assimilated into military organizations. Breathless prediction of dramatic changes to the conduct of war wrought by technology have failed to materialize. Skeptics have all too often discounted the role of technology in war. Although technology not the only, or necessarily the most important, determinant of success, its effects should not be ignored" [16].

The development and use of these technologies for military applications must be considered within the larger strategic framework of what overall goals and objectives are desired. One of the primary means to enable this are "offset strategies."

2.0 OFFSET STRATEGIES

As part of a comprehensive strategy beginning in the 1970s, ideas related to "competitive strategies" were examined and adopted into the peacetime competition inside of the U.S. Department of Defense. Competitive strategies are typically considered in four different aspects: "denial, cost imposition, attacking a competitor's strategy, and attacking a competitor's political system" [17]. In conjunction with competitive strategies, offsets may be pursued, in order to address imbalances and erosion of advantages when a nation-state competitor reaches parity in one or more areas of military capability. In addition to the specific character and actions of an offset strategy, since the 1950s, U.S. approaches have consistently included foundational assumptions about the key role of allies and the importance of economic growth.

2.1 The First Offset

After the end of World War II, Allied forces were victorious but exhausted and a massive post-conflict draw down in forces occurred. However, the Soviet Union retained massive conventional forces occupying Eastern Europe and the late 1940s gave way to increasing concerns about the risk of Soviet invasion of Europe. Due the American experiences in both World Wars, the Eisenhower Administration conceived an approach that would offset the vast numerical superiority of the Soviet Union and Warsaw Pact conventional forces against the U.S. and NATO allies in Western Europe. This "First Offset" strategy had several key pillars: miniaturization of nuclear weapons, allied forces, and economic growth. This culminated in the Eisenhower Administration's "New Look" strategy, focused on deploying large quantities of tactical nuclear weapons, while advancing and expanding nuclear deterrence capabilities based on the theory of mutually assured destruction.

While implementing the First Offset became the primary effort, parallel efforts continued in earnest. Relying on tactical nuclear weapons to respond to Soviet provocation was not deemed proportional or credible. This concern became more acute as the Soviets reached nuclear parity. These parallel efforts were generated from the work of General Schriever and USAF Project Forecast, and supported and expanded by Dr. Harold Brown across the Department of Defense and the U.S. military Services, The research and development emerging and disruptive technologies carried out during the decade of the mid-1960s to mid-1970s became the foundational seeds to enable a next offset. More recently, the expiration and withdrawal from several key arms treaties has renewed thinking on nuclear deterrence and strike posture [18] [19] [20].

2.2 The Second Offset

In the 1970s, the Soviet Military maintained conventional numerical superiority in Europe and was gaining nuclear parity with the U.S. Simultaneously, there was a growing political movement against the reliance on tactical nuclear weapons. Disadvantaged by the possibility for a surprise invasion in Europe for a *fait accompli*, as well as constrained by the dearth of effective options below the nuclear threshold, considerations for a "Second Offset" strategy began to emerge.

The U.S. Department of Defense began a Long-Range Research and Development Planning Program (LRRDPP) in the mid-1970s [21]. This effort, championed by Dr. Harold Brown, now as the U.S. Secretary of Defense, conceived and matured a portfolio of research and technologies to develop and field new weapons systems, including new intelligence, surveillance, and reconnaissance (ISR) networks and platforms, stealth, unmanned aerial vehicles, advanced electronic control systems, night-vision, and extended-range precision-guided munitions. The LRRDP's concluding assessment in 1975 was "based on the analysis it appears that non-nuclear weapons with near zero miss may be technically feasible and militarily effective." [22]

The application and combination of these technologies catalysed further innovation with systems-of-systems demonstrator programs (like "Assault Breaker" [Figure 2-1]) and operational concepts and doctrinal shifts (such as Air-Land Battle, USMC's Maneuver Warfare, the US Navy's Outer-Air Battle, or NATO's Follow-On Forces Attack [23] [24]. The novel combinations available with these technologies enabled new operational concepts to effectively "look deep and shoot deep" with Battle Networks (or Reconnaissance-Strike Complexes, as the Soviets called them). The Soviet conception had three components: (1) long-range/wide-area sensors; command-and-control (with as much automation as possible); and (3) guided and/or precision weapons, which would be delivered by missiles or strike aircraft (instead of artillery) [25]. The U.S. version of battle networks were advanced integrated combinations of surveillance, targeting, and command & control networks and capabilities, and could be used to offset rapid force advancement and neutralize numerically superior follow-on forces, while avoiding the expense of conventional parity and enabling the possibility to stay below the nuclear threshold. Although not as expressly considered as a formal part of the Second Offset, the role of allies and the knock-on effects of technologies for spurring economic growth (such as GPS, computing, miniaturization and new materials) were also important [26].

Figure 2-1: Comparative Depictions of the Assault Breaker Concept- US (left, [25]) and Soviet (right, [27]). These depictions began as revolutionary concepts supported by emerging technologies. After 40 years, these have become more standard.

2.3 Towards A Third Offset

In the 2010s, as the "unipolar moment" after the Cold War ended, and great power competition re-emerged, the possibility and necessity for establishing a "Third Offset" began to be debated [28]. In 2014, then U.S. Secretary of Defense Chuck Hagel announced the beginning of a "Third Offset" strategy [29], which would include a new version of the LRRDPP, the Defense Innovation Initiative (DII).

A primary part of the debate were questions over what exactly was being "offset". Then U.S. Deputy Secretary of Defense, Bob Work and Vice Chairman of the Joint Chiefs of Staff, General Paul Selva, stressed that the paramount challenge was offsetting the rapid proliferation of advanced "battle networks" at the operational and campaign level of warfare, as well as a reduction in forward deployed forces in theater. These battle networks consist of four grids which are interrelated- a sensor grid (to "see" what is happening, a C4I grid (to "make sense" of what happening), an effects grid (to deliver and achieve desired military effects), and a logistics and support grid [30]. With adversaries achieving parity of theatre-wide battle networks, as well as developing and fielding counter-network capabilities (cyber, EW, counter-space), this would risk conventional deterrence for the U.S. and allies and partners.

To offset this parity, several options were proposed and continue to be debated. From 2015 onward, the U.S. Department of Defense proposed exploiting A.I. and autonomy, to insert them into battle networks and achieve faster speed and completion of information and decisions for rapidly compressed cycle time of observation to action within and across these battle network. The resulting ability for long-range precision-strike, at volume, across all domains (air, land, and sea, as well as space and cyberspace) would help to assure overmatch and strengthen conventional deterrence.

This comprehensive strategy had "pillars" of technological, operational, and organizational innovation, coupled with the need for enhanced innovative military and civilian talent management, in order to counter rising threats to U.S. conventional deterrence capabilities and maintain U.S. technological superiority. Technologically, Deputy Secretary Work focused the Third Offset on five key areas: autonomous learning systems; human-machine collaborative decision-making; assisted human operations; advanced human-machine systems combat teaming; and network-enabled autonomous weapons and high-speed projectiles hardened for electronic and cyberwarfare environments [31] [32]. Secretary Work and General Selva also emphasized their view of the criticality of not just the technology, but also in parallel developing and refining operational and organizational constructs, with the associated doctrine, training, exercises across the entire Joint Force. This specific set of efforts, enabled by jointness and a creative workforce, was intended to be an institutional strategy for competition [33].

Another variant of a Third Offset proposed a shift from theatre-wide battle networks to instead building, fielding, and operating a global surveillance and strike (GSS) network, scaling across all domains and military service components [28]. Others suggested the primary challenge was the dual-use nature of the associated emerging and disruptive technologies to be engines of economic growth, in additional to their dual-use potential for military advantage [Figure 2-2]. Unlikely previous competitions that were primarily military, with industry and academia in supporting roles, the current U.S.-China competition is occurring predominantly in commercial and academia dimensions, with military aspects consigned to a less prominent role. These emerging and disruptive technologies were rapidly proliferating, democratizing access to them through commercial sectors [34]. Subsequent changes in Administration and DoD leadership caused the overarching term of "Third Offset" to be largely abandoned, although a large swath of associated efforts continued, evolved, and advanced.

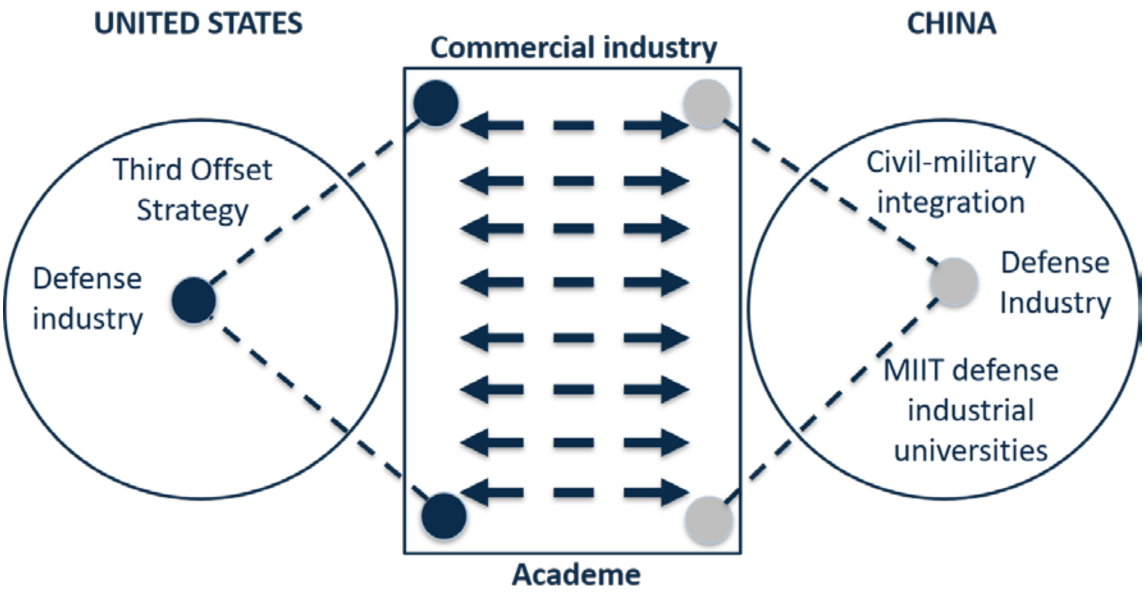


Figure 2-2: Simplified Visualization of the China-U.S. Competition for Emerging Technologies (reproduced from [35]). This emphasizes the current dynamics of competition primarily in commercial industry and academia, with military aspects in a more supporting role, as compared to previous great power competitions, where the military aspects were more central to the competition dynamics.

Within the strategic framework, at the Operational level, specific concepts are necessary to help guide and shape technology development and integration into a virtuous cycle for military advantage. One of the primary means to facilitate this is the use of Operational Concepts.

3.0 OPERATIONAL CONCEPTS

Operational concepts are a principal tool to formulate and congeal the conceptual basis for military planning and shape the overall design and employment of military forces and capabilities.

3.1 The "Modern System" and Measure-Countermeasure Dynamics

Force employment in the modern system of conventional counterforce warfare has greatly benefited from the dominant influence of technology to increase lethality. Technology has enabled the neuralization of mass movement of forces in the open to occur at increasing distances. To reduce the vulnerability of military forces to sensors and weapons, a

> “tightly interrelated complex of cover, concealment, dispersion, suppression, small-unit independent maneuver, and combined arms at the tactical level, and depth, reserves, and differential concentration at the operational level of war. Where fully implemented, the modern system damps the effects of technological change and insulates its users from the full lethality of their opponents’ weapons” [36].
>
> In the modern system: “offensive military capability is the capacity to destroy the largest possible defensive force over the largest possible territory for the smallest attacker casualties in the least time; defensive military capability is conversely the ability to preserve the largest possible defensive force over the largest possible territory with the greatest attacker casualties in the longest time” [36].

With the framework of the modern system, several competitions may be explored, where the eternal military dynamics of measure-countermeasure evolve. These competitions include: hider-finder (C5ISRT- counter-C5ISRT and stealth-counter-stealth); mass vs dispersion against the “storm of steel”; penetration vs local defense (e.g. strike-counter-strike, submarines-ASW, and aerial attack vs IADS); and resupply vs disruption (logistics- counter-logistics). More generally, these competitions may be expressed in terms of action-reaction-countermeasure with an adversary. These competitions include military measure-countermeasure dynamics, enabled by changes in both capabilities and technologies. Several dynamically interacting frameworks have been proposed, including the twelve-step process ([Figure 3-1] and an expanded version of the Sense-decide-Act framework [Figure 3-2]. Each of these frameworks emphasize the critical feature of dynamic interaction between opposing forces.

Own Action	Own Countermeasures	Enemy Action	Enemy Countermeasures
Scout	Anti-scouting	Scout	Anti-Scouting
Command and Control	Command and Control Countermeasures	Command and Control	Command and Control Countermeasures
Action (Shoot)	Counterforce	Action (shoot)	Counterforce

Figure 3-1: 12 Factors for Military Engagement [37].

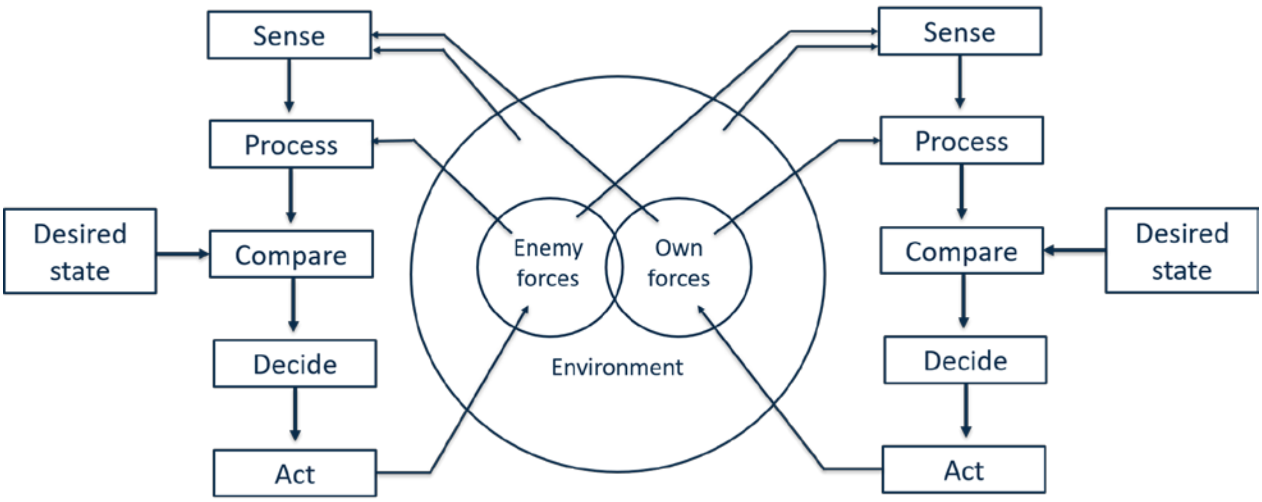


Figure 3-2: Enemy and Friendly Command-Control Cycles Operating Simultaneously in the Same Environment (reproduced from [37]). This is an expansion and refinement of Boyd’s “OODA Loop”. The side who can effectively complete this complex task the quickest, and most reliably will have a significant advantage.

3.2 Historical Operational Concepts

During the 1980s to 2000s, key Operational Concepts included: AirLand Battle, NATO Follow-on Forces Attack, Combined Arms, and Maneuver Warfare, and Net-Centric Warfare. The AirLand Battle Concept was the first major attempt to shift the U.S. Army away from emphasizing attrition warfare to instead implementing maneuver warfare. Concerns over Soviet and Warsaw Pact numerical superiority in Central Europe during the 1970s led to the first version of AirLand Battle to be developed in 1982. This first version's doctrinal objective was to interdict the second echelon forces and hold them, while the first echelon was defeated, focusing on a "deep battle" using an all-arms joint effort. With the technological possibilities of that time and near-future, the doctrine emphasized fighting out to 150 km, while simultaneously having battlefield awareness out to 300km, where targets could be identified and targeted for destruction, disruption, or delay [38]. During the 1990s, Net-Centric Warfare posited three primary layers for a theater-wide battle network- a sensor layer, a C2 layer, and a shooter layer to successfully conduct naval warfare, but leveraging support from other forces and other physical domains [39].

During the 2000s to 2010s, key Operational Concepts included: Prompt Global Strike, AirSea Battle, the proliferation of G-RAMM (Guided Rocket, Artillery, Mortars and Missiles), Cross-domain denial capabilities [40] and Archipelagic Defense [41]. As an example, AirSea Battle consisted of four major components: Withstanding Initial Attack; Network Blinding Campaign; Missile Suppression Campaign; Continuing to Seize the Initiative [42] [43]. At the beginning of the 2010s, the Joint Operational Access Concept (JOAC) was released, emphasizing the criticality of cross-domain synergy [44].

3.3 Contemporary Operational Concepts

Despite various terminology and composition, nearly all contemporary Operational Concepts share the same underlying emphasis, trying to effectively conduct combined arms in the 21st Century, while operating at a tempo approaching machine speed. Although often incorrectly considered to be new, the contemporary operational concepts emerging over the last five years are firmly rooted in ideas and principals from the late-Cold War to present day. Examples include the U.S. Army and U.S Air Force's Multi-Domain Battle/Operations (MDB/MDO), the U.S. Navy's Distributed Lethality and eventually Distributed Maritime Operations, the USMC's Littoral Operations in a Contested Environment (LOCE) and Expeditionary Advance Basing Operations (EABO) [45]. More recently, the U.S. Joint Staff has attempted to integrate these various Service-led concepts into a more unified and coherent whole [46]. The 2012 JOAC, with its emphasis on cross-domain synergy, has evolved to Joint All-Domain Operations (JADO). The Vice Chairman of the Joint Chiefs of Staff has explicitly emphasized that a fundamental characteristic driving the U.S. Joint Warfighting Concept 2020 is that there will be "no more lines on the battlefield." The elements of JADO have been divided and distributed to the U.S. military Services to lead. The US Air Force is leading the C4ISR layer, consisting of the JADC2 concept, with the underlying ABMS technology portfolio to enable it. The U.S. Navy is leading global and joint fires; the U.S. Army is leading contested logistics; and the U.S. Marine Corps is leading information advantage [47].

While each of these elements of JADO start relatively simplistically, the difficulties of design and implementation within and across each element, coupled with additional considerations for the degree of mission command (level of unit control) and decision aids, including for units with autonomous force elements make this exceedingly difficult [Figure 3-3]. While graphically appealing simplified representations are helpful, the true connections and interdependencies are often very complex (as shown on the right in [Figure 3-3]. They also emphasize various degrees of fundamental characteristics of their force composition, being numerous, distributed, persistent, and nondescript.

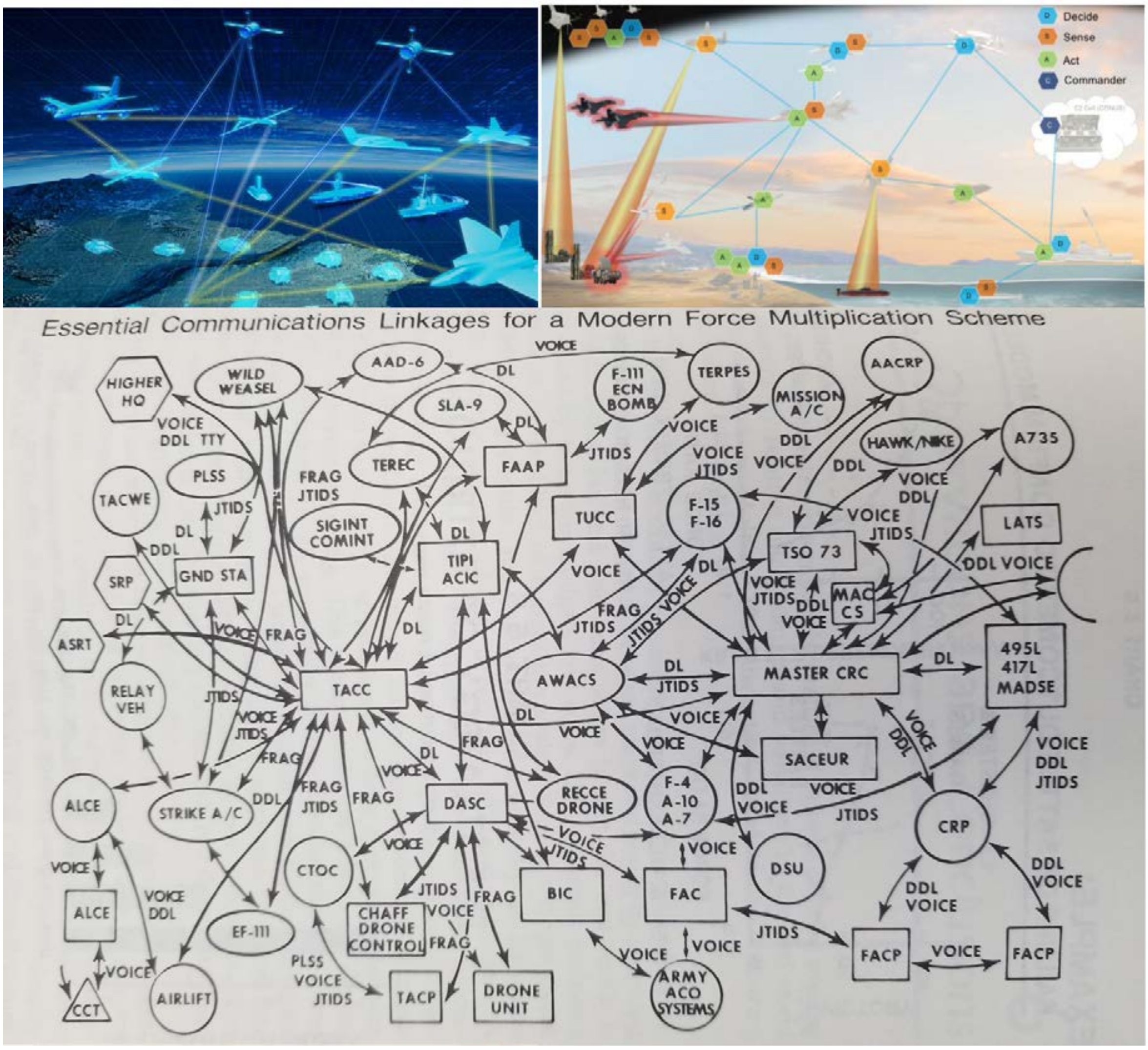


Figure 3-3: Increasing Fidelity of All-Domain Operations: Initial Vision (top left, [48]), Top-Level Functional Breakdown (top right, [10]), Depiction of Actual Communications Linkages (bottom, [49]). This chart shows the stark contrast between idealized depictions of the future interoperability of systems, and the stark reality of the operational linkage of modern system (even from the 1980s). Although disruptive technologies make existing technologies obsolete, the transition is not immediate, and a "system-of-systems" necessarily evolves from existing technologies, systems, and force structure.

3.4 A Framework for Comparing Operational Concepts

As new Operational Concepts are developed, they should be compared to previous concepts, as well as other alternatives, to understand the primary military utility the force employment and technology combinations are seeking to enable. Across Operational Concepts, there are three principal dimensions which can be independently examined as part of a comprehensive framework for comparison. These dimensions include the degree of concentration of forces (aggregated/disaggregated), the degree of coordination (networked vs independent operations), and the degree of cycle speed (including both speed of decision and speed of action) [Figure 3-4]. Across different Operational Concepts, the syncopation of effects, increased range (across all layer), increased penetration of effects, increased attrition, and increased speed of action and response are key enablers.

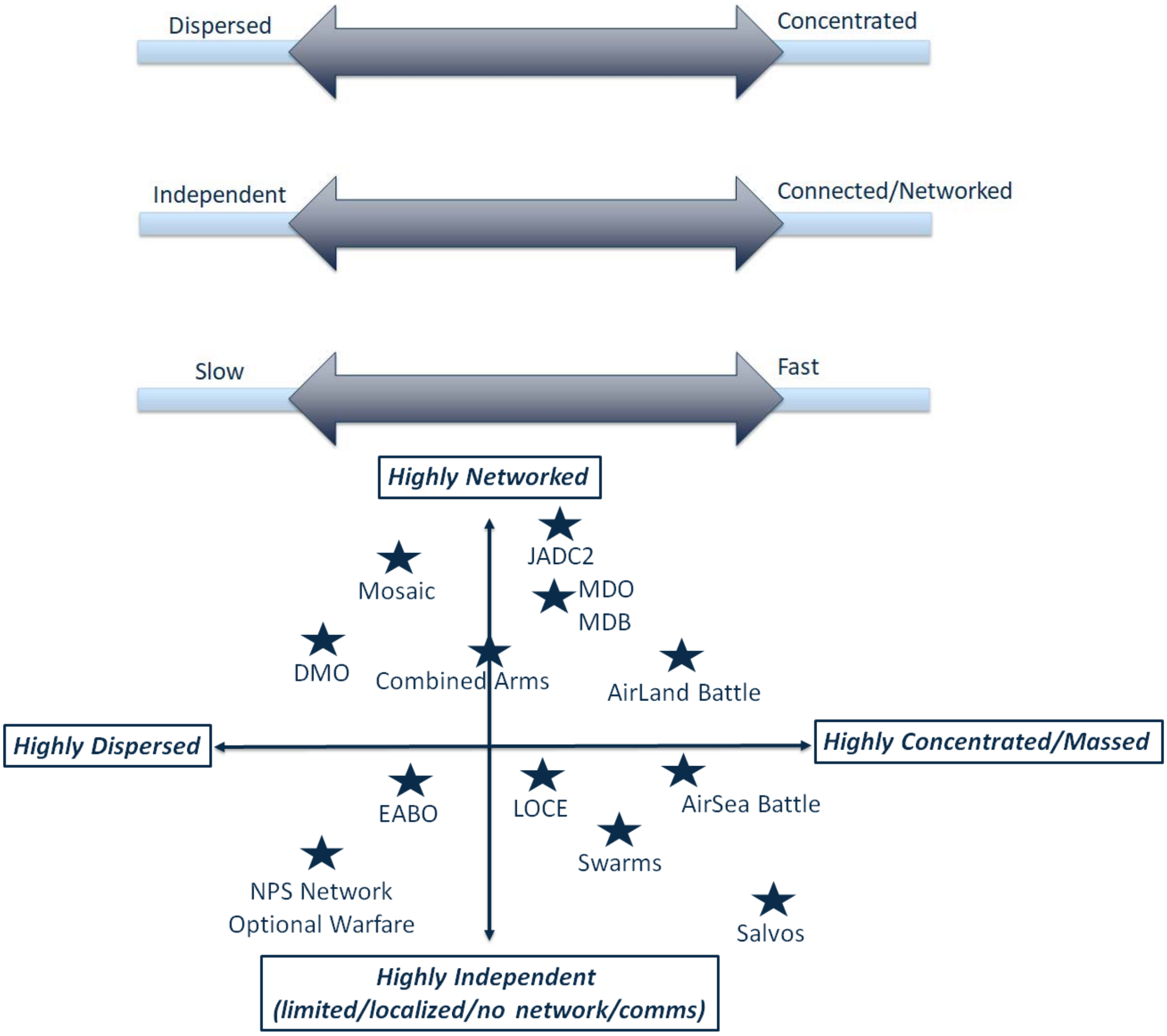


Figure 3-4: A Framework for Comparing Principal Features of Operational Concepts, with major variables (top) and relative placement for several operational concepts from the modern era (Cold War to current day).

3.5 Considering Alternative Operational Concepts

The paramount focus of the U.S. military today is on Joint All-Domain Operations (JADO), to offset specific conventional superiority from an adversary. Although this is the primary effort, alternative concepts must also be considered - both for military utility and to help further push the maturation of emerging and disruptive technologies. Some examples of alternative Operational Concepts include Deterrence by Detection [50], where unmanned aerial vehicles are used for persistent ISR which can be distributed across a coalition; Inside-Out [51], which uses precision-strike networks (particularly land-based anti-ship and anti-air capabilities) along the First Island Chain inside China's anti-access/area denial network, supported by air and naval forces outside; Mosaic Warfare [10], which stresses the rapid re-composability of heterogenous forces; Network Optional Warfare [52] [53], which addresses the means operating in contests and communications and EMS severely degraded and denied environments; and concepts to use emerging and disruptive technologies to enable sustained resistance fighting by indigenous “Techno-Guerrillas”. Within each Operational Concept, understanding how a specific technology contributes or enhances a particular capability, or set of capabilities is essential.

4.0 ANALYZING EMERGING AND DISRUPTIVE TECHNOLOGIES

To analyse emerging and disruptive technologies, two aspects must be considered. The first is how to decompose the technology into critical elements. The second is how to apply this understanding into the various hierarchies of analysis. These advanced methods enable more complex considerations to be analysed. Examples include how multi-mission platforms link to numerous, less expensive, more singularly mission-focused systems, and how numerous, heterogenous systems can be coordinated and functionally integrated, and to what extent.

4.1 Decomposing Technologies

Technologies must be decomposed into their constituent functions and characteristics to be useful for any analytical effort. General terms like “Autonomy”, “Quantum”, or “Artificial Intelligence” are insufficient and to broad to provide any analytical utility. For Autonomy, the various technologies can be decomposed into several functional groupings: mobility, perception, and coordination. For Quantum, the various technologies can be decomposed into several functional groupings: sensing, communications, computing, encryption, and materials. For Artificial Intelligence, the various technologies can be decomposed into several functional groupings: perception, learning, reasoning, understanding, and problem solving. In addition to decomposition of emerging and disruptive technologies, the understanding of their interrelationships, with other technologies and components, as well as humans is essential.

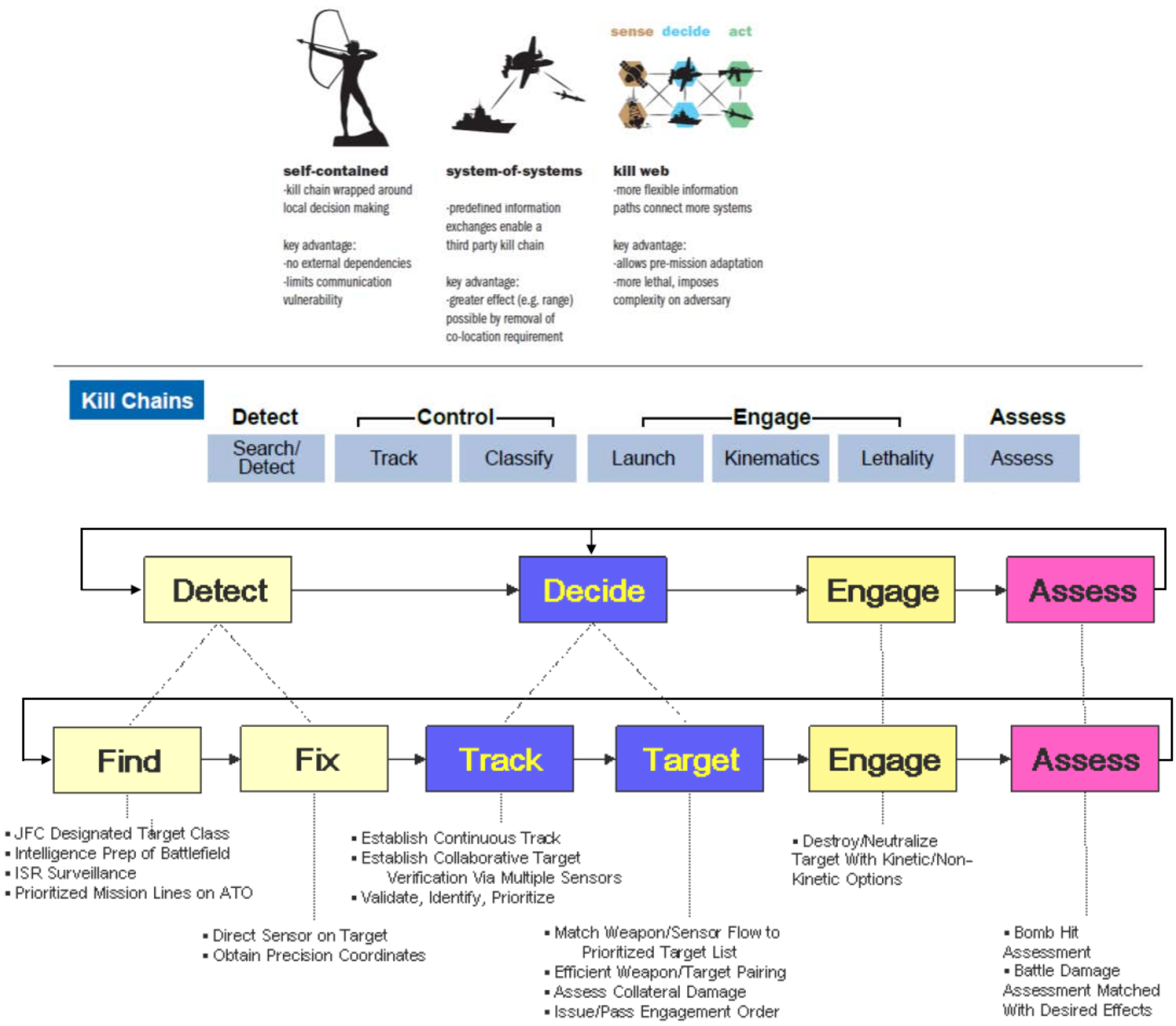
4.2 Mission Engineering Approaches- Echelons of Analysis

Various approaches have been employed to explain military operations and linkages between systems and functions. Simplified constructs, such as John Boyd’s Observe-Orient-Decide-Act (OODA) loop, or “Find-Fix-Finish” have been used to conceptually simplify the extremely complex dimensionality, interdependencies, and interactions of military systems to deliver effective operational results.

As these conceptual models have evolved and expanded [Figure 4-1] to add necessary levels of fidelity and understanding, two variations have become standard reference models for “kill chains” or “effects chains.” In the U.S., one is primarily used by the Air Force and is known as F2T2EA (Find-Fix-Track-Target-Engage-Assess). The other is primarily used by the Navy and consists of the following steps: Search-Detect-Track-Classify/ID-Engage-Assess-Defend. With modern military systems and technology, each step in these conceptual frameworks can be completed by one or more systems, and some systems can complete multiple steps, or the entire kill chain alone, returning to the most antecedent construct, but with many orders of magnitude more effectiveness and lethality.

In the design and procurement of modern military systems, Systems Engineering has become a preferred tool for analysis. However, the primary tier of analysis using systems engineering methods is typically focused on the system or component level. Further aggregation into “systems-of-systems” levels to achieve specific military mission outcomes has become known as Mission Engineering [Figure 4-2]. Mission Engineering analysis enables multiple combinations and linkages to be interrogated and analysed [54]. Most recently, Mission Engineering has been formally adopted into the U.S. Defense acquisition process and codified in the overarching framework of DoD 5000 [55] and provides guidance of how to implement a Mission Engineering approach across a ten-step process [Figure 4-3].

Mission Engineering, occurring at one hierarchical level beyond traditional systems engineering [Figure 4-2], is a relatively nascent framework to analyze systems of systems charactertistics, behaviors, and outcomes. However, the importance of using these Mission Engineering methods will continue to increase and become more essential in the ORA community.



Critical pillars of employing firepower -
(coordinated fire support, weapon-target pairing, collateral damage analysis, kinetic/non-kinetic target integration, automated engagement orders, and multi-dimensional deconfliction)

Figure 4-1: Evolution of Kill Chains: Historical (top [10)]) and Current Conceptual Frameworks (bottom, [54]). While the modern era has introduced many new technologies and systems, the fundamental essence remains- knowing the most, the quickest, in order to effectively engage and adversary.

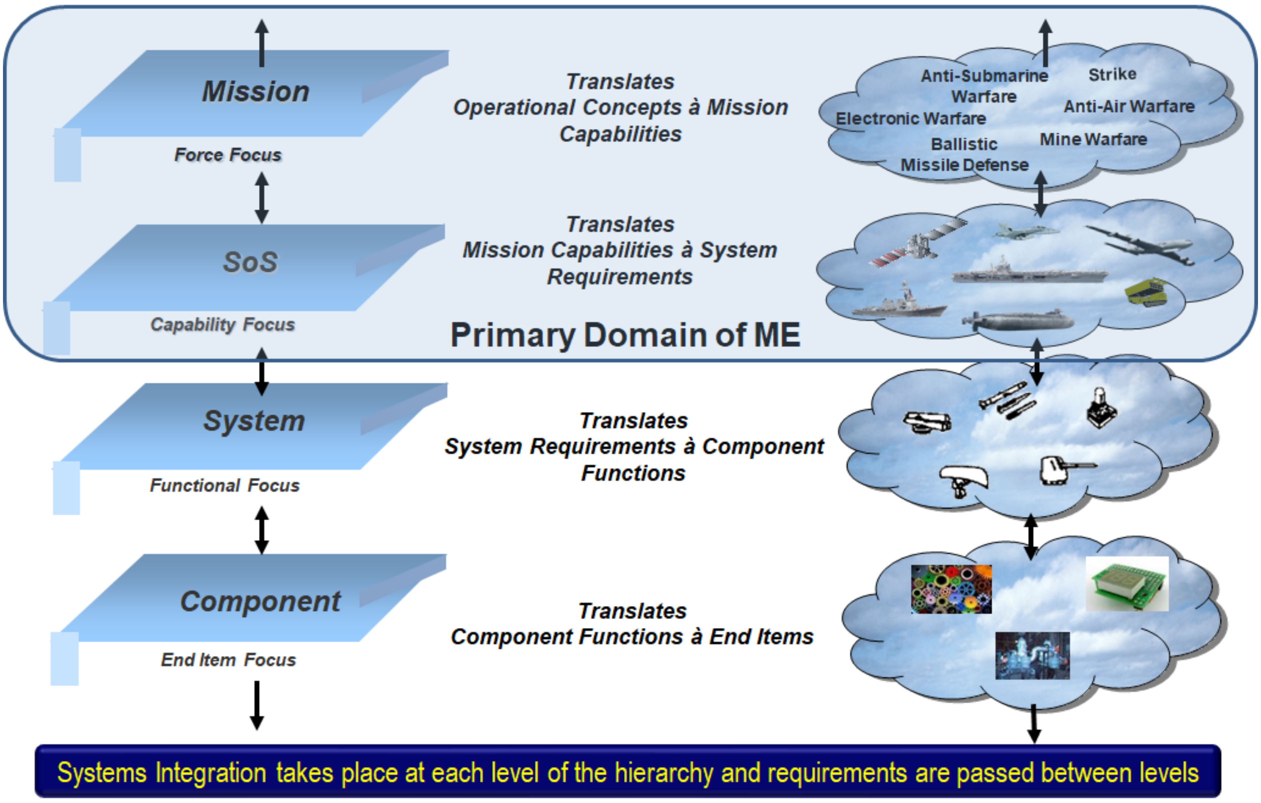
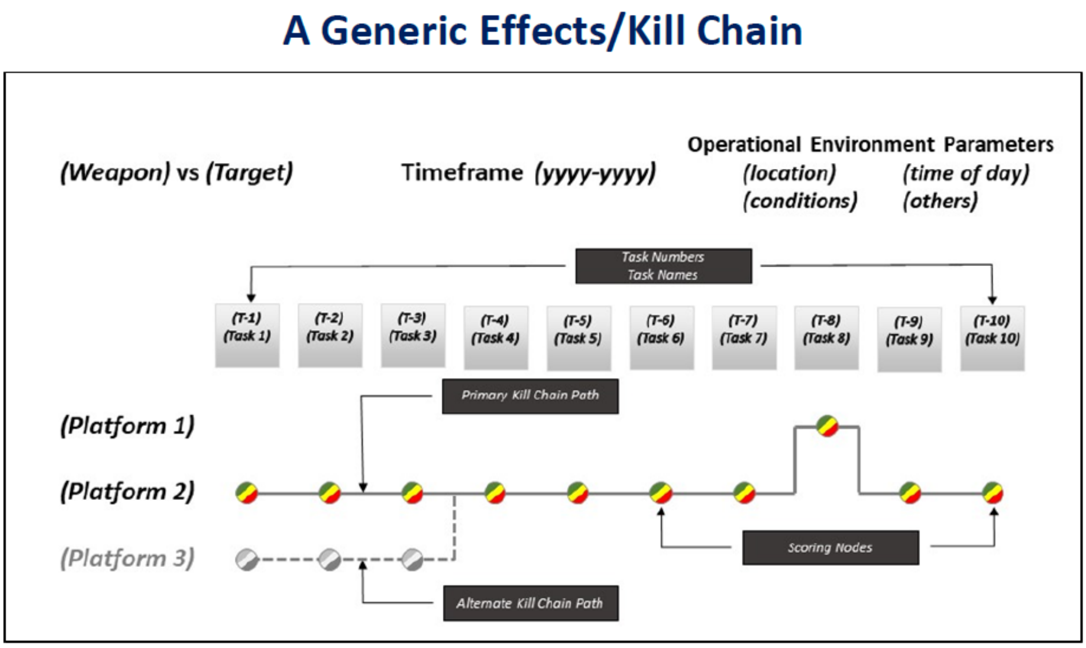


Figure 4-2: Tiered Analysis Hierarchy in a Mission Engineering Process [54], showing the relationship of levels of analysis (bottom to top): component, systems, system-of-systems (SoS) and mission.



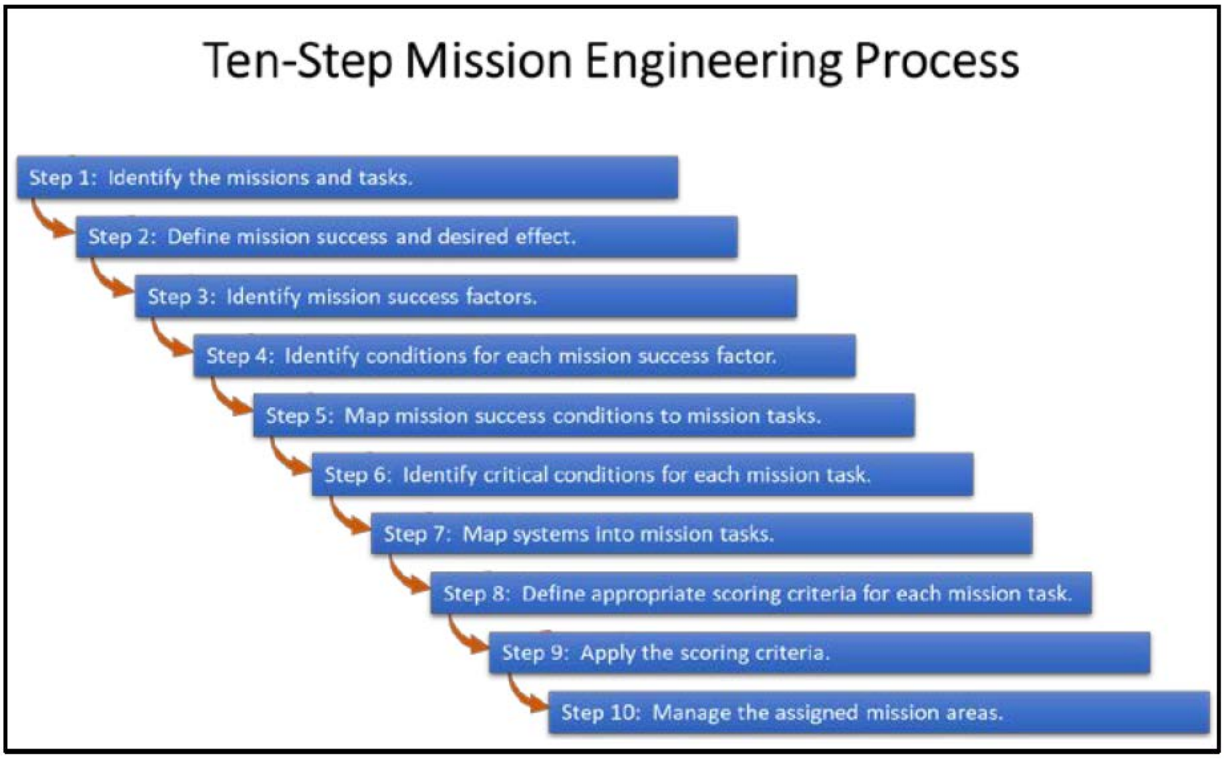


Figure 4-3: Applying a Mission Engineering Process: Generic Effects Chain (top) and Steps in the Mission Engineering Process (bottom) [55]

5.0 FUTURE CONSIDERATIONS

The combination of people, technologies and institutions is required to create and sustain an infrastructure to take advantage of emergence [56]. Allies and like-minded nations should continue to seek ways to collaborate and mature emerging and disruptive technologies. The NATO alliance, with its long-standing functions and organizations, can achieve virtuous synergy between long-term capability planning and development in the Armaments Groups, technology maturation in the Science & Technology Organisation (STO), and leverage the breadth and depth of the NATO member countries' ORA community. This will enable the Alliance to achieve a scale and leverage for employing emerging and disruptive technologies well-beyond what any single nation can accomplish alone.

In the U.S. DoD, there is an emerging emphasis on "Threat-Informed, Concept-Driven, Capabilities Development." This construct encompasses the primary vectors of effort, but not fully account for the role and impact of emerging technologies. In addition to technologies, corresponding efforts must also consider processes for transitions and adoption, links between echelons of analysis, enhanced interaction between Requirements & Concepts, Technologies, Acquisition, and PPBE, as well as associated organizational design. As emerging and disruptive technologies gain awareness and understanding, there must be experimentation, implementation, and evolution of alternative and additional Operational Concepts. Advancements in Technology Intelligence must also continue and evolve. Despite concerns and pronouncements about "Black Swans" or "technology surprise," for emerging and disruptive technologies, surprise only happens to those who are not paying attention.

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