(Graphic courtesy of the U.S. Army)

Visualizing the Synchronization of Space Systems in Operational Planning

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When a war is decided upon, it becomes necessary to prepare, not an entire plan of operations—which is always impossible—but a system of operations in reference to a prescribed aim; to provide a base, as well as all the material means necessary to guarantee the success of the enterprise.

—Baron Antoine-Henri De Jomini, *The Art of War*

More than ever, space systems are essential to U.S. military operations. Satellites, ground stations, end-user equipment, and the network architectures that connect them enable a distinctly American way of conducting global operations. While the United States has long enjoyed a relative advantage within the space domain, the capabilities of adversaries to deny, degrade, disrupt, or destroy U.S. space assets have significantly expanded in the past two decades. Antisatellite systems, jammers, cyber action, and nuclear threats place U.S. space systems in jeopardy and require serious consideration in operational planning. Because the United States will likely not enjoy uninhibited access to its space systems in future conflicts, military forces must be able to anticipate and visualize how friendly, enemy, and neutral space systems will affect the operational environment. Gaining and maintaining a relative advantage in such an environment will require the synchronization of tactical actions across all domains—including the actions of space systems—to achieve strategic ends.

In their multiple forms, space systems are available means that operational planners may choose to employ in a variety of ways. To begin achieving synchronization of space systems along with tactical actions in other domains, the joint force must share a baseline understanding of space systems and their potential roles as well as how to visualize their employment in conceptual planning. Toward that end, this article offers a practical explanation of space systems and provides a visualization tool as an example of a conceptual working product that a staff might produce to begin synchronizing space systems activity with activity in the other domains.

Defining Space Systems

From his military experiences during the Napoleonic Wars, Baron Antoine-Henri De Jomini understood warfare as an interaction of complementary functions that comprised a system of operations.[1] In his view, a successful commander understood both how to create a system and how to employ it effectively. While today's complex operating environment and the vast array of available means inhibit a commander from understanding the entire system of operations in detail, a conceptual understanding of the components of the system remains necessary. As a subset of the entire system of operations, space systems require special consideration because they come in multiple forms and perform a variety of functions—some of which may be unfamiliar to large portions of the force.

While joint doctrine offers a definition of space systems (more on that subject shortly), multiple definitions of a system exist within the body of systems theory. One broadly useful definition of a system is a "representation of an entity as a complex whole open to feedback from its environment."[2] What distinguishes a system from the environment with which it interacts depends on where one defines the system's boundary, and considerable leeway exists for the individual observing the system to define it according to his or her own needs. In the discussion of military space operations, a satellite provides a ready example of a system that consists of multiple subcomponents. One may view each of the satellite's subcomponents—the guidance and control subsystem, for example—as a system in itself. Oppositely, multiple satellites constitute a system of satellites or a constellation, and in cases where multiple constellations interact with each other, one may consider the larger grouping a system.[3]

An advantage of systems theory is that it allows for simplifying assumptions, but it also requires the practitioner to be cognizant of those assumptions.[4] In the context of military space systems, specific definitions of the system become particularly important, and the operational planner must deliberately acknowledge them, revisiting the simplifying assumptions as the situation develops. To continue along with the theme of satellites, a system definition that considers only the satellites of a constellation may have utility, but such a model lacks fidelity. Constellations depend upon ground stations, radio frequencies, and a multitude of personnel to complete their missions. In joint doctrine, "space systems consist of three related segments: ground, link, and space," and it is in this sense—broad enough for operational application but not so expansive as to become unwieldy—that the idea of space systems becomes particularly useful to the operational planner.[5]

Importantly, this definition of space systems precludes the use of domain-specific models for three reasons. First, the satellites themselves reside in outer space, but control stations and uplink/downlink sites exist on land, sea, and in the air. Second, the network architectures that make the satellites useful take advantage of the electromagnetic spectrum and depend upon data routing and processing by a variety of hardware and software components—elements of the cyber domain. Finally, systems like jammers, missiles, and even nuclear weapons may operate from, through, or in the other domains. In general, then, discussions of the space domain imply the cross-domain nature of space systems. Planners, therefore, must be aware of the interconnectedness of space systems, even if there are practical limits to how holistically one can define such systems.

Enabling Means

For planning purposes, one may divide the general category of space systems into two different categories of means: enabling means and hostile means.[6] Hostile means are those that threaten other space systems, and like enabling means, they require consideration of how both friendly and enemy forces may employ them. This article focuses on the enabling means, which, unlike hostile means, do not cause damaging effects to enemy space systems but include the various uses of friendly space systems in support of multi-domain military operations. Enabling means include defensive space control (DSC) and the missions of environmental monitoring (EM); missile warning (MW); intelligence, surveillance, and reconnaissance

(ISR); satellite communications (SATCOM); and position, navigation, and timing (PNT).[7]

The integration of enabling means has served as a major goal of the joint force for nearly four decades, and much Army professional writing, particularly since the beginning of the Global War on Terrorism, explored how the force could integrate space-based capabilities into the warfighting functions. In the contemporary force, intelligence staffs routinely incorporate space-based products into their repertoire, space operations officers model the effects of terrain and enemy activity on PNT accuracy, MW systems enjoy well-established dissemination architectures, and SATCOM—both military and civilian—enable global communications and serve as a conduit for cyber operations. While such tactical integration is indispensable to modern military operations, operational art demands a more conceptual view of how to synchronize space capabilities in relation to those in other domains. Not only will such a conceptual view allow for a more thorough plan, but it will also aid in the generation of tactical options.

A Visualization Tool

To situate enabling space systems within the framework of operational art requires a consideration of how an operational planner may synchronize them in time, physical space, and purpose with operations in other domains. The systems approach is particularly important to this method because, while it is unlikely that the operational planner will manipulate the orbits of the satellites themselves, considerations of ground station emplacement, radio frequency distribution, and potential enemy action all bear on the operational problem.

The figure (on page 110) is based on a synchronization and visualization tool developed during the early stages of a recent exercise at the Command and General Staff College's School of Advanced Military Studies (SAMS).[8] It is primarily a planning tool, intended to aid an operational planning team in its conceptual approach to the operational problem. This version speaks directly to a corps-level operation and the space capabilities that will likely be available to enable it. The specifics of the graphic may change for combatant command or theater-level operations that have more assets available or more authority to request and employ assets, but the general format remains practical. It is not a tool for precise synchronization but for achieving shared understanding among the staff before beginning detailed synchronization later in the planning process. As such, the graphic provides a way to visualize space enabling operations in time and physical space—in this case, along with a ground assault—but one might easily adapt it to include operations in any or all domains.

In this iteration, the visualization tool consists of fourteen rows, but the number of rows may increase or decrease depending on the needs of the particular mission. Generally, the top half of the chart depicts traditional elements considered during mission analysis, including terrain, weather, and anticipated friendly and enemy dispositions. Rows 9–12 depict the missions of the enabling space systems under consideration. In practice, planners update such a chart (typically as a whiteboard product) throughout the planning process and may create and destroy multiple versions as the situation changes. Circumstances may require more or less detail, but the process of managing the tension between the conceptual and the detailed drives development of the plan. The visualization for this plan picks up at the beginning of the ground offensive (G-Day) and carries forward until G+5.

Visualization of Traditional Elements

Rows 1–8 provide traditional elements to consider during mission planning to include a time reference, phases of the air tasking order cycle by day, light and weather data, and enemy and friendly situations.

Row 1. Row 1 shows the primary time reference based on G-Day.

Row 2. Row 2 shows the air tasking order (ATO) cycle in its relation to G-Day. On G-Day, the combined force is executing ATO "C" while the other lettered ATOs are in various stages of planning and preparation that will lead to their future execution.

Row 3. Row 3 depicts light data with sunrise and sunset

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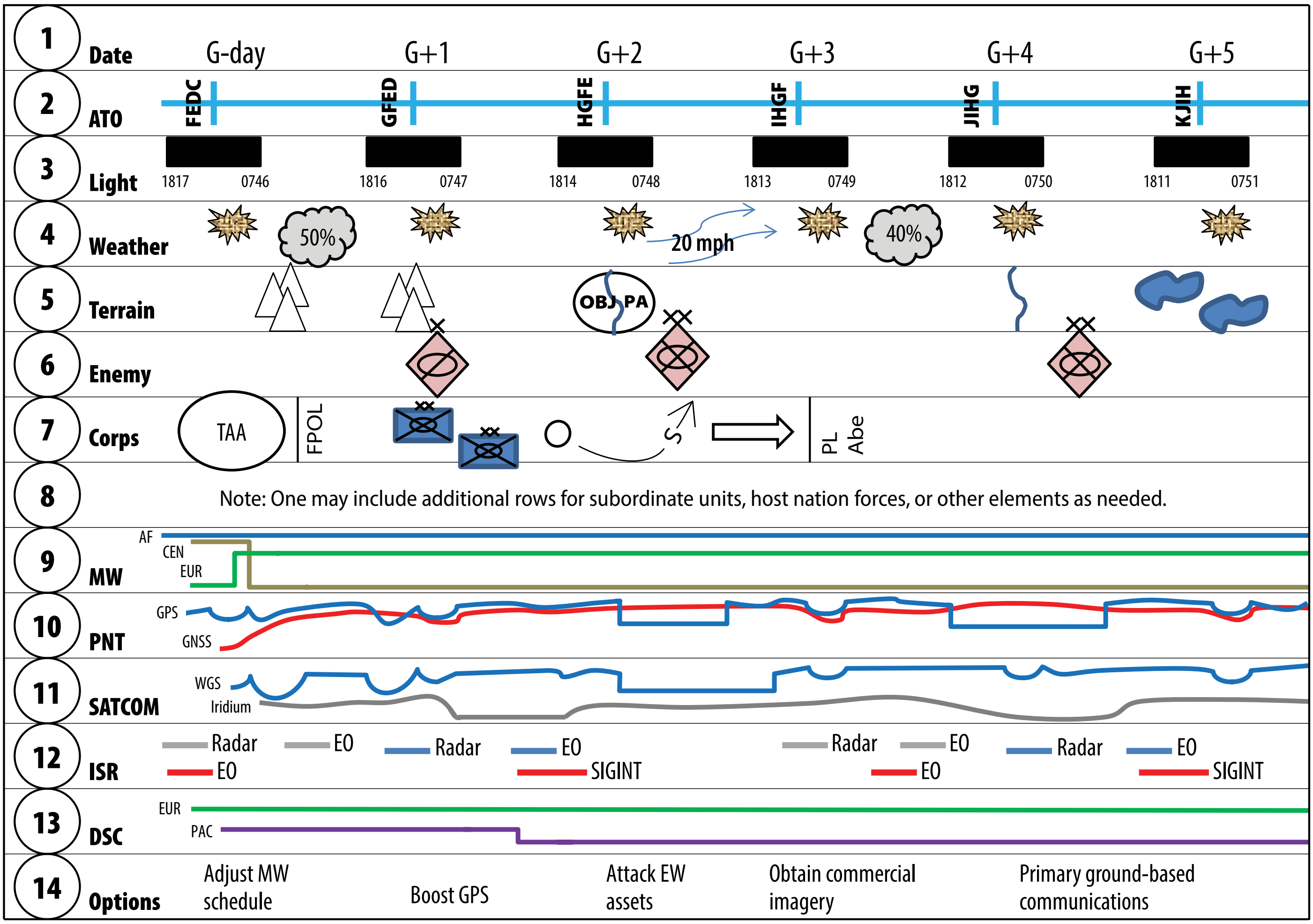


(Figure by author)

Figure. A Visualization Tool

- Cloud cover
- Enemy mechanized infantry division
- Enemy mechanized reconnaissance brigade
- Friendly mechanized infantry division
- Hours of limited visibility
- OBJ PA — Objective Pennsylvania
- Marsh
- Mountains
- River
- Scintillation
- Seize
- TAA — Tactical assembly area
- Wind speed

AF—U.S. Air Force

ATO—Air tasking order

CEN—Joint Tactical Ground Station in U.S. CENTCOM

DSC—Defensive space control

EO—Electro-optical imager

EU—Joint Tactical Ground Station in Europe

EUR—DSC unit in Europe

EW—Electronic warfare

FPOL—Forward passage of lines

G-Day—First day of the ground offensive

GNSS—Global navigation satellite system (enemy)

GPS—Global positioning system (friendly)

ISR—Intelligence, reconnaissance, and surveillance

MW—Missile warning

PAC—DSC unit in the Pacific

PL—Phase line

PNT—Positioning, navigation, and timing

SATCOM—Satellite communication

SIGINT—Signals intelligence

WGS—Wideband Global SATCOM system

times. The black bars represent hours of limited visibility with sunrise and sunset times at the ends of the bars.

Row 4. Row 4 depicts terrestrial weather including cloud cover and anticipated wind speeds; it is the first row that incorporates a space-specific element. It shows expected scintillation (electrical charging of particles in the ionosphere) windows that may degrade satellite communications and GPS signals. While scintillation typically occurs at night at latitudes from twenty degrees north or south of the equator (think Central Africa and the Indo-Pacific region), actual instances of the phenomenon are not predictable.[9] Furthermore, the intensities of those instances and the effects on communications are not predictable. Therefore, a consideration of scintillation, like the consideration of terrestrial weather, serves as a planning factor when building flexibility into the operation.

Row 5. Row 5 depicts the terrain as it affects the timing of the operation from a friendly perspective. The terrain depicted in the visualization tool corresponds to significant terrain determined from a map analysis and includes mountains, rivers, and marshes. Although not shown in the figure, row 5 may also include man-made terrain features like bridges and urban areas. Maps naturally provide more precise means for detailed planning, but even the conceptual graphic should include the initial distance analysis between significant terrain features or objectives. At this stage in the planning effort, the visualization shows that the ground unit expects to reach mountains on G-Day and again on G+1 before reaching the main river crossing complex (Objective Pennsylvania, or OBJ PA) on G+2. Another river crossing operation follows on G+4 with marshes slowing ground maneuver on G+5.

Row 6. Row 6 depicts the templated enemy in its temporal and spatial relationships. Intelligence suggests an enemy reconnaissance unit will occupy the disruption zone in the mountains during the hours of darkness on G+1. The main enemy force, which is defending at the river crossing complex, will be in position no later than G+2 with organic electronic warfare (including satellite and GPS jamming equipment) and an operational reserve within reinforcing distance. A second enemy division defends near the marshes beyond the second river crossing.

Row 7. Row 7 depicts the predicted dispositions of friendly units. On G-Day, the corps is in the tactical assembly area with special operations forces beginning their operations. The main body conducts a forward passage of lines with host nation forces as it leaves the TAA, and two infantry divisions encounter the enemy force in the disruption zone. They anticipate seizing OBJ PA on G+2.

Row 8. As Row 8 suggests, a more complete infographic could contain additional rows for individual maneuver units, host nation forces, logistic efforts, and more. In keeping with the focus of space systems and operational art, the additional rows provide an example of how one might visualize space enabling means.

Visualization of Space Enabling Means

Rows 9–12 depict the MW, PNT, SATCOM, and space-based ISR missions, and row 13 depicts the defensive space control mission.

Row 9. Row 9 depicts three different lines, each representative of the mission status of a unit engaged in satellite-based MW. The blue line shows the U.S.-based Air Force unit that is continuously on mission, the brown line shows the Army's joint tactical ground station in U.S. Central Command (JTAGS–CEN), and the green line shows the JTAGS unit in Europe (JTAGS–EUR). In this scenario, all three are capable of providing MW to the task force through robust communications architectures. The rise of the "EUR" line followed by the drop of the "CEN" line on G-Day indicates that JTAGS–CEN is scheduled to go off mission just after JTAGS–EUR comes onto mission. Given the high probability of enemy missile activity early in the campaign, the operational planner may request JTAGS–CEN to defer its scheduled maintenance period and remain on mission. It may also be prudent to request JTAGS–EUR to come back onto mission earlier than anticipated.

Row 10. Row 10 depicts a conceptual flow of the accuracy of the GPS system (blue) and the enemy's global navigation satellite system (GNSS, red). In the course of its normal operations, the accuracy of GPS dips and rises as a result of the relative motions of the satellites. Terrain and enemy can also affect accuracy. On the GPS curve, accuracy dips for the ground elements on G-Day and G+1 when friendly forces are within the mountain range, again on G+2 as the enemy main effort employs its electronic warfare assets near the river crossing site, and a third time as friendly forces near the river crossing on G+4. While such anticipated dips may affect the ground maneuver, they also carry implications for the employment of precision-guided munitions and unmanned aircraft systems. Smaller dips reflect the potential effects of atmospheric scintillation—depicted in row 3—during hours of darkness.[10] By way of comparison, the enemy's GNSS curve drops slightly on G-Day as its forces travel into the mountains but is predicted to remain steady throughout the remainder of the operation.

With this visualization in hand, the staff may begin considering how to mitigate the effects of degraded GPS for friendly forces and how to enhance degradation to the enemy's satellite navigation system. As efforts transition to detailed planning, the staff space operations officer should begin determining, through computer modeling and simulation, when the dips in signal strength begin causing problems for PNT-dependent systems and what that means for the plan. A more detailed version of the visualization tool could include threshold lines to depict the anticipated effects of signal degradation on various capabilities.

Row 11. Conceptually, row 11 functions like row 10. In the consideration of SATCOM, one may include any number of constellations depending on those in use by the force. In this depiction, the blue line represents the availability of the Wideband Global SATCOM (WGS) system, a commonly used military satellite communication system. The gray line shows the availability of the Iridium system, a civilian space system that the U.S. military frequently uses. As with the GPS accuracy shown in row 10, the WGS availability in row 11 may dip slightly with scintillation, terrain, and enemy effects; these anticipated degradations require more detailed analysis as planning continues. For Iridium, the dips represent known gaps in coverage. Such forecasted gaps allow for anticipation of communications contingencies.

Row 12. Row 12 depicts space-based intelligence, reconnaissance, and surveillance platforms. As in the PNT row, row 10, blue denotes friendly while red denotes enemy. Importantly, as in row 11, gray denotes commercial systems that may be available to augment the intelligence collection of either belligerent. Such commercial imagery provides an opportunity to augment the intelligence collection of both belligerents. The short lines indicate windows of observation that the satellites have while they pass over the ground. The absence of a line indicates that the satellite is physically unable to observe the operation. The lengths of these windows vary depending on the satellite and its orbit. A typical imagery satellite may pass from horizon to horizon in five to seven minutes with other members of its constellation (assuming it is part of a constellation) revisiting periodically. Signals intelligence (SIGINT) satellites may pass out of view in minutes or hours, depending on the orbital characteristics of the satellites. Geosynchronous SIGINT satellites can observe a given location continuously.

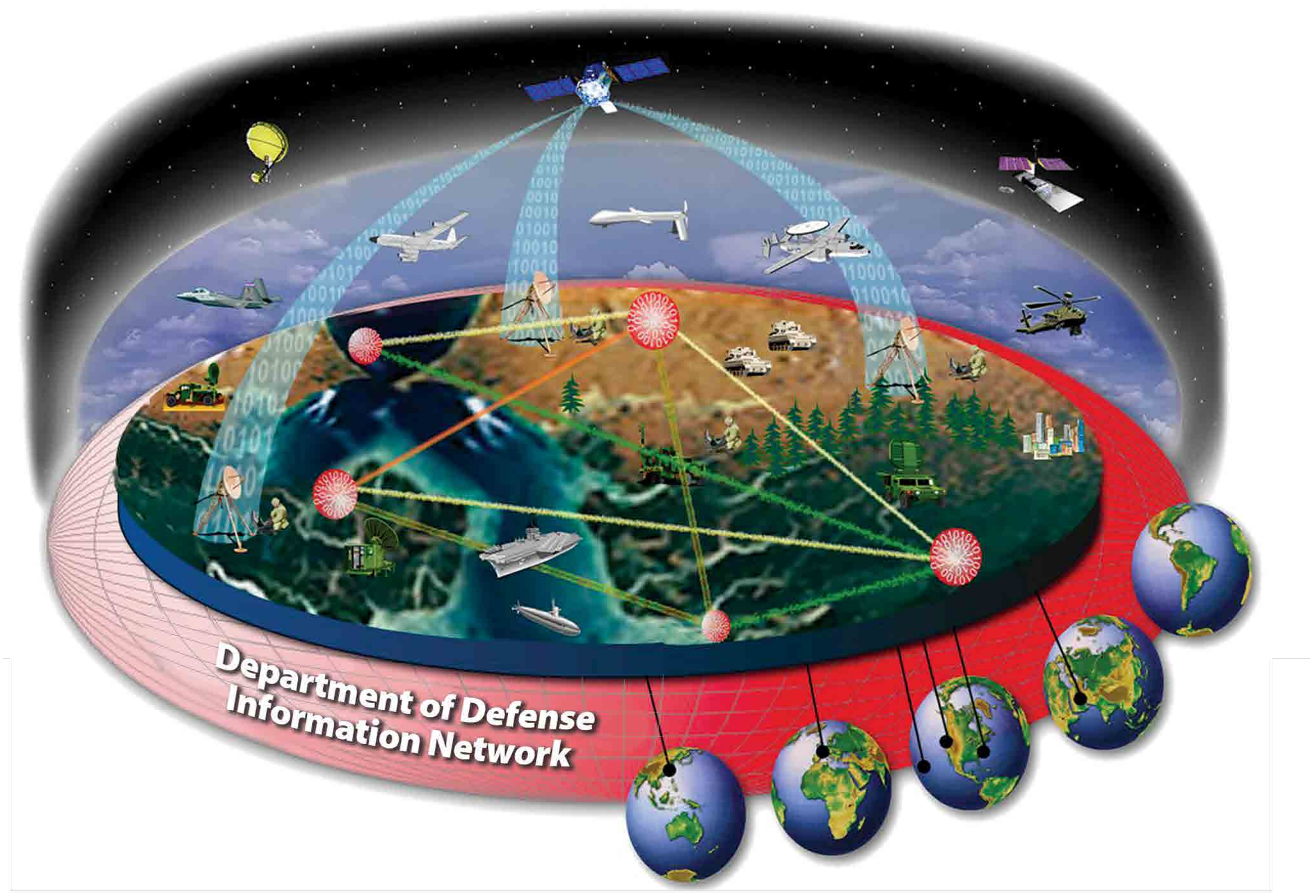
On G-Day, enemy electro-optical (EO) imagers are in position to photograph the corps assembly area. Commercial radar and commercial EO systems may also be collecting over friendly forces during this time. Friendly radar imagery provides an option for gathering intelligence as the enemy moves into the mountain valley during the hours of darkness between G-Day and G+1 or in the event that cloud cover blocks the view of the EO satellites. Also on G+1, enemy spacecraft will be in a position to collect SIGINT, a prediction that may drive plans to implement communications discipline or military deception measures. Since the orbital patterns of satellites are predictable, this general pattern repeats periodically.

Row 13. Rows 10 and 11 highlighted some of the vulnerabilities considered in the employment of space systems. Protecting communications—both to and from the satellite—requires DSC missions to monitor SATCOM links to detect interference. As with the MW forces of row 9, row 13 depicts units in various geographic positions and their operational tempo.[11] The green line represents a DSC unit stationed in Europe (EUR). It operates at a steady state, and for the sake of the infographic, it is monitoring channels on one or more WGS satellites. Similarly, the DSC unit in the Pacific (PAC, purple) is on mission but scheduled to come off mission on G+2. The graphic depicts PAC's off-mission status to remind planners that the asset provides an option for additional support, if necessary.[12] As the timeline looks beyond G+5, this asset may again become active.

Row 14. Row 14 highlights options and potential decision points based on analysis of the information in the previous rows for commanders and staffs to consider during planning and wargaming.

Conclusion

While the employment of space systems for military purposes is not a new idea, the anticipated conflicts of the future will require a deeper appreciation of space systems in operational planning. The belligerents who more thoroughly understand space systems and how to



Synchronization of space systems to support coordinated tactical actions in other domains requires a baseline understanding by the commander and his or her staff of space system potential roles and the ability to visualize their employment in conceptual planning. To overcome the challenges associated with this endeavor, tools must be developed such as the one proposed in this article to facilitate efficient synchronization of a vast array of complex systems operating across multiple domains. (Modified version of original figure courtesy of the Joint Task Force–Global Network Operations)

synchronize their capabilities with multi-domain forces will enjoy an asymmetric advantage over their opponent. While the topic of space system synchronization may expand to include any number of satellites, constellations, ground stations, and frequencies, the synchronization of the MW, PNT, SATCOM, ISR, and DSC missions remains a prime concern for the joint force and provides a convenient starting point for understanding, visualizing, and synchronizing space systems.

As a visualization and planning tool, an infographic like the one on page 110 provides the valuable service of allowing conceptual synchronization that encourages optionality and informs the subsequent employment of space systems. In this way, space operations become an integral part of the planning process and contribute to the development of all warfighting function concepts from an early stage. Throughout the execution of the operation, an updated visualization provides insight into how the space systems are contributing to current tactical action and furthering the force's progress toward its strategic objectives. Furthermore, as operational planning progresses from the conceptual to the detailed (and likely back again), the plan for the use of space systems—indeed for the systems of all domains—must proceed likewise.

In this respect, the graphic illustrates the multi-domain nature of modern conflict, the need to synchronize assets among the domains, and the expansion of the battlefield geometry that this synchronization entails. When the operational planner can visualize the array of friendly and enemy forces in time and physical space, vulnerabilities and opportunities become more readily apparent. Anticipating responses to both helps generate options and potential decision points for commanders and staffs—row 14. In this way, the plan emerges early in the planning process, allowing commanders and staffs to leverage support relationships (including reach-back support) and request resources sooner rather than later.

Surely, the expanded consideration of space systems adds additional complexity to the operation, but to understand how the various domains and their myriad of means can work together to achieve strategic ends is the hallmark of operational art. As a practical matter, this is very difficult. It implies that commanders and staffs must work in multiple media and have at least a general knowledge of means in all domains. As joint doctrine asserts, the complex process of operational art is necessarily dependent upon the knowledge of commanders and staffs of the means available, their understanding of tactics and doctrine, and their ability to imagine creative applications. Within this construct, multi-domain operational art also implies interservice coordination and shared mission understanding. Space systems are essential to such applications, and by virtue of their tendency to operate across domains, they perhaps force holistic consideration of operational art in a way that the traditional domains do not. Accordingly, contemporary commanders and staffs must consider the space domain as one of many in the employment of operational art with the tactical actions of space systems synchronized in time, multi-domain space, and purpose. ■

Notes

Epigraph. Antoine-Henri Jomini, *The Art of War*, trans. G. H. Mendell and W. P. Craighill (Philadelphia: J. B. Lippincott, 1862), 50 [punctuation edited].

1. Jomini, *The Art of War.*
2. Alex Ryan, "What is a Systems Approach?," *Arxiv preprint arXiv:0809.1698*, 10 September 2008, 28, accessed 25 October 2018, https://pdfs.semanticscholar.org/dafc/dc5b54e42f874dbe30bdae398f5b181cb9f1.pdf.
3. A system of satellites that use the GPS constellation to assist in determining their locations provide an example of such interaction.
4. Ryan, "What is a Systems Approach?," 31.
5. Joint Publication (JP) 3-14, *Space Operations* (Washington, DC: Government Publishing Office [GPO], 2018), I-2.
6. Ibid., II-1 to II-8; JP 3-14, *Space Operations* (Washington, DC: Government Printing Office, 2013 [obsolete]), II-4 to II-9. The terms "enabling" and "hostile" are not doctrinal, but I have picked those labels because I believe they convey the nature of the two categories. Prior to 2018, joint doctrine defined the space mission areas as space situational awareness, space force enhancement (intelligence, surveillance, and reconnaissance [ISR]; missile warning [MW], environmental monitoring [EM], and satellite communications [SATCOM]; and position, navigation, and timing [PNT]), space support (launch and on-orbit operations), and space control (both defensive and offensive). The 2018 version of JP 3-14 dropped the terms "space force enhancement" and "space support" but retained the same list of capabilities. I have chosen to include defensive space control (DSC) with enabling means while considering offensive space control missions—whether through cyberattack, jamming, antisatellite missile, etc.—as a hostile means.
7. For more information, see 2018's JP 3-14, *Space Operations*. Prior to the 2018 version, joint doctrine characterized the EM, ISR, MW, SATCOM, and PNT missions as "space force enhancement missions."
8. I must acknowledge Dr. Bruce Stanley, associate professor at School of Advanced Military Studies, for instructing me on this method of visualization. I have adapted the concept to portray one way to visualize synchronization of some space systems.
9. Jeffrey Lanphear and Gabriel A. Medina, "Space Environment," in *AU-18: Space Primer* (Maxwell Air Force Base, AL: Air University Press, 2009), 125; Eric Niller, "Weird Space Bubbles May Have Caused U.S. Battle Deaths," Seeker, 26 September 2014, accessed 25 October 2018, https://www.seeker.com/weird-space-bubbles-may-have-caused-us-battle-deaths-1769118964.html. U.S. forces experienced signal degradation due to scintillation during the Persian Gulf War in Iraq and during Operation Anaconda in Afghanistan—both at latitudes of thirty degrees or more.
10. "Satellite Communications," National Oceanic and Atmospheric Administration Space Weather Prediction Center, accessed 25 October 2018, http://www.swpc.noaa.gov/impacts/satellite-communications.
11. While the units listed in the missile warning section are fielded units, the units listed in row 13 are entirely notional.
12. Doctrinally, DSC also includes measures to protect ground stations and on-orbit assets. While this article does not include those aspects of the DSC mission, they deserve consideration in their own right.