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WARGAMING RELIANCE ON COMMERCIAL SPACE PARTNERS: A DETERMINATION OF GUIDING PRINCIPLES AND APPLICATIONS

by

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The 2010s saw a revolution in the space industry leading to the commercial proliferation of space technologies once reserved for national space programs and militaries, dubbed by many as Space 2.0. This rapid rebalancing of capabilities from traditional state actors to commercial entities contributed to a reevaluation of U.S. space institutions and practices resulting in an increased U.S. military reliance on commercial entities to build space capability, capacity, and resilience. To that end, there is renewed interest in discerning the impacts of this expanded commercial space reliance on current U.S. military doctrine, thus placing new demands on the practice of wargaming among the U.S. military services. Specifically, wargaming must now account for this increased reliance by establishing guiding principles and wargaming methodologies to properly account for this revolution in space-based capabilities. This thesis addresses this problem by sampling the scope of commercial space capabilities, evaluating governing policy and doctrine, and examining a representative sample of the U.S. military's reliance on commercial space. The unique qualities of commercial space are evaluated to identify a list of guiding principles for wargaming applications. Then, wargaming methodologies that encompass these guiding principles are identified and proposed. Finally, these principles are applied to the USMC's Assassin's Mace wargame to demonstrate and evaluate their utility and application.

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WARGAMING RELIANCE ON COMMERCIAL SPACE PARTNERS: A DETERMINATION OF GUIDING PRINCIPLES AND APPLICATIONS

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ABSTRACT

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LIST OF ACRONYMS AND ABBREVIATIONS

ASAT	anti-satellite
CENTCOM	United States Central Command
CNA	Center for Naval Analysis
CSCO	Commercial Satellite Communications Office
COMSAT	Commercial Satellite Corporation
DOD	U.S. Department of Defense
DSC	defensive space control
DSS	2020 Defense Space Strategy
FCC	Federal Communications Commission
FCSA	Future Commercial SATCOM Acquisition Program
GEO	geosynchronous
INTELSAT	International Telecommunications Satellite Organization
ISR	intelligence, surveillance, and reconnaissance
LEO	low Earth orbit
M&S	modeling and simulation
MEO	medium Earth orbit
MSS	mobile satellite service
NDAA	National Defense Authorization Act
NOAA	National Oceanic and Atmospheric Administration
NSPD-3	National Space Policy Directive 3
SATCOM	satellite communication
SPOT	Satellite Pour l'Observation de la Terre
USG	United States government
USSF	United States Space Force

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EXECUTIVE SUMMARY

Recent advancements in the commercial space industry have significantly rebalanced the historical ratios of state-owned to commercially owned space-based capabilities and capacity [1]. In recognition of this shift in the space landscape, it is now explicit Department of Defense (DOD) strategy to leverage commercial space to augment capacity and build resiliency [2]. Therefore, the DOD must establish principled methods for incorporating this reliance on commercial space partners into its wargaming practices. This research sought to address this need by deducing guiding principles and wargaming methodologies that facilitate the inclusion of the DOD's reliance on commercial SATCOM and commercial space-based ISR partners into its wargaming efforts.

This research first surveyed the scope of commercial SATCOM and commercial space-based ISR capabilities to exhibit their relative features, capability, and relevancy to the modern battlefield. Then, this thesis reviewed the historical relations between the U.S. Government (USG) and the commercial SATCOM and ISR industries. Finally, this survey of historical context concluded with an introduction to current DOD contracting of commercial SATCOM and commercial space-based ISR that showed the growth of this now-robust relationship and dependency.

With the collective regulatory and policy context examined, commercial space partners were shown to face uniquely commercial challenges during times of conflict that reflect the commercial paradigm defined by relations with customers, relations with regulators, their current business model, and their future commercial viability.

From this paradigm, this thesis showed how these commercial considerations could be leveraged to influence a commercial space partner's ability or willingness to support the DOD during times of conflict. This research then summarized the results of this analysis into a set of six guiding principles as follows:

1. Assets may hold strategic value to commercial partners
2. Market access cannot be assumed and may be leveraged
3. Current and future profitability must be protected

4. Stakeholders must be known and accounted for

5. The existence of undisclosed influence must be acknowledged

6. Proliferation complicates capability denial

Once this research established the commercial paradigm and guiding principles, it then introduced the craft of wargaming and, more specifically, DOD wargaming efforts. From this context, this thesis determined that the recommended incorporation methods should be structured for application to analytic wargames. Then, the commercial paradigm and guiding principles were synthesized into recommended changes to wargame constructs and gameplay mechanics. Specifically, wargames including this dependency should ensure representation, improve player orientation, and increase relative proliferation into the game construct. Then, to improve gameplay modeling, wargame designs should incorporate the commercial paradigm and the guiding principles into game interactions between players. Moreover, wargame designs should incorporate the relative resiliencies and susceptibilities of commercial space assets and capabilities into their modeling of space-enabled capabilities. Decision aids were created for each of the previous recommendations.

Finally, this thesis evaluated the effectiveness of these recommendations by applying them to the Marine Corps analytic wargame, Assassin's Mace, as part of a sponsored wargame conducted at the Naval Postgraduate School. This application demonstrated how each of the wargame inject methods could be applied to an existing DOD analytic wargame in pursuit of a known wargame objective with associated key issues. The results included the explicit representation of space-based ISR and the delineation between commercial and national theater ISR capabilities. Additionally, their relative resiliency and proliferation were incorporated. Finally, commercial SATCOM was included as a means of redundant command and control with the caveat that its utilization includes some additional susceptibility to communication exploitation. Ultimately, this process revealed that the developed tools are well suited for modeling DOD reliance on commercial space partners in analytical wargames, but many of the modeling recommendations are not easily applied to existing games without also requiring extensive remodeling of the space domain if not already included.

Overall, the thesis successfully established guiding principles and wargaming methodologies to enable wargame modeling of DOD dependencies on commercial space partners.

References

[1] United States Space Foundation. "The space report 2015: the authoritative guide to global space activity." Colorado Springs, CO, USA, 2015. [Online.] Available: https://spaceportcamden.us/download/The_Space_Report_2015_Overview_TOC_Exhibits.pdf

[2] Department of Defense, "Defense Space Strategy summary," June 2020. [Online]. Available: https://media.defense.gov/2020/Jun/17/2002317391/-1/-1/1/2020_DEFENSE_SPACE_STRATEGY_SUMMARY.PDF

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I. INTRODUCTION

The first part of the twenty-first century witnessed a growth in the commercial space industry on a scale and at a pace not previously seen in the nearly 70 years since the space age began. For the first time, commercially owned and operated space capabilities and capacity grew to rival all but the most technologically advanced government systems. Moreover, commercial space operators now represent a diversity of nations and interests vastly exceeding the short list of traditional nation-state space-programs seen in the decades prior [1]. Thus, this new space age is rightly called "Space 2.0" by those aware of this rapid growth in space actors and capabilities that, collectively, represent the first major space race since the original 1960s race to the moon [2]. However, this exciting growth also brought with it a new array of challenges for civil and military policymakers, a reality acknowledged by the 2020 U.S. Department of Defense (DOD) *Space Strategy Summary*:

> Rapid increases in commercial and international space activities worldwide add to the complexity of the space environment. Commercial space activities provide national and homeland security benefits with new technologies and services and create new economic opportunities in established and emerging markets. The same activities, however, also create challenges in protecting critical technology, ensuring operational security, and maintaining strategic advantages. [3]

In short, this rapid growth in commercial space capabilities played a significant role in the re-evaluation of the U.S. space security construct which included the re-establishment of U.S. Space Command, creation of the U.S. Space Force (USSF) in 2019, and the designation of space as a warfighting domain [3]. By extension, this reevaluation of U.S. space institutions and the space domain also brought with it an official recognition that space is now "contested," "congested," and "competitive" with numerous nationalities, companies, capabilities, interests, and customers competing in a complex environment [4]. Moreover, the space environment is no longer purely sculpted by the actions, policies, and interests of major state actors, namely the United States and Russia, despite intentional efforts by U.S. space policy to ensure it remains a "free and open domain" [5], [6]. Finally, as commercial capabilities have grown, so too has U.S. military reliance on this "free and open domain" and commercial space partners for services ranging from mobile satellite

communications to theater broadband internet, remote sensing to signals intelligence [7], [8]. Thus, the inclusion of this pervasive and growing reliance on commercial space partners into the U.S. strategic thinking is an imperative.

Therefore, the DOD must incorporate this new reality of reliance on commercial space partners into its plans, policy, and doctrine, which, in turn, demands increased incorporation of this reliance into the DOD's space-related wargaming. Unfortunately, despite the increased incorporation of space into DOD wargaming over the past decade, commercial space reliance remains largely absent from most wargaming efforts within the DOD [9]. Furthermore, there is no apparent uniformity among the wargaming methodologies used by the DOD to incorporate commercial space actions and effects, which, in turn, obfuscates insights that might otherwise be drawn from DOD space-related wargames [9]. Therefore, to analyze the strategic, operational, and tactical implications of relying on commercial space, the DOD must address this lack of structure by establishing uniform guiding principles and methodologies for the inclusion of this new, growing, and constantly changing facet of national security: commercial space reliance.

A. PURPOSE

This thesis addresses the challenge of wargaming DOD's reliance on commercial space partners to facilitate greater incorporation of this reliance into future DOD wargaming efforts. This research distills guiding principles and develops wargaming methodologies that apply across a wide range of DOD wargaming scenarios. For the purposes of this research, wargaming refers specifically to the act of evaluating scenarios as well as competing forces and their decisions through their representation by human players with a focus on interactions, consequences, and implications [10]. This thesis treats wargaming as distinct from modeling and simulation's evaluation of technical and physical interactions.

B. RESEARCH QUESTION

This thesis' primary research question is: which overarching guiding principles and wargaming methodologies best enable the sound and equitable inclusion of commercial space-based satellite communication (SATCOM) and intelligence, surveillance, and

reconnaissance (ISR) into the spectrum of DOD analytical wargaming efforts? This thesis answers this question by addressing the following subsidiary research questions:

1. What is the relevant scope of commercial space-based ISR and SATCOM that warrants inclusion into DOD wargaming based upon its demonstrated military applications and current utilization by the DOD?
2. What is the policy, doctrine, and regulatory context of current DOD reliance on commercial space-based ISR and SATCOM partners?
3. How is the perspective of a DOD-contracted commercial space partner unique from the perspective of DOD decision-makers in times of conflict due to uniquely commercial considerations?
4. What guiding principles can be deduced from an understanding of the commercial paradigm and their partnership with the DOD during times of conflict?
5. What wargaming methodologies should be employed by DOD wargamers to incorporate the full scope of guiding principles while remaining usable to a broad range of DOD wargaming practitioners?

C. SCOPE

This thesis limits its analysis to developed applications of commercially owned and operated space capabilities that have direct bearing on military operations. This thesis also constrains its analysis of U.S. DOD wargaming efforts to those routinely incorporating dependencies on space, and it does not include efforts to model or simulate space interactions separate from the distinct discipline of wargaming. Lastly, the thesis constrains its recommended wargaming methodologies to a rules- and turns-based approach that can be executed manually or with minimal programming requirements. Moreover, the methodologies do not seek to account for the extreme range of commercial space reliance considerations, but rather they enable evaluation of likely conflict scenarios faced by wargaming practitioners.

D. THESIS ORGANIZATION

After this introduction, Chapter II provides an overview of past and present commercial space technologies, their uses, and their application to the modern battlefield. Chapter II concludes with a selection and summary of commercial SATCOM and remote sensing constellations that the DOD should include in its wargames to adequately represent its current dependencies. Chapter III reviews the scope of U.S. and DOD policy concerning commercial space, current relations to the commercial space industry, and current formal utilization of commercial systems by the DOD. This review justifies the assertion that DOD's commercial space partners already play a vital role in the U.S. security construct. This, in turn, justifies increased inclusion of commercial space partners into DOD wargaming initiatives. Chapter IV provides an overview of the space domain and space conflict, highlighting the unique challenges faced by commercial space operators compared to government-owned and -operated military satellites. Furthermore, Chapter IV evaluates the unique paradigm of commercial space actors within the context of space warfare and identifies the resulting forms of internal and external influence faced by commercial actors. Chapter IV concludes with the enumeration of the following six guiding principles:

1. Assets may hold strategic value to commercial partners
2. Market access cannot be assumed and may be leveraged
3. Current and future profitability must be protected
4. Company stakeholders must be known and accounted for
5. The existence of undisclosed influence must be acknowledged
6. Proliferation complicates capability denial

Chapter V translates the principles from Chapter IV into a set of wargaming methodologies that enable the application of these principles across a broad range of DOD analytic wargaming initiatives. Specifically, Chapter V recommends future wargames include greater commercial space partner representation, increased proliferation, and greater player orientation. Moreover, Chapter V recommends future wargames utilize a "closed" wargame setting where player interactions are limited to reflect directed

communications and limited battlespace awareness for commercial actors. Finally, Chapter V recommends that actions against government-operated military satellites and commercial satellites should not be treated as equal given the disparity in their designs and protective measures.

Chapter VI summarizes the results of a wargame conducted at the Naval Postgraduate School utilizing the proposed methodologies to demonstrate the utility of the guiding principles and methodologies. Finally, Chapter VII summarizes the research's conclusions and recommends future areas of research to include improved standardization of player orientation and education. Additionally, it recommends further effort be made to identify and standardize theater- and service-specific space considerations to better align wargaming objectives and key issues with service-specific requirements.

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II. COMMERCIAL SPACE CAPABILITIES

To better define the impact of "Space 2.0" on wargames incorporating commercial space reliance, this growth in commercial space capabilities must first be surveyed to highlight pertinent technological advances in the commercial space industry that should be incorporated into DOD wargaming initiatives. Many efforts have already been made to capture the scope of these changes into single studies, books, and other resources. Notable public examples include the Space Foundation's annual "Space Report" and the Satellite Industry Associations annual report [11], [12]. However, a complete review of modern commercial space capabilities exceeds the scope of this thesis; instead, this chapter first provides the most pertinent highlights of the histories of commercial SATCOM and ISR that, together, demonstrate the commercial space industry's close relationship with the U.S. government (USG). Then, representative samples of current commercial satellite constellations are provided that exemplify those constellations and capabilities that have the greatest relevance to the modern battlefield and by extension, DOD wargaming.

A. HISTORY OF THE COMMERCIAL SPACE INDUSTRY AND CAPABILITIES

Despite the rapid growth in commercial space capabilities of the early twenty-first century, commercial space enterprises are not a new phenomenon, especially in light of their extensive history dating back to the 1960s. In fact, commercial space efforts led the way in some instances, preceding even national systems and capabilities since the dawn of space-enabled communications and remote sensing [13]. Thus, this overview begins with an introduction to the history of commercial satellite communications starting in 1962 followed by an introduction to commercial remote sensing to help contextualize both the capabilities and the historical availability of these commercial systems.

The history of commercial SATCOM begins with the first commercially developed, funded, and operated communications satellite program, AT&T Bell's Telstar communications satellite program [14]. This program made history as the "first privately sponsored space-faring mission" when it was launched in July, 1962 [14]. Shortly

thereafter, Hughes Space and Telecommunications launched its Syncom satellites, thus "pioneer [ing] geosynchronous communication satellite design" [13]. However, recognizing the strategic impact of the nascent commercial satellite communication industry and the need for standardization, the USG quickly regulated the satellite communication industry starting with the 1962 Communications Satellite Act. This act effectively regulated ownership-of and access-to commercial satellites and their services through the creation of the "public-private entit [ies]," Communications Satellite Corporation (COMSAT) and the International Telecommunications Satellite Organization (INTELSAT), which were both conglomerations of commercial satellite companies and federal programs [13], [15]. The creation of these organizations staved off the creation of a purely commercial monopoly within the commercial space communication industry, and it also enabled the regulation and standardization of then-current and future commercial satellite communication (SATCOM) systems. However, the unintended consequence was that commercial SATCOM regulations stymied growth throughout the following three decades [13]. This was further exacerbated by the lack of commercial space launch providers given that only national space programs could launch satellites into orbit at that time. Specifically, it was not until the foundation of the publicly held French launch provider Arianespace SA that commercial companies had access to launch capabilities not held and, by extension, controlled by nation-state space programs [16]. Thus, in summary, commercial satellite communication efforts walked in step with national space program directions with little leeway until the 1980s and 1990s. However, this trend did not continue, and was upended by a series of changes that, together, brought about a more robust commercial SATCOM industry in the decades to follow.

First, the late 1980s saw growth in mobile communications for applications in the maritime and aviation industry, along with the necessary miniaturization of digital hardware, that brought new demand for the commercial SATCOM industry [13]. Second, launch costs were simultaneously reduced due a variety of factors including the 1984 Commercial Space Launch Act and competition from European government launch providers [13]. Thus, although not accomplished through any other means than the persistent increase in demand, technological improvements, and supportive U.S.

commercial space policies that encouraged growth, the U.S. commercial space industry grew continuously through the 1990s and 2000s. In fact, the U.S. commercial space industry is, as of 2018, a $158 billion industry representing over half of the global commercial space market and almost four times the size of the USG's space budget [17], [18]. However, this restricted beginning followed by significant growth is also evident in the important commercial remote sensing industry, a point also warranting a brief summary [11].

Although remote sensing and intelligence, surveillance, and reconnaissance (ISR) by satellites was developed at the onset of the space age, it did not transition to a commercial industry until the passing of the 1984 Land Remote Sensing Commercialization Act. Recognizing the value of satellite remote sensing and the stifling effect on industry caused by a lack of clear policy, the United States enacted a series of policy changes clearing the way for "the [commercialization of] remote-sensing functions relating to private sector operations," and the preservation of "the right to acquire and disseminate digital remote-sensing data" [19]. Thus, through the signing of an initial policy in 1984 and a revised version of the remote sensing national policy in 1992, the United States paved the way for a rapidly expanding U.S. commercial remote sensing industry that saw its first significant privatization efforts occurring shortly thereafter [20]. Specifically, the U.S. government attempted to commercialize the U.S. Landsat program through the late 1980s, and, although ultimately failing to remain economically viable, it ushered in a new era of commercial investment into the new industry [20]. However, this growth was not isolated to the United States.

Concurrent with these efforts in the United States, the French Satellite Pour l'Observation de la Terre (SPOT) program of 1982 also represents another example of this transition. The SPOT program was designed from the outset as a joint government-commercial venture and ultimately resulted in the creation of SPOT IMAGE Corporation in 1986, a commercial vendor of remote sensing data to both government and commercial users [21]. In doing so, SPOT IMAGE Corporation became one of the first commercial operators of a remote sensing satellite, albeit with the support and leadership of the French national space agency [21]. However, the final hurtles remained of achieving a

commercially designed, launched, and operated remote sensing satellite, an honor that, although pursued by many concurrent efforts in the late 1990s, was effectively captured by IKONOS nearly a decade later.

Space Imaging, now Maxar Technologies, designed IKONOS in response to the 1992 revision of the Land Remote Sensing Policy Act that fully allowed commercial ownership and operation of remote sensing satellites by U.S. companies [20]. With its launch in September 1999, IKONOS brought to market the first ever commercially available sub-meter resolution imagery [20]. Moreover, IKONOS began a trend of ever-improving commercial remote sensing capabilities that are now paced by numerous competing vendors of sub-0.5 meter imagery that represent the current state of the art within the commercial remote sensing industry [22]. In doing so, IKONOS ushered in an age where numerous companies from multiple nations now possess the ability to image objects as small as vehicles, equipment, and supplies, making these commercial actors and their capabilities relevant to the modern battlefield and present over almost any portion of the globe multiple times per day.

Thus, in summary, both commercial remote sensing and commercial satellite communications experienced trying and uncertain beginnings underneath the shadow of competing national space programs that, to varying degrees and at different times, conceded to a growing undercurrent of demand for the commercialization of space. Now, current permissive national policies sustain a commercial remote sensing market that is highly diverse and competitive, producing services and products that come close to matching and, at times, exceeding national systems in both capability and capacity. In light of this, it is appropriate to review a sampling these capabilities for perspective and when considering their employment on the modern battlefield and the necessity of their inclusion in DOD wargaming.

B. CURRENT COMMERCIAL SPACE TECHNOLOGIES AND THEIR POTENTIAL APPLICATIONS

To properly wargame commercial space reliance, a baseline of representative technologies must first be developed that can be used to represent the most applicable on-

orbit systems impacting national security. Given that this analysis is inherently focused on technologies that have ramifications on battlefield operations, this baseline only presents representative technologies from the two most militarily relevant types of commercial space technology: communications and remote sensing.

1. Communications

Commercial satellite communications have historically been the most ubiquitous form of commercial space enterprises, but their capabilities have consistently trailed those of terrestrial networks in speed and bandwidth [23]. However, as technology has developed, so too has the capacity and capability of these systems. Now commercial communication satellites occupy the full spectrum of traditional orbits, and their capacities dwarf national systems in both proliferation and throughput [24]. The following three satellite constellations each represent a commercial SATCOM constellation in one of the three most common orbital regimes. Moreover, in addition to their numerous private users, they are also common SATCOM constellation types leveraged by governments seeking to complement their national systems. Chapter III covers specific USG reliance. Chapter IV reviews the orbits themselves, both their advantages and disadvantages.

First, IRIDIUM, detailed in Table 1, exemplifies the modern capability to utilize a large constellation of dozens of satellites to enable nearly worldwide SATCOM for mobile satellite phone users [25]. This constellation is positioned in the low Earth orbit (LEO) regime and constituted with 66 medium-sized satellites transiting constantly overhead [25]. Constellations like these form the basis for cellphone-like communications coverage for numerous mobile users who are not constrained to a geographic location on the ground and allow, in some instances, for users to be mobile.

Table 1. IRIDIUM Satellite Constellation Overview. Adapted from [25].

NAME: IRIDIUM	
ORBIT: LEO – 780 km	
NUMBER: 66	
SERVICE: Meshed constellation providing mobile communications	

Second, Table 2 depicts a medium Earth orbit (MEO) constellation providing high-capacity data connectivity for primarily fixed-location users on the ground [26]. Examples of these users might be fixed command posts, slow moving ships, or other basing. Constellations such as these utilize far fewer satellites given that their higher altitude enables line-of-sight connectivity with a larger physical region on the ground. To enable these higher requirements per spacecraft, each satellite is typically larger, more advanced, and more expensive than those seen in LEO constellations.

Table 2. O3b mPower Satellite Constellation Overview. Adapted from [26].

NAME: O3b mPower	
ORBIT: MEO- 8,000 km	
NUMBER: 6	
SERVICE: Meshed constellation providing fixed global broadband internet	

Finally, ViaSat, a geosynchronous (GEO) SATCOM constellation, represents the high-end in both orbital altitude and satellite capacity [27]. These satellites are located at a

significantly higher altitude than either MEO or LEO constellations, and remain fixed over a set location on the ground due to the specific orbital dynamics of their altitude [27]. This removes some of the complexity of networking users across multiple satellites throughout multiple orbits and allows for larger, more powerful satellites that are custom built for the servicing of set geographic locations. This, in turn, lends itself to high-capacity satellites with ViaSat owning many of the largest. These satellites service multiple fixed ground terminals with bandwidths exceeding many government constellations [24]. The U.S. DOD uses these constellations, among others, to supplement national SATCOM capabilities by leasing bandwidth from these and other providers.

Table 3. ViaSat Satellite Constellation Overview. Adapted from [27].

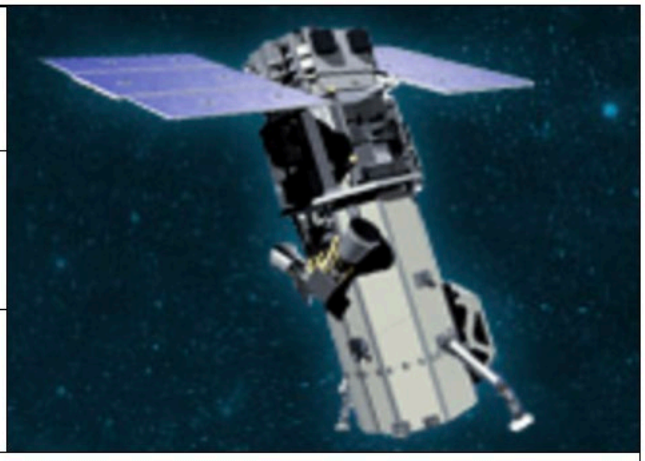
NAME: ViaSat	
ORBIT: GEO – 36,000 km	
NUMBER: 3	
SERVICE: Global high-throughput broadband internet service	

2. Remote Sensing

Although the sector of commercial remote sensing is extensive and expanding, this research only references a single example, Worldview-3, shown in Table 4, which represents one of the highest-resolution commercial imaging satellites in orbit. Worldview-3 is an optical imagining satellite in LEO capable of capturing images with ground sample distances of 0.31 meters, meaning it can distinguish objects separated by as little as roughly one foot and is easily sufficient for tactical military applications [28]. This specific satellite operates independently, although Maxar Technologies does operate other

older Worldview satellites capable of similar resolutions and a fleet of smaller and lower-resolution satellites providing additional imagery [28].

Table 4. Worldview-3 Satellite Overview. Adapted from [28].

NAME: Worldview-3	
ORBIT: LEO-617 km	
NUMBER: 1	
SERVICE: High resolution imaging with 0.31 m resolution	

Of note, Maxar intends to launch a constellation of LEO satellites called Maxar Legion in 2021 that are capable of 0.29 m resolution with, more importantly, up to 15 overflights of a given region each day [29]. This ability to rapidly image and re-image a location on Earth has significant intelligence value that is increasing demand in both the commercial and government remote sensing customer bases [29]. Most importantly, however, the USG now actively supplements its national ISR capabilities with multiple imaging contracts across numerous vendors to meet increased demand as described in Chapter III.

C. SUMMARY

The commercial SATCOM and ISR industries' collective history and current capabilities both point to the larger trend of continued growth in the commercial space industry. More importantly, however, commercial space-based capabilities are no longer niche services for a handful of customers. Instead, they represent an already massive and growing capability set that are now tactically relevant and heavily relied upon by government users and international actors alike. Therefore, the DOD can no longer ignore

the effects these capabilities have on the modern battlefield. Thus, commercial actors and their systems must be accounted for in DOD wargaming since they collectively now represent the preponderance of space-based capability on the modern battlefield.

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III. REVIEW OF U.S. GOVERNMENT RELATIONS TO THE COMMERCIAL SPACE INDUSTRY

The commercial space industry's relationship with the U.S. government is as old as the industry itself, with a long series of specific interactions, policies, acts, and laws that have steadily shaped the formal relationship of the U.S. commercial space industry with the U.S. government and, by extension, the DOD. This history provides the framework for the predominant pressures and likely courses of actions in the event of conflict in the space domain. Thus, this history weighs heavily on any prospective paradigm relating to the wargaming of DOD reliance on commercial space partners. Therefore, this chapter introduces a brief history of the development of this relationship between the commercial space industry and the U.S. government followed by an outline of their current relations and engagements.

A. U.S. COMMERCIAL SPACE POLICY AND DOCTRINE

As with the historical overview of the development of the commercial space industry, the histories of remote sensing and satellite communications policies are sufficiently distinct to warrant treating them as two separate accounts within this research. Therefore, this introduction starts with the history of U.S. policy for commercial remote sensing then addresses historical commercial SATCOM policy.

1. Historical Context

As previously referenced, the 1984 Land Remote-Sensing Commercialization Act set in motion significant growth within the U.S. commercial remote sensing industry. However, it, along with its revision in 1992, also set the tone for the relations between the USG and the U.S. commercial remote sensing companies with an overture of explicit "promotion" [13]. However, these acts were passed when the best commercial imaging capabilities, such as SPOT-1, were still only capable of 10-meter resolution, thus posing little plausible risk to military operations or national security [21]. Specifically, there were few satellites such as SPOT. This, in turn, resulted in long revisit times on the order of days. Moreover, a lack of onboard storage meant their resolution only covered relatively

small physical areas, making them of limited use at an operational level [21]. Furthermore, dissemination of the imagery could be easily controlled with the internet still in its infancy, a lack of commercial systems, and a relatively small market. However, the increasing capabilities and the first Gulf War precipitated a significant review of U.S. policy and ushered in sweeping changes to these regulations and formal arraignments between the USG and commercial remote sensing companies.

The first major incident prompting new regulations occurred with the onset of the first Gulf War. Specifically, as U.S. military planners conducted the buildup to U.S. operations in the gulf, it became an increasing concern that commercial ISR products and imagery might negate force protection measures and reveal U.S. intentions [30]. The fear was that SPOT-1, the French commercially operated ISR satellite, had no formal obligation to protect U.S. military or national security interests [30]. Moreover, it was known that Iraq had already procured imagery of Kuwait from SPOT prior to its invasion of the country [30]. However, with the onset of hostilities, the "French terminated all sale of the Gulf-related imagery within days of the invasion. Being a commercial venture, the board of directors stated their intent to sustain a non-military image" [30]. Thus, despite the benign outcome, the USG immediately reviewed its policy on commercial remote sensing leading to a sweeping set of changes starting with the National Space Policy Directive 3 (NSPD-3) of 1991.

The NSPD-3 furthered USG commitment to promoting the commercial space industry through its removal of some restrictions on the USG purchase of commercial space products but added that it must be done so "consistent with national security" [31]. Then, in 1992, a much larger policy change occurred with the signing of the 1992 Land Remote Sensing Policy Act. The 1992 Land Remote Sensing Policy Act established, among other things, comprehensive regulation for licensing private remote sensing companies within the United States. More specifically, however, it said that "no license shall be granted by the Secretary unless the Secretary determines in writing that the applicant will comply with international obligations and national security concerns of the United States" [32]. This justification was later expounded upon in the form of a Code of Federal Regulation (C.F.R.) passed in 2000 known as 15 C.F.R. Part 960, which requires a "licensee to limit data

collection and/or distribution by the system during periods when national security or international obligations and/or foreign policies may be compromised" [33]. This policy of the USG restricting commercial operations of U.S. licensed remote sensing companies is now known colloquially as "shutter control" and applies directly to the guiding principles proposed in Chapter IV [34]. However, this legal ability to restrict imaging in response to national security concerns did not dampen broader U.S. commitment to actively supporting the growth of the U.S. commercial space remote sensing industry.

In 2003, the administration of George W. Bush published the U.S. Commercial Remote Sensing Policy, a policy that took a major leap forward in USG support to commercial industry while at the same time complicating future conflict scenarios [35]. Specifically, this policy stipulated that, more than simply supporting the U.S. commercial remote sensing industry through deregulation and investment, the USG would now "rely to the maximum practical extent on commercial remote sensing capabilities" [35]. Moreover, it formalized the stipulations known as shutter control into broader policy by noting that the USG "may require additional controls including limits on use" and "communication link protection measures" [35]. In other words, not only would the USG support the industry, but the United States would also now pursue a policy of formal reliance on commercial products for the execution of official USG operations with the understanding that the USG reserved the right to exercise limits on use to protect national security. However, this policy did not stand alone in this initiative and has taken root in the form of several other policies and initiatives thereafter.

In 2006, the White House Space Transportation Policy committed the U.S. government to "purchas [ing] commercial capabilities and service when they are available in the commercial marketplace and meet United States Government requirements" [13]. This ultimately echoed the 2003 policy and, in a manner more inwardly directed at USG policymakers, maintained the USG commitment to identify new ways to utilize the commercial sector. Lastly, the National Space Policy published in 2010 again committed "U.S. government departments and agencies…[to] actively explore the use of…arrangements for acquiring commercial space goods" [13]. Consequently, efforts such as the Commercial Systems Program Office at the National Reconnaissance Office now

intentionally incorporate commercial space partners and capabilities to augment USG capabilities and use nationally owned systems to, instead, "meet…unique tailored needs" [36]. Thus, in short, by 2010, the USG was fully committed to a policy of direct procurement of and reliance on the U.S. commercial remote sensing industry for unclassified imagery requirements, a reality that, as previously noted, fueled the development of an impressive commercial sector, commercial space capabilities, and an ever-growing marketplace [37]. However, the above policies do not sufficiently cover USG relations with the commercial SATCOM industry, which warrants further discussion.

In contrast to the history of USG relations to commercial remote sensing companies, the history of relations between the USG and commercial SATCOM providers is relatively simple.

Unlike the realm of remote sensing, where U.S. government systems are regarded as the world-leader and ISR applications have undeniable direct applications to national security, communication via SATCOM represents a more ubiquitous, global, and diverse industry with a less-obvious correlation to security issues. Therefore, it should be expected that SATCOM evolution is more a response to market demands and less a product of directed national policy. For instance, prior to the first Gulf War, there were few official policies except the aforementioned policies instructing the USG to promote "to the maximum practical extent" the commercial space industry. Instead, oversight was achieved through participation in regional/international organizations such as INTELSAT, EUTELSAT, and others.[1] Specifically, these organizations, comprised of members from numerous countries, achieved regulation through consensus and provided services to a wide range of customers and governments around the world [38]. Also, this absence of direct investment in commercial SATCOM was driven by a relative lack of demand given that DOD SATCOM requirements were met almost exclusively by the existing military SATCOM constellations launched the decade prior [39]. However, with the onset of hostilities, demand for SATCOM skyrocketed and the DOD immediately set up

[1] Of note, these organizations would later privatize into singular commercial satellite service providers, and their names will refer to the private companies in future references.

sustainment support from a multitude of commercial vendors to include commercial MSS and other fixed commercial satellite communications [38]. Specifically, SATCOM providers such as INTELSAT and INMARSAT provided direct support to Naval vessels, inter-coalition communication links, and supplemental bandwidth for forward deployed commanders. In fact, some estimates place the total commercial SATCOM supply at 50% of the total bandwidth used by coalition forces [38]. Thus, in summary, USG policy toward commercial SATCOM was that of a customer, interested in supporting an industry that it actively participated in and managed through international organizations, for both strategic purposes and tactical necessity. However, this boom in USG partnership with commercial SATCOM saw a second distinct phase with the end of the first Gulf War.

The 1990s and 2000s saw another shift in this relationship as the U.S. military began seeking "supplemental" commercial SATCOM services after realizing that its current military SATCOM systems were not projected to meet even current demand in times of conflict [39]. By Operation Iraqi Freedom in 2003, military SATCOM demand grew to nearly twenty times what it was twelve years earlier [39]. A 2003 United States Government Accounting Office (GAO) report summarized the state of military use of SATCOM by noting that the absence of a strategic structure for procuring necessary commercial SATCOM was leading to inefficiencies that necessitated greater intentional and strategic procurement of such services [40]. Details aside, the report effectively captured the broader reality that the USG was fundamentally a customer working within an industry that was not directly managed by explicit USG leadership [40]. Thus, through the first two decades of the twenty-first century, the USG was fundamentally in the position of a customer in an international marketplace. It was only through the regulation provided by the Federal Communications Commission (FCC) of commercial SATCOM providers servicing customers in the United States that the USG maintained oversight to nominally protect its own national security interests [41].

Thus, although the USG held varying degrees of preeminence within the remote sensing and SATCOM sectors of the commercial space industry, its overall trajectory in this time of robust commercial space industry growth is toward the position of a customer within this international marketplace. With this in mind, the following section briefly

describes the current state of USG laws, doctrine, and policy that currently apply to U.S. licensed commercial space service providers.

2. Current Policy, Doctrine, and Regulatory Framework

Armed with the context of the history leading up to the current relationship between the USG and the commercial space sector, it is now appropriate to evaluate, in order, current USG perspectives, guiding space doctrine, and, finally, an overview of current licensing requirements.

The topic of DOD reliance on commercial systems is currently receiving significant attention at the national level in light of the recent standing up of the USSF. Numerous legislative bodies, civil and military leaders, and policy documents have addressed the issue, and they all echo a similar refrain: the United States must leverage commercial capabilities if it wishes to ensure space effectively supports national security [3], [42], [43]. One example of this organizational direction is seen in the 2020 publication of United States Space Force Vision for Satellite Communications (hereby referred to as Vision for SATCOM). This document outlines the new direction USSF must follow to assure the availability of SATCOM in future conflicts, with emphasis on the means of strategic enterprise procurement. Specifically, instead of focusing on providing the preponderance of SATCOM to meet USG needs, national systems will instead be "purpose-built" to address "those frequency bands, coverage areas, or specialized capabilities not offered by the commercial SATCOM industry" [43]. This has been readily affirmed in public statements by the commander of USSF, General Raymond, who outlined a broader organizational attitude that the line between government and commercial capabilities should be bridged to meet the demands of "the warfighter" [44]. Moreover, recent congressional debates in the build-up to the signing of the Fiscal Year 2021 National Defense Authorization Act (NDAA) yielded a stipulation that the "fencing" of funds would occur unless commercial solutions for space domain awareness were procured [45]. Clearly, although the importance of space domain awareness is not critical to this research, Congress' willingness to withhold funding unless commercial solutions were found further emphasizes the broader commitment to commercial space partnership. Finally, the

Commercial Satellite Communications Office is now operating under the USSF to execute the Future Commercial SATCOM Acquisition (FCSA) program and has, as of March 2020, awarded close to thirty distinct contracts with commercial SATCOM vendors to address capacity shortfalls [46]. In short, Congress, the USSF, and military leadership all echo that commercial space service providers are now indispensable partners in ensuring national security space demands are fulfilled, and this is further revealed by official U.S. policy and strategy.

A complete review of national space strategy lies outside the scope of this summary, but it should be noted that reliance on commercial space systems is encouraged at the highest levels of doctrine, as seen the 2017 United States National Security Strategy down through the 2020 Defense Space Strategy [3], [47]. However, a significant extension of this policy warranting further discussion is seen in the 2020 Defense Space Strategy (DSS) in the form of a formal commitment in return for strategic partnership with industry. Specifically, the DSS states that, for the United States to "maintain space superiority," it will "be prepared to protect and defend U.S. and, as directed, allied, partner, and commercial space capabilities" [3]. In other words, the DOD is now willing to engage in the active defense of critical commercial space assets to preserve their capability in a time of conflict. This commitment cannot be overemphasized because it directly shapes the realm of likely scenarios when wargaming DOD's dependence on commercial space assets. Therefore, future analysis must account for a desired adherence to a defense posture that includes commercial partners throughout the spectrum of armed conflict, a point that is discussed in greater detail in a later section.

Lastly, it is worth looking at how the above attitude and doctrine are enumerated in current regulation and licensing practices. Currently, commercial remote sensing is licensed through NOAA and commercial SATCOM is licensed through the FCC [48], [49]. However, both licensing processes are vetted against the combined interests of the Departments of Commerce, State, Defense, Interior, and the Office of the Director of National Intelligence. An example of how this is applied is seen in a memorandum covering the licensing of "Private Remote Sensing Satellite Systems." The policy specifically states that "The Secretary of Commerce will impose constraints on private remote sensing

systems when necessary to meet…foreign policy concerns, and/or national security concerns of the United States" [50]. In other words, not only will companies actively contracted to support the USG be subject to restrictions on their use, but rather all remote sensing commercial ventures licensed in the United States must conform to the security interests of the USG when seeking licenses in the United States.

Thus, in summary, the current state of USG relations with the commercial space industry is one of intentional engagement across a wide range of technological fronts. This engagement is propelled forward by USG security interests that are intrinsically linked to the successful incorporation of commercial capabilities into national security space efforts. This relationship is further enhanced by the recognition that the commercial space industries' willingness to engage in explicit support to U.S. defense efforts brings with it an obligation to defend those assets in a time of conflict. Moreover, it is a commitment that heavily shapes the wargaming guiding principles and wargaming methodologies.

3. Current DOD-Commercial Space-Reliance

Finally, the following is a representative list of current DOD-awarded contracts to commercial ISR and SATCOM companies that provides a baseline for wargaming commercial space representation. This list is, by no means, exclusive, but it does show the range of current purchasing initiatives that represent the scale of DOD and USG utilization of commercial space service vendors. Recall that these contracts leverage the range of commercial SATCOM and ISR capabilities covered in Chapter II.

- On November 24, 2019, "Iridium Satellite LLC [was] awarded a $9,378,867 [contract] to support commercial satellite-based network services for the Department of Defense (DOD) in the areas of satellite, ground node, user equipment/terminal software and hardware development, integration and testing" [51].

- On June 18, 2020, the "U.S. Space Force Commercial Satellite Communications Office (CSCO) awarded Peraton… a $56 million contract under the Future Commercial Satcom Acquisition (FCSA) program… for the U.S. Central Command (CENTCOM)." [52]

- On September 15, 2016, it was announced that "Inmarsat Government in Reston, Va., will provide a variety of commercial SATCOM telecommunications to the U.S. military under terms of a potential $450 million contract." [53]

- "The Pentagon's commercial satellite communications (COMSATCOM) office will release a final proposal request next April for a potential 10-year, $1 billion contract to provide the Navy's broadband enterprise satellite services, with plans to award a contract in October 2020." [7]

- "SES Government Solutions and Isotropic Systems have received an antenna evaluation contract with the U.S. Air Force Research Laboratory to test Isotropic Systems' multi-beam terminal over SES's O3b Medium Earth Orbit (MEO) constellation." [54]

- On March 3, 2020, Peraton announced it "[had] been awarded a $218.6 million contract to provide commercial satellite communications services for the United States Africa Command (AFRICOM)." [55]

- On October 21, 2016, Planet announced "[it had] just signed a landmark agreement with the National Geospatial-Intelligence Agency, the U.S. government's source of geospatial intelligence" to provide imaging services and products. [56]

- On October 15, 2019, it was also announced that "the NRO awarded Planet an unclassified, multi-year subscription service contract for daily, large-area, 3–5 meter resolution commercial imagery collection." [57]

By no means is this list complete, but the scope of providers, services, and relative recency of the initiatives further supports the assertion that U.S. national security is now a ready customer of commercial space-based SATCOM and remote sensing products and is already heavily dependent on their services.

B. SUMMARY

In summary, the relationship between the USG and the commercial space industry has certainly adapted over the years to account for the preponderance of capability now found in the commercial sector. However, and more meaningfully, the relationship is now well defined by rules, regulation, policy, and defense commitments that show that the contracted commercial sector is now well established and a trusted member of the broader U.S. remote sensing and communications construct. It is this fact that now opens the door to the notion that the commercial sector may be held at risk by an adversary to the United States in times of conflict, a reality that now drives the identification of guiding principles and wargaming methodologies.

IV. SPACE CONFLICT AND GUIDING PRINCIPLES

Armed with an understanding of DOD-commercial space relations and reliance, the challenge of modeling these interactions must now be addressed. However, prior to constructing wargaming methodologies, we must first identify the unique dynamics and ensuing guiding principles bounding DOD reliance on commercial space during times of conflict. To identify these attributes, this chapter starts with a brief introduction to the space domain and space conflict. Then, more specific commercial space reliance considerations during times of conflict are identified and summarized into key guiding principles for incorporation into the proposed wargame design covered in the next chapter.

A. THE SPACE DOMAIN AND SPACE CONFLICT

To better understand the pressures and challenges on commercial space operators during hostilities, the most important attributes of their context, the space domain and space conflict, must first be introduced. The space domain and its distinction from terrestrial domains of conflict has received considerable attention over the past two decades from the DOD and cannot be exhaustively covered here. However, several key attributes must be reviewed to add context to a discussion of space conflict and to the challenges and physical constraints faced by commercial space operators.

1. The Space Domain

First, the perpetual physical motion of orbits is a major distinction from terrestrial domains. For instance, the motion of on-orbit satellites is inherent, continuous, and, for most orbital regimes, causes them to routinely transit over multiple borders and regional boundaries. Typical orbits range in altitude from approximately 250 km for low earth orbit (LEO) satellites all the way to 36,000 km for geosynchronous (GEO) satellites. Additionally, some orbits extend even further out into cislunar space between the Earth and the Moon, but the orbits of interest for this research are limited to LEO through GEO. Furthermore, orbital velocities are measured in thousands of kilometers per hours, and orbital periods range from around ninety minutes to twenty-four hours or more allowing some satellites to circle the earth multiple times a day while some remain fixed overhead.

Thus, orbits and their physical attributes are not singular in their properties and span a wide range of velocities, altitude, characteristics, and temporal considerations. Therefore, wargames modeling satellite orbits must account for this variety when representing on-orbit constellations with particular emphasis on temporal and location attributes when attempting to model a satellites availability to a specific terrestrial region.

Given this brief introduction to the varying orbital attributes in the space domain, a discussion of key terrain is now appropriate. Given the wide range of orbital regimes, their different properties lend themselves to a variety of applications with some being more suited for certain applications than others. One example is a geosynchronous orbit located around 36,000 km from Earth at such a distance that it orbits the earth every twenty-four hours. Therefore, it maintains its relative position to the earth and effectively stays above a single terrestrial point so long as it is maintained at that orbital location. This relatively stationary position makes it convenient for communication applications given that ground antennas do not typically need to track the satellite throughout the day to remain pointed at the satellite. However, its large distance from Earth makes imaging from a geosynchronous satellite less appropriate unless one is attempting to take low resolution pictures of a large portion of Earth, a utility more suited for weather monitoring than for tactical intelligence. Meanwhile, a LEO orbit, given its very low orbital altitude, might lend itself to an imaging satellite taking advantage of the low altitude to produce high resolution imagery or sensing. However, utilizing the same orbit for communication brings with it the potential need to track the satellite, especially if using a directional antenna. In short, the range of applications, constellation designs, and potential orbits are too numerous to fully cover, but they are well summarized in Table 5 taken from the Joint Doctrine Publication for Space Operations, JP 3-14.

Table 5. Orbital Regimes and Applications. Source: [58].

Orbit Type and Characteristics				
Type	Description	Advantages	Disadvantages	Applications
Geosynchronous Earth orbit	Roughly circular ~23,000 miles above Earth's surface	Continuous coverage over specific area Coverage nearly hemispheric	Far from Earth - resolution and signal limitations Easier to jam signal latency	Communication Surveillance Reconnaissance Weather collection Missile warning
Highly elliptical orbit	Long ellipse ~600 miles at perigee (closest to Earth) ~25,000 miles at apogee (farthest from Earth)	Long dwell time over a large area Coverage of high North or South latitudes	Continuous coverage requires multiple satellites	Communication over high North or South latitudes Scientific Surveillance Reconnaissance Missile warning
Medium Earth orbit	Roughly circular Between ~1,000-22,000 miles above Earth's surface	Stable orbit Less signal latency	Highest radiation level environment	Positioning, navigation, and timing Communication
Low Earth orbit	Roughly circular Up to ~1,000 miles above Earth's surface	Near Earth - high resolution and signal strength	Small coverage area over Earth surface Limited coverage windows for any specific geographic region	Surveillance Reconnaissance Weather collection Manned space flight Communications

Table 5, from JP 3-14, summarizes typical orbital regimes and their common uses. Of note for our analysis are the LEO, MEO, and GEO orbits used by the four example satellite constellations described in Chapter II.

Lastly, it is important to note that satellites are usually exceptionally expensive and always relatively expensive to build and launch. Satellites range in size, but example costs for satellites like those discussed in Chapter II typically range from $4,000 to $14,000 per pound, or total costs ranging from $10 million to $300 million [59]. Moreover, servicing a satellite is extremely complex and rarely done due to the cost and reality that most satellites are not designed for on-orbit servicing [60]. Therefore, failures, whether intentional or accidental, usually have significant and irreversible effects, and may render the satellites or individual payloads inoperable. Moreover, even small collisions with space debris or other objects at orbital speeds likely mean total loss of the satellite. All these factors combine to demonstrate that operating satellites in space is expensive and predicated on undisturbed operating conditions to allow for continued operation. Additionally, anomalies or failures can typically only be addressed by what already exists on the satellite in the

form of redundancy and troubleshooting capabilities. Therefore, in summary, space operations are inherently complex, expensive, and sensitive to outside interference. With that said, it is now appropriate to review the classical framework for space conflict.

2. Space Conflict

Space conflict is, for the purpose of this research, defined as any direct or threatened act of aggression toward space-related assets or space providers. These actions may come from a variety of actors across the full spectrum from criminals to nation-states. They may be openly threatened by words or preceding actions, or they may not be discovered until well after an attack is executed. Moreover, they may be permanent in their effects or entirely reversible. Regardless, acts of aggression in space span across a wide spectrum that can have both intentional and unintentional consequences both in the space domain and terrestrially. To this end, these acts of aggression, their impact, and their reversibility are commonly summarized based on severity and reversibility, as shown in Figure 1.

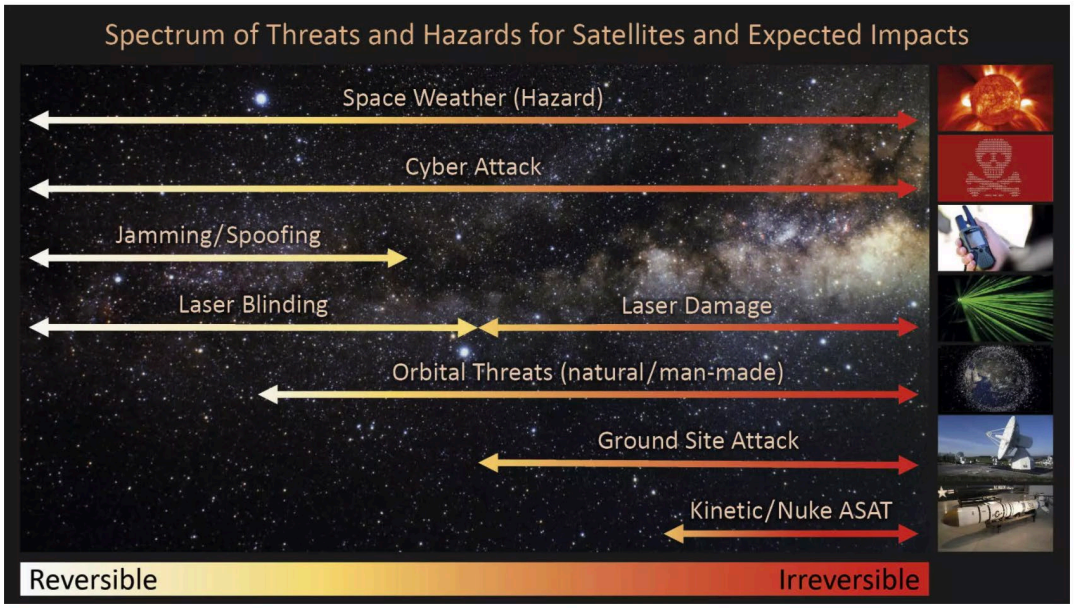

Figure 1. Spectrum of Space Conflict. Source: [61].

Figure 1 shows the relative level of reversibility along the bottom and a sampling of the kinds of threats faced by on-orbit objects. In this instance, reversibility is analogous to lethal and non-lethal effects often used to describe fires in other combat-related contexts. Additionally, one must note that not all threats are readily available to all actors as some require higher degrees of technical capability and/or developed launch systems to place an object in orbit. One example would be a kinetic anti-satellite weapon, also known as an ASAT weapon, or nuclear payload that requires launch and control capabilities not possessed by many nations. Moreover, "cyber-attacks" are shown as covering the full spectrum of reversibility because their effects can vary widely. However, cyber-attacks also pose a significant risk because they can potentially be executed by a wide range of actors to achieve unanticipated and asymmetrical consequences. These kinds of attacks are often hard to detect and attribute, factors that make them desirable depending on the intended outcomes of the attack. Lastly, some forms of attack are inherently directed at a specific target while others have indiscriminate effects on many targets regardless of ownership, purpose, or nationality. An example of a directed attack might be a jammer used against a certain uplink or downlink channel on a single satellite, while a kinetic kill ASAT, although initially directed at a specific target, may cause massive amounts of debris that affect numerous orbital regimes for days to years afterwards. Thus, in summary, potential threats to on-orbit systems span a large spectrum, varying in their degree of reversibility, and spanning the full range of isolated to indiscriminate.

Secondly, space conflict is also characterized by the objectives of the competing parties. More specifically, when considering conflict in space, it is important to characterize the desired objectives of the parties involved. For example, a space power such as the United States may have the objective of maintaining the welfare of its military space assets and commercial space assets alike due in part to its military dependence on these systems, but also on the strategic, scientific, and economic importance of the space domain itself. This is easily ascertained because it aligns with stated national policy [3], [62]. Thus, by extension, the United States may pursue courses of action and responses to situations that maintain the future viability of the space domain or account for other non-defense-related factors. However, in contrast, state actors that are less dependent on space

or who wish to degrade another nation's space capabilities, may pursue more intentionally destructive courses of action that maximize both the immediate and long-term impacts. Now, these examples should not be mistaken as dictating responses in every tactical situation, but rather provide brief examples of how objectives can shape which acts of aggression a space actor may pursue or avoid. With this perspective, it is now worth considering some of the tools space actors can use to mitigate threats to their assets.

Space capabilities that enable protection from adversaries are typically called defensive space control (DSC) capabilities [58]. These capabilities can range from passive efforts such as built-in protections or redundancies all the way to maneuvers to prevent engagement or changes of satellite configuration to prevent the degradation of a sensor [6]. Of course, the nature of specific protective systems or techniques are typically closely held and classified, but the emphasis is less on their capabilities, which are ever evolving, and more on who typically makes use of them: state actors. As seen earlier, space design, construction, and launch are expensive. Therefore, added systems or capability such as additional maneuverability or other self-protection measures are not typically found on commercial satellites because they translate to additional weight and costs that undercut profit and have limited application for a non-combatant. Meanwhile, a state-actor designing a military satellite will incorporate these features from the beginning with the expressed intent of use in a contested environment. However, since this is discussed at length in the following chapters, further analysis must wait. Instead, it must simply be noted that not all space actors have the capability, necessity, or desire to equip themselves with tools to protect themselves from traditional space threats, especially commercial actors. This reality has far reaching implications for strategies, tactics, modeling, and wargaming, and heavily influences this discussion of commercial-specific considerations and guiding principles.

B. THE COMMERCIAL PARADIGM

As we have seen in the history of commercial space, its relationship to the DOD, and in the classical thought on space conflict, there exists a division of paradigms between competitive space powers and traditionally non-combatant commercial actors in space. This bifurcation of the status of space actors is a false, if understandable, projection of

historical delineations between combatants and non-combatants seen in more classical combat domains. However, with the blurring of these lines brought about by DOD's contracting of commercial SATCOM and remote sensing to augment the U.S. national military establishment, it is now time to identify what uniquely commercial considerations heavily influence how commercial actors will respond when threated during times of conflict. From these, new vectors of influence are identified that will guide the development of the guiding principles.

1. Unique Attributes of Commercial Space

Ultimately, discerning the guiding principles governing commercial space reliance hinges on the characterization of a uniquely commercial paradigm common to commercial space actors. More specifically, there exist considerations for commercial actors pursuing business goals that are not common to the typical perspective of military planners charged with the mission of national defense or prevailing in times of conflict. These considerations are the byproduct of the reality that commercial actors are, at least partially, accountable to their own solvency and, by extension, their investors and customers. Failure to account for this in the long term obviously has significant impact on a come and may, ultimately, results in dissolution. This stands in contrasts to state actors who do not face insolvency if they fail to maintain functioning space-based capabilities. Therefore, it is unsurprising that companies are, to varying degrees, subject to a common set of constraints in their decision making that stands apart from traditional considerations for state actors. This research identified four facets of this overarching self-interest that are uniquely commercial in nature, listed below:

1. Relations with customers
2. Relations with regulators
3. Current business model
4. Future commercial viability

Elaborating on these, the first consideration, relations to customers, is the need for a company to maintain a customer base willing and able to purchase their services or

products. This customer base is characterized by the consumer's willingness to buy a service or product and by the size of the customer base. Additionally, a customer base may consist of either civilian or government buyers, and a company's relationships to both affect their willingness to purchase said services or products, directly affecting sales and profitability.

Secondly, a commercial actor must consider their relationship to regulators who allow access to these customers through the exercising of many of the regulatory processes described in Chapter III. A failure to ensure good working relationships to regulators can, therefore, negate access to customers, which then further affects sales and profitability. On the contrary, newly improved relations with foreign regulators might also increase access to customers not previously reachable. Either way, the ramifications of this commercial consideration directly influence commercial decision making and are, therefore, a necessary inclusion as a central tenet of the commercial paradigm.

Third, commercial actors must preserve their business model, which manifests itself in the physical hardware in orbit and on the ground, and in the type of product being delivered. With regard to the on-orbit assets, and given the aforementioned expenses associated with establishing these systems on orbit, commercial actors view their assets as critical and, in many instances, irreplaceable lynchpins in their business model. Therefore, any potential loss of these systems could render a company unable to execute their basic business model for months or years depending on the type of loss. Additionally, any potential harm to their ground systems or, especially, their satellites are potentially devastating. Ultimately, the loss of the physical means to execute a business model is a massive loss that may not be recoverable in the short term. Physical assets, especially on-orbit assets, thus represent strategic investments for the company and often represent capital investments that are difficult to replace despite being insured in most instances. Therefore, there is significant motivation to avoid unwanted interference with these assets, especially if the company can influence the situation to avoid such losses. Likewise, restrictions on the types of services being provided or the means of how these services are being provided, such as a policy like "shutter control" can have equally damaging effects on a business model, though these affects would likely be more reversible if the restraints

were removed. Thus, the current business model also must be accounted for as a primary consideration within the commercial paradigm.

Lastly, commercial actors must also consider future commercial viability. Although this consideration appears to be a combination of the first two principles projected out into the future, it is in fact distinct and fundamental. Specifically, while the first two facets account for the current pressures faced by a company, they are also predominantly external pressures that influence whether a company is able to do business and remain profitable. In other words, access to markets and the well-being of physical assets are predominantly affected by external actors imposing risks on the decision makers of a company. Future commercial viability is, however, concerned with a commercial company's willingness to engage in servicing its existing customers in the future, a decidedly internal choice that is not the direct product of an external actor's pressures. Specifically, a company might cease its engagement with past customers to grow a new customer base, an internal choice in pursuit of profitability, security, or other internal ambitions. For example, if a commercial company does not believe its current customer base, which includes the DOD within the context of this research, is sufficient in either scale or profitability, the company may choose to no longer offer these services to the DOD in favor of more lucrative endeavors. This is not to say that this concept is divorced from the concepts of access to markets and a company's business model, but it is to say that companies have a vision for their future business model that is the product of internal ambitions and not strictly a reaction to external pressures. This might manifest slowly, but it certainly is an influencing consideration for commercial actors when considering their own actions in times of conflict.

In summary, although these considerations cannot be uniformly applied to each situation, each company, in its own way, must consider all four of these constraints, thus characterizing the additional factors unique to the commercial space paradigm. These factors heavily influence how a commercial actor might respond in times of conflict to either directed aggression toward them specifically or to broader concerns about hostility in the space domain. In doing so, they present newly identified vectors to influence commercial actors, a reality warranting more discussion in the following chapter.

2. Commercial Considerations as Avenues of Influence

The threats posed by these new vectors of potential influence on commercial actors must be considered in addition to the more classical threats affecting space-related systems seen in Figure 1. This list is not meant to be exhaustive. Rather, it must simply be noted that several new categories of threats are revealed that are especially pertinent to commercial actors, starting first with influencing a commercial actor's ability to do business.

a. Relations to Customers and Regulators

It was previously shown that a commercial actor's relations to customers and regulators had profound effects on their ability to execute its business model. This influence was achieved by taking away, redirecting, or increasing a company's access to willing customers. In light of this, the following new threat vectors for influencing these relations are revealed:

- Adversaries may attempt to leverage control or access to markets to deny access to traditional customers through laws or regulations. Conversely, adversaries may promise or ensure expanded access to new markets in an attempt to influence decision makers. The objective would obviously be to curtail a commercial actor's support of DOD operations by imposing costs on business operations within an adversary's political boundaries for the company in question or provide more lucrative opportunities elsewhere.

- Adversaries may utilize taxation, fines, or threatened legal action, both justified or unjustified, to further dissuade a company from supporting DOD efforts.

- An adversary may attempt to alter a customer base by directly threatening significant customers of a commercial company with related sanctions, fines, or other punitive acts to dissuade customers from engaging in business with a specific commercial actor.

- Adversaries may also attempt to strategically purchase all available SATCOM resources being offered from commercial satellites in key orbital positions in GEO to deny USG procurement of services.

As an example of this kind of threat, the United States leveraged the same style of influence as recently as July, 2020, when it sanctioned eleven Chinese companies for ties to human rights violations. Specifically, these Chinese companies were prohibited from accessing American goods and technology, which, in turn, dissuaded American companies from doing business with these eleven Chinese suppliers [63]. In short, a nation dissuaded commercial companies from conducting business with China by denying access to China's markets through sanctions. More directly applied to commercial space reliance, this might occur as a restriction to customers or frequency bands for a SATCOM provider within a country or outlawing the purchasing of imagery from a remote sensing company. Regardless, these examples show that commercial actors supporting the DOD must be ready to face both the political and financial challenges of heavily altered access to markets if its customer base is diversified across multiple regions or is, in part, regulated by an adversary.

b. Current Business Model

Secondly, it was shown that commercial actors' solvency is a direct product of its maintenance of its business model, both from a physical and service perspective. Therefore, an adversary seeking to directly influence the immediate decisions of a commercial actor may hold at risk a company's assets or threaten the denial or destruction of its physical assets or means of providing service as seen in the following examples:

- An adversary may threaten an attack on a satellite. This attack may be reversible or permanent, and it may be executed through either physical or cyber means.

- Attacks can also be wrought against ground infrastructure, which, depending on the architecture of the space system, may also represent significant investment or be fundamental to the service itself.

- Lastly, an adversary may attack the means of distribution of a service, whether it is through a website or user terminals. Either way, the flow of information or a channel for service may be disrupted.

One example of this threat vector was the aggressive proximity operations conducted by Russia against Intelsat as reported in 2015 [64]. Although no harm was done to these assets at the time, the active rendezvous and proximity operation against two Intelsat satellites in GEO highlighted how little Intelsat could have done to directly respond to this potentially destructive act. Additionally, as early as 2014, it was reported that the Chinese military was directly targeting "US satellite partners," clearly imposing an additional direct cost on U.S. commercial space providers [65]. Ultimately, attacks like these are more direct than broader, relationship-focused acts of aggression. Therefore, they are more suited to immediately affect commercial decision makers with the likely intent to cause an operator to voluntarily shut down its operations and, thus, contractual support to the DOD. Furthermore, these forms of attack can be directed, in general, at all SATCOM or remote sensing satellites with little distinction. Thus, in summary, commercial actors are not immune to attacks on its business model, and, in fact, may be the least prepared to counter such moves because of the previously noted limited assets and defensive counter space capability.

c. Future Commercial Viability

Lastly, it was shown that a company must account for its future commercial viability, a reality that, for the purpose of this research, is a product of internal ambitions and systemic challenges instead of threatened hostile acts. This type of consideration, as distinct from threats of denial of access to markets or future imposed regulation, is best explained via the following examples:

- If a company can be led to believe its current business model will cease to exist post-conflict due to significant orbital debris resulting from conflict or other systemic problems, it may terminate otherwise historically profitable contracts. Instead, they may choose liquidation or other operational concepts to remain profitable in the long term.

- If a company believes the commercial space industry is in rapid decline due to significant policy changes, regulation, or conflict, it may choose to diversify its operations and/or curtail its services, even if said policies or regulations are not specifically directed at the company.

An example of this kind of consideration is harder to come by, but there exist parallels with the Battle of the North Atlantic during World War II. Specifically, open submarine warfare on shipping quickly demanded the need for military escorts of directly subsidized or nationalized shipping [66]. In other words, a domain, the ocean's surface, was denied to unprotected commercial actors supporting national military goals, which necessitated the immediate intervention by the state to ensure continued service. In short, commercial actors are also responsive to their own confidence in their future viability. Thus, it becomes necessary to appreciate how the DOD must account for collateral damage to the space domain's usability or to the space industry as a whole. Affecting these broader domains can have long-term effects on the availability of commercial operators in the future, even if those effects are not immediately felt.

In summary, these new vectors of attack provide a thorough basis for identifying guiding principles inherent in DOD reliance on commercial space actors. Therefore, it is now time to identify the guiding principles that are used as a summary of these identified commercial considerations and ensuing attack vectors.

C. GUIDING PRINCIPLES

In light of the above identified vectors for influencing commercial actors providing services to the DOD, the following six guiding principles are deduced which serve as the basis for the creation of wargaming methodologies:

1. Assets may hold strategic value to commercial partners: It was shown that commercial assets represent strategic investments of both time and money, and they are lynchpins of a commercial actor's business model that cannot be quickly replaced. Therefore, unlike the DOD, which may view a capability as strategic supported by tactical components, commercial actors potentially view their assets as strategic to their business model.

Therefore, a commercial actor can be influenced greatly by adversaries holding their assets, both ground and on-orbit, at risk.

2. Market access cannot be assumed and may be leveraged: Markets are, as previously shown, heavily regulated. Moreover, the DOD often represents only a fraction of a given commercial actors' customer base. Therefore, markets must be seen as a point of leverage against either the commercial actor's profitability or against the DOD's position as a customer. Access to willing markets is, therefore, a powerful tool in shaping a commercial actor's willingness to lease its services to the DOD. Likewise, restricting or increasing access to these markets also weigh heavily on the business calculus of a commercial vendor seeking to ensure profitability.

3. Current and future profitability must be protected: Commercial actors are accountable to their own profitability, and therefore cannot be expected to pursue courses of actions that knowingly sacrifice their sources of revenue. Moreover, if market conditions degrade or the space domain becomes unusable, commercial actors cannot be expected to continue to provide services if they cannot support business operations.

Additionally, there are also three implied considerations that are not specific to a singular commercial vector of influence but that also deserve inclusion into our list of guiding principles as outlined below:

4. Company stakeholders must be known and accounted for: The effectiveness of the identified attack vectors is at least partially dependent on a company's allegiance. This allegiance can be a product of a customer base, registration, or, more importantly, the national identity of key decision-makers. Therefore, threats to space partners must always be viewed in light of a company's demonstrated allegiance, registration, and customer-base nationality.

5. The existence of undisclosed influence must be acknowledged: In much of the above discussion, interactions in the forms of coercion, threats,

commitments, and informal agreements were discussed as if they were known by both DOD and commercial actors real-time. However, it must be acknowledged that communication is often directed and may not be readily available to all parties, whether intentionally or unintentionally. Therefore, any wargaming of these scenarios must account for limited or delayed proliferation of awareness when acts of aggression in the form of communication are used.

6. Proliferation complicates capability denial: Lastly, the proliferation of commercial space systems challenges unilateral actions in the space domain. U.S. government attempts to curtail commercial actions to support DOD security interests will be undermined by the reality that foreign-registered companies often possess similar capabilities and are not responsible to DOD or USG direction. However, this same proliferation makes it difficult for an adversary to "blockade" the commercial reliance of another country's military given the interconnectedness of multiple international sectors of communication and business [6]. In other words, directed denial of space-based services to degrade an opponent's military will be hard to achieve without inadvertently affecting numerous industries on an international level resulting in significant collateral effects.

D. CONCLUSION

In summary, this chapter introduced the basics of the space domain and space conflict. Then, key commercial considerations were identified, which, in turn, revealed many new forms of influence that are especially effective against the commercial paradigm. Then, in light of these forms of attack and influence, the overarching guiding principles were identified that must form the foundation of attempts to model and wargame DOD reliance on commercial space. Now, wargaming methodologies can be created that are guided by these principles, an effort covered in the following chapter.

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V. PROPOSED METHODOLOGIES FOR WARGAMING COMMERCIAL SPACE RELIANCE

With a commercial paradigm and guiding principles established, it is now necessary to develop methodologies that enable the application of these principles to the discipline of wargaming. However, given that the craft of wargaming spans a large spectrum of purposes, users, formats, rules, applications, and interfaces, it is necessary to first define wargaming and, specifically, how it is commonly utilized by the Department of Defense. Therefore, this chapter introduces and defines wargaming as it pertains to this research and its utilization within the DOD. Then, based on this context, the intended style of wargame used for this research is identified. Finally, a set of wargaming methodologies are proposed that enable the application of the guiding principles to the selected style of wargaming.

A. WARGAMING INTRODUCTION

Wargaming historians typically trace wargaming's direct application to military planning back to the Prussian *Kriegsspiel*, literally translated "war-game," of the 1820s [10], [67]. Since then, it has been used in a wide range of analytic, educational, and experiential activities ranging from tactical scenarios to instruct small units all the way up to operational and strategic planners considering campaign analysis at the highest levels. To that end, the design of wargames varies greatly based on several factors including their purpose, information structure, level of detail, and target audience. However, this diversity also produces a wide range of definitions and terminologies that obfuscate this discussion unless explicitly defined and scoped. Therefore, for the purposes of this research, a "wargame" will refer to a "representation of conflict or competition, in which people make decisions and respond to the consequences of those decisions" as defined by *Joint Publication 5-0: Joint Planning* [68]. However, beyond this definition, it is also important to further distinguish the discipline of wargaming from the discipline of modeling and simulation (M&S), especially in light of the growth of computer-based analytical tools available today, which are often conflated with wargaming.

Specifically, wargaming is distinct from modeling and simulation in that it seeks to understand the human decision-making process vice quantifying the relative value of different force structures or technologies. For instance, a study using M&S seeks to compare the operational effectiveness of alternative force structures, which, in simpler terms, is an assessment of how well a force fights. Alternatively, a study leveraging wargaming seeks to develop concepts of employment or concepts of operation that allow a commander to test the effectiveness of new doctrine or determine how to best leverage new technology. In other words, it seeks to determine how a force fights. To that end, this thesis's recommended wargaming methodologies improve the representation of DOD reliance on commercial space partners and assets. This improved representation enables warfighters to better understand and evaluate what effects any potential unavailability of these assets might have on the planning and successful execution of military operations. However, to suggest revised methodologies for modeling DOD's reliance on commercial space partners, a style of wargaming must first be identified that will provide greatest benefit to the DOD wargaming community. Thus, it is worthwhile to briefly review the range of DOD wargaming efforts.

B. DOD SPACE WARGAMING

A full review of DOD wargaming practices is outside the scope of this research. However, several organizations such as the Center for Naval Analysis (CNA) and RAND Corporation provide useful reviews and support to the DOD wargaming community [9], [69], [70]. To that end, this brief discussion of DOD wargaming relies heavily on a 2019 report by RAND Corporation titled *Next-Generation Wargaming for the U.S. Marine Corps*. This research "gather [ed] information on the tools, approaches, best practices, and other lessons learned from a wide variety of organizations involved in defense or national security wargaming, in order to make recommendations to the U.S. Marine Corps as it [sought] to expand its wargaming capability" [9]. This research compiled overviews of 21 organizations within the DOD wargaming community. From this analysis, it also identified 77 unique wargaming tools ranging from basic tabletop boardgame-style wargames to advanced computer simulation tools. However, it also noted that "manual board game mechanics" were exceptionally prevalent within DOD wargaming because this

style “imposed processes on gameplay and adjudication, making the outcomes of player decisions more transparent and easier to document” [9]. Dr. Appleget notes this same theme in *The Craft of Wargaming, A Detailed Planning Guide for Defense Planners and Analysts*, which discussed the important role of “analytic wargames” in military applications because of their suitability for organizing the “scenario,” “data,” “rules,” “players,” and “analysis” [71]. Furthermore, *The Craft of Wargaming* describes their distinguishing characteristic as their intent to “[seek] answers” to a “sponsor’s problem,” and possessing an “objective,” which makes them well suited for military applications. However, analytic wargames should not be thought of as uniform given that they may utilize a spectrum of “styles,” “player engagement formats,” or other widely varying traits [71]. This thesis, therefore, develops methodologies that are presented according to two separate spectrums that, together, provide maximum applicability across a range of analytic wargames as discussed in detail the following section.

The first spectrum utilized is the Level of Warfare. This spectrum is utilized because military wargames are often directed at a specific level of warfare and recommended injects to one level of warfare may be of little value to another level. Therefore, to maximize the utility of these wargaming methodologies, recommendations are presented along this spectrum. Next, the spectrum of “information structures” is used as the second variable [71]. *The Craft of Wargaming* described information structures as taking one of two forms: open or closed. Open wargames allow for the game information to be equally available to all players involved while closed wargames restrict the availability of this information to certain players at certain times. Thus, in a closed format wargame, “each player will only be provided the information that their collection assets could reasonably be expected to obtain and report” [71]. Moreover, closed format wargames typically “require separate rooms for each team represented, as well as a white cell or control cell that maintains the ‘ground truth’” [71]. This method was, thus, selected because the guiding principles highlight the role directed communications play when evaluating DOD’s reliance on commercial space-partners. However, the full spectrum of open and closed format wargames is used to maximize utility to as many DOD wargame applications as possible.

Armed with the context of a selected wargaming style, it is now appropriate to synthesize our commercial paradigm and guiding principles into recommended wargaming methodologies, which are divided into both construct and execution recommendations.

C. GAME CONSTRUCT RECOMMENDATIONS

To apply the commercial paradigm and guiding principles to analytic wargames, the wargame must first incorporate them into its design. Specifically, the wargame's measurement space must accurately represent commercial space actors and their interactions with the DOD. Then, through this improved game setup, gameplay mechanics are refined to better incorporate the guiding principles and, ultimately, facilitate more consistent and accurate environments to examine player decision-making. Therefore, to begin, the following recommendations are made specifically to game construct.

1. Representation

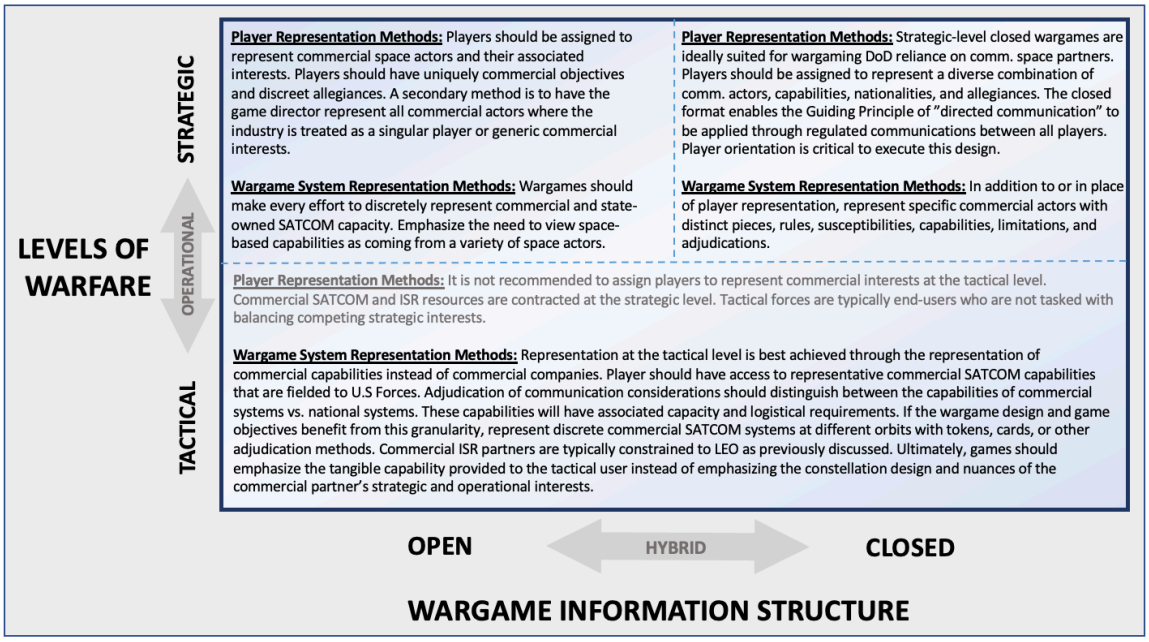
First, this thesis shows that commercial interests, goals, and ambitions are unique enough to necessitate inclusion into wargames that evaluate objectives associated with SATCOM and space-based ISR. Therefore, it is critical that these wargames start incorporating commercial space through representation in the game construct. However, the means of representation vary greatly and cannot be prescribed due to the wide range of wargame designs and objectives. Examples of representation might manifest as players representing commercial space partners, game pieces, rules, adjudication techniques, or general player education before a game to name a few examples. Although each of these examples cannot be typified fully, the following recommendations can be made based upon the guiding principles that relate to under-represented facets of DOD's reliance on commercial space partners.

Ideally, a wargame should incorporate all pertinent commercial actors, each provided with their own unique company and associated interests. This is based upon the commercial paradigm that illuminated the competitive nature of commercial interests which must account for profitability and solvency. Players representing commercial actors are not a requirement, but wargames should represent these actors and their interests if appropriate for their wargame objective and key issues. It is preferable that, if multiple

commercial companies can be represented, some should be more closely aligned with either allied or adversary nations to represent the scope of allegiances inherent in the commercial space industry. This recommendation to account for allegiance is shown in the commercial paradigm and guiding principle two and four. Likewise, their business models should reflect this allegiance in the form of customer bases, revenue sources, and relations to national regulatory bodies that are distinct. Moreover, commercial actors are typically aligned with traditional customer nations, contractual obligations, or national heritage. Of note, not all details such as these are appropriate for all wargame designs and objectives. Instead, the wargame designer must identify the ideal means of representation to achieve their intended objectives. However, the following example means of representation are provided to demonstrate potential tools that can be molded into relevant injects for a variety of wargame designs.

The following examples are broken down by levels of warfare and the spectrum of wargame information structures. Table 6 specifically shows the recommended injects, suggested wargame objectives, and drawbacks for ends of both spectrums.

Table 6. Commercial Representation Aid



Ultimately, the manner of inclusion remains the prerogative of the wargame designer. Regardless, representation of unique and competing commercial space entities establishes more accurate portrayals of the competing interests inherent to DOD's new method for sourcing space-based capabilities.

2. Orientation

Secondly, representation of commercial actors and interests, whether by players, game pieces, rules, etc., requires an orientation to the paradigm being represented. In other words, if DOD participants are representing a commercial actor in a wargame, they require an introduction to the unique perspective of commercial space actors to represent their contributions and perspectives accurately. Similarly, if commercial actors are represented through gameplay mechanics, pieces, or rules, then those players that interact with those injects must also be oriented to the commercial paradigm to understand the unique qualities represented. This orientation should include both an introduction to the commercial paradigm and to the common factors affecting a commercial actor's decision making, namely the guiding principles. Specifically, this orientation should cover the following relevant information that enables accurate portrayal of commercial space actors if a high degree of granularity is desired by the wargame designer and objectives:

1. A summary of the commercial paradigm, which provides the four key commercial considerations comprised of relations with customers, relations with regulators, their current business model, and their future commercial viability. These collectively represent the generic considerations that should guide a team or actor's decision making. This is used to orient the players to commercial interests, especially if the players come from a military or non-commercial background.
2. A designation of a specific commercial company with specific details of their constellation and its capabilities, especially those capabilities that have relevance to the battlefield. This may also include information about when a constellation can provide services, its revisit rates, its potential capability, and key limitations if they are relevant to the wargame. It

should also include a cursory introduction to the constellation's vulnerabilities and resistance to offensive space control measures. This introduction orients play interactions with commercial space actors by increasing their awareness of commercial interests, capabilities, and vulnerabilities.

3. Finally, the overview should introduce historical allegiance, current relationships and contracts with the involved nations, details regarding its customer-base, sources of revenue, and commercial ambitions. It is critical that players representing commercial actors understand the driving considerations for their own choices. Players with military backgrounds may not innately think about the economics and regulatory considerations affecting their choices, but this is made easier by outlining a company's financial and business model dependencies. This level of detail may only be pertinent to a select set of wargaming objectives, but they should be considered if interaction with commercial actors becomes a significant to key issues being reviewed.

By way of example, Table 7 shows a representative orientation that might be used by a player representing a commercial SATCOM actor in a wargame.

Table 7. Example SATCOM Orientation Product. Adapted from [72].

Iridium Communications Incorporated	
Constellation Name: Iridium NEXT	
Country of Origin: USA **Ownership:** USA	
Service: Narrowband voice and data to mobile users	
Coverage/Orbit/Constellation:	-Global coverage, LEO orbit, 66 total satellites
DoD Agreements/Contract:	-$100.9 million dollars to provide general SATCOM support to meet voice and data requirements.
Non-DoD Agreements/Contracts:	-None
Revenue Balance:	-Commercial: $362.2 million / Gov: $100.9 million
Total Users:	-Commercial: 1,324,000 / Gov: 152,000 -80% of Users are in the United States *notional
Notional Additional Concerns:	-Desires for expanded growth in customer base are increasing internal pressures to expand into Asia. *notional

In summary, representation of commercial SATCOM and ISR providers necessitates a thorough orientation if the wargame design and objectives anticipate interactions with commercial services and interests. Orientations are necessary regardless of if players will be assigned to represent commercial actors due to the unique commercial paradigm covered previously, especially when wargaming the operational and strategic levels of warfare.

3. Proliferation

Lastly, the previously discussed proliferation in commercial space capabilities and capacity demands incorporation into wargame constructs because it challenges traditional attitudes toward the role of commercial space in two ways.

First, a greater number of commercial assets and capacity force game players to acknowledge and incorporate DOD's leveraging of commercial space into their decision-making process. Specifically, as shown in the guiding principles, commercial actors possess, in aggregate, more ISR and SATCOM capacity than state-owned and -operated constellations. Moreover, this proliferation of commercial space capabilities and actors is consistent with actual ratios of commercially-owned to state-owned satellites which stands at nearly 4:1 as of December, 2020 [73]. More telling than the ratio of satellites, however, is the ratio of total satellite capacity. Current summaries of DOD SATCOM capacity estimate total throughput at roughly 55 Gigabits-per-second (Gbps) while commercial SATCOM capacity is estimated to be greater than 2,200 Gbps [74]. Thus, if a preponderance of the capability and capacity is in the commercial sector, then future space security postures must account for and leverage this reality. Therefore, wargames should make efforts to incorporate greater numbers of commercial space capabilities, capacity, and actors to reflect current ratios and encourage player incorporation of increased commercial bandwidth and imaging capabilities more accurately.

Secondly, this increased ratio of commercial systems to national systems also encourages players to acknowledge that the preponderance of space capabilities on the battlefield is not under the direct control of military and political decision makers. Therefore, decisions that strain relationships with commercial space actors at the strategic level may have significant ramifications when attempting to meet SATCOM and ISR needs in the current conflict and beyond. This is, albeit, more applicable to strategic and operation level wargames, but wargame designs that incorporate this commercial preponderance foster player education on the importance of these relationships. This is especially important when players consider how to interact with commercial actors in a wargame when commercial space actors are represented.

However, as with the previous considerations, the exact manner of incorporating proliferation varies from wargame to wargame based on many competing wargame design factors, driven by the wargame's objective and key issues. Therefore, the following two charts are provided that offer examples based on the level of warfare and the information structure utilized by a wargame. These examples are not prescriptive, but, instead,

demonstrate how the above two key considerations can be applied to meet wargame design demands.

Table 8 and Table 9 provide four examples each across the previously mentioned spectrums of warfare and information structure to assist wargame designers seeking explicit examples of how to incorporate proliferated commercial ISR and SATCOM. Each example provides a recommended inject to achieve an example wargame objective while also acknowledging drawbacks associated with the proposed injection. Many of these recommendations come with the associated challenge of educating players on the fundamentals of the space domain and space conflict discussed previously. However, proliferation of commercial capacity and capability demand this inclusion when wargame objectives permit. This inclusion broadens player thinking on an increasingly important topic from the tactical to the strategic level. Therefore, wargame designers should compare their intended wargame style against the chart to identify example injects and spur appropriate incorporation of commercial proliferation into their wargame.

Table 8. Commercial ISR Proliferation Aid

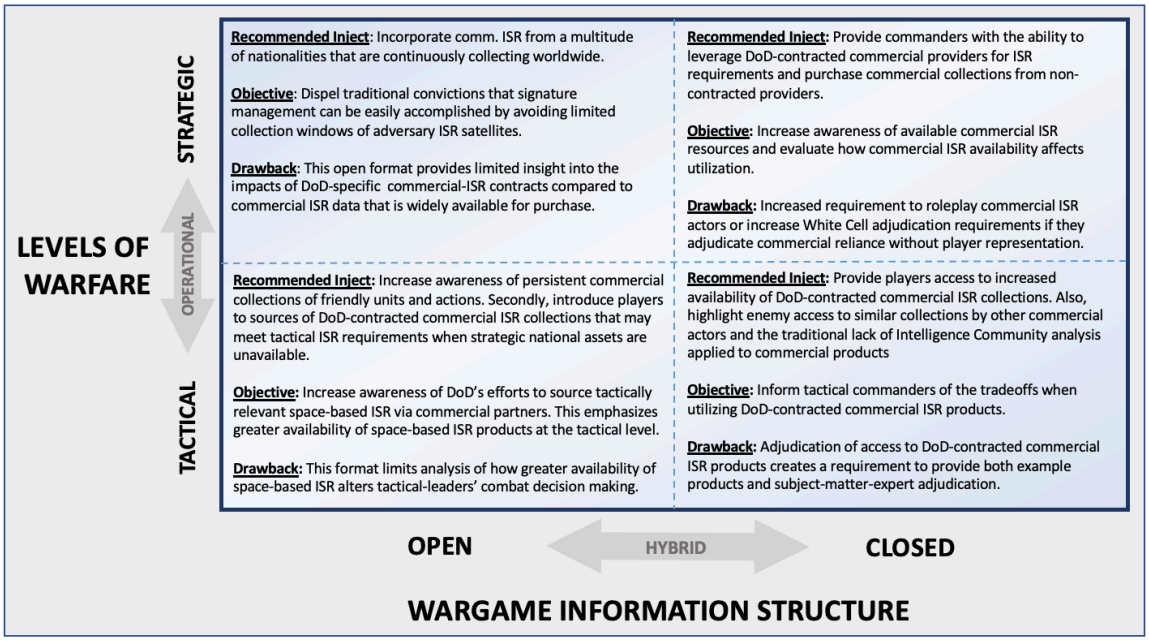
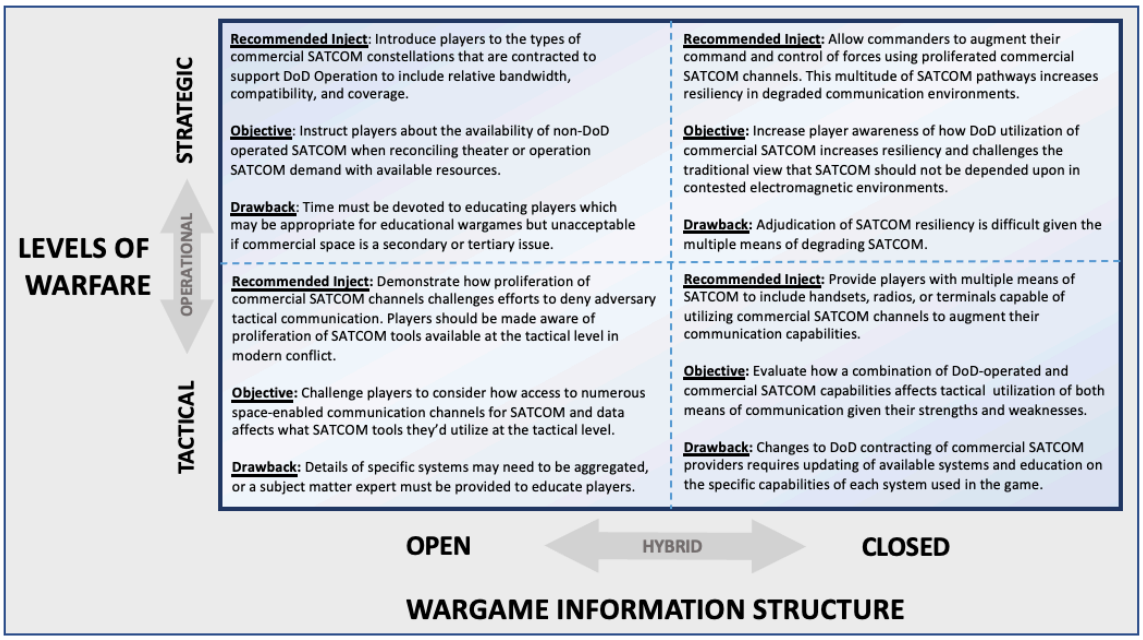


Table 9. Commercial SATCOM Proliferation Aid



For example, if a wargame designer intends to incorporate both DOD reliance on commercial SATCOM and reliance on commercial ISR in a strategic, closed information structure wargame, the unifying theme is to allow players to contract with commercial providers to augment ISR and command and control. Ideally, these commercial actors would be represented by players pursuing objectives based upon the commercial paradigm. This incorporation will bring with it the added burden of additional adjudication and representation challenges. However, the players will gain an understanding of the capabilities, objectives, and interests of commercial space actors who can help meet their communication and ISR requirements. Detailed representation of these commercial actors and their constellations, to include strengths and weaknesses, will further educate players on the potential risks and overall limitations of this additional support.

Thus, by using these aids to better incorporate commercial ISR and SATCOM proliferation, wargame players will make decisions in a more accurate context. This leads to more realistic outcomes sculpted by DOD reliance on these now-proliferated commercial space partners. In summary, the three above changes of representation, proliferation, and orientation to wargame setup provide simple means to inject the

commercial paradigm and commercial paradigm in a way that can be broadly applied and enable the following recommended methodologies to gameplay mechanics.

D. GAME EXECUTION RECOMMENDATIONS

These game execution methodologies build upon the framework created by amended game setup to create more accurate gameplay dynamics. Moreover, they are broken down below into two types, interaction recommendations and effects recommendations, starting first with recommended changes to wargame interactions.

1. Interactions

As previously discussed, interactions between players in a wargame are a product of the design of the wargame itself, specifically its information structure. This design may vary significantly based on the desired objective, key issues being addressed, player expertise and other considerations. However, this research previously notes that many of the guiding principles, namely "market access cannot be assumed and may be leveraged," "company stakeholders must be known and accounted for," and "the existence of undisclosed influence must be acknowledged" all highlight how directed and undisclosed communications influence a commercial space partners willingness to provide services to the DOD. This real-world interaction is clearly an example of a closed information environment which implies that it ought to be modeled as a closed information structure in a wargame. However, the following analysis shows that, although preferably modeled as a closed information environment, wargame designers also have tools to model this closed real-world information structure as an open information structure in a wargame if required to meet a specific objective or to conform to a broader requirement for an open information structure. Thus, this analysis begins with recommendations for a closed information structure followed by recommendations for open information structures and ends with a combined decision aid.

a. Closed Information Structure Interactions

A closed information structure is well suited to portray many of the dynamics highlighted by the guiding principles. However, as previously shown in the Commercial

Representation Aid, Table 6, many of these interactions are specific to the operational or strategic level of warfare. Tactical level wargames might instead highlight commercial capabilities instead of commercial actors because tactical level units have little opportunity to interact with commercial actors directly. Therefore, the following recommendations are intended for operational or strategic, closed information structure wargames.

First, if a wargame represents commercial actors with players, commercial space players should be separated from the other teams and from each other throughout gameplay to account for the broad spectrum of awareness among commercial space actors. Specifically, the guiding principles note that undeclared and directed communications must be accounted for in the modeling of DOD's relations to commercial space actors. Therefore, commercial space actors would not have access to the intentions, goals, and strategies of state actors unless incorporated into planning. Likewise, commercial actors would likely not be aware of each other's intentions and relations to state actors unless intentional coordination was involved. Therefore, players representing commercial space actors must not be given unrealistic awareness of the battlespace or internal decision-making processes from other players unless intentionally involved. Instead, their awareness of the battlespace and other actors should be limited to their individual communications with other players and whatever awareness is gained from their own capabilities if they possess ISR satellites. Thus, it is appropriate that gameplay should reflect this disunity by separating such players during gameplay. This is consistent with recommended closed information structure recommendations found in *The Craft of Wargaming*.

Secondly, wargames designs should consider allowing individual commercial space players to physically move from their cell to another team's cell to model the inclusion of select commercial partners in DOD operations cells. Thus, in some instances, blue (or red) cells may invite commercial players into their internal conversations, much like a representative may participate in an operations center. However, it is recommended that this choice to move to another team's location be a decision on the part of the players and not a default setup inherent in the game. Of note, this inject also requires a methodical data collection strategy to capture these interactions. At a minimum, white cell players will be needed to collect the general courses of action and strategies employed by all actors to

influence their decision making. This further highlights the need for thorough player orientations if players are used to represent commercial actors or interests.

Lastly, when modeling DOD reliance on commercial space partners, it is recommended that communications be treated as a discrete action to allow responses by other players to be exchanged. In other words, traditional wargaming typically involves the operation of forces that manifest in an action, but they may not typically include communication as a distinct and intentional action. This is a byproduct of wargaming's historical emphasis on force-on-force kinetic combat [70]. However, as demonstrated in the guiding principles, commercial space actors may be influenced through communication as much as through kinetic actions. In fact, a commercial space actor's greatest response might only be elicited through directed communication given that kinetic or cyber acts against a commercial actor may negate their ability to choose a course of action altogether. Therefore, wargames should incorporate DOD's communication with its commercial space partners and the commercial space industry at large with a closed information structure when possible. However, the following recommendations are made that provide options for wargames with open information structures.

b. Open Information Structure Interactions

An open information structure, to reiterate, generally allows all players to view information available to all other players. This structure is not as well suited to modeling closed communication dynamics in the real world. However, because of the proliferation and value of open analytical wargames, it is important to create tools that enable the incorporation of DOD's reliance on commercial space partners into this wargame format.

First, instead of trying to model the interactions between commercial actors and other actors on the battlefield, it is recommended that an open wargame emphasize the value system of commercial actors along with their capabilities and capacity. In other words, the wargame should emphasize the commercial paradigm where commercial actors have uniquely commercial interests and outlooks on a given scenario. One example would be to emphasize the first guiding principle that notes the strategic value of individual satellites or constellations to commercial providers. This commercial perspective is already

known to nations attempting to influence commercial actors in the real world. Therefore, this first guiding principle is well suited to an open information structure as well as closed.

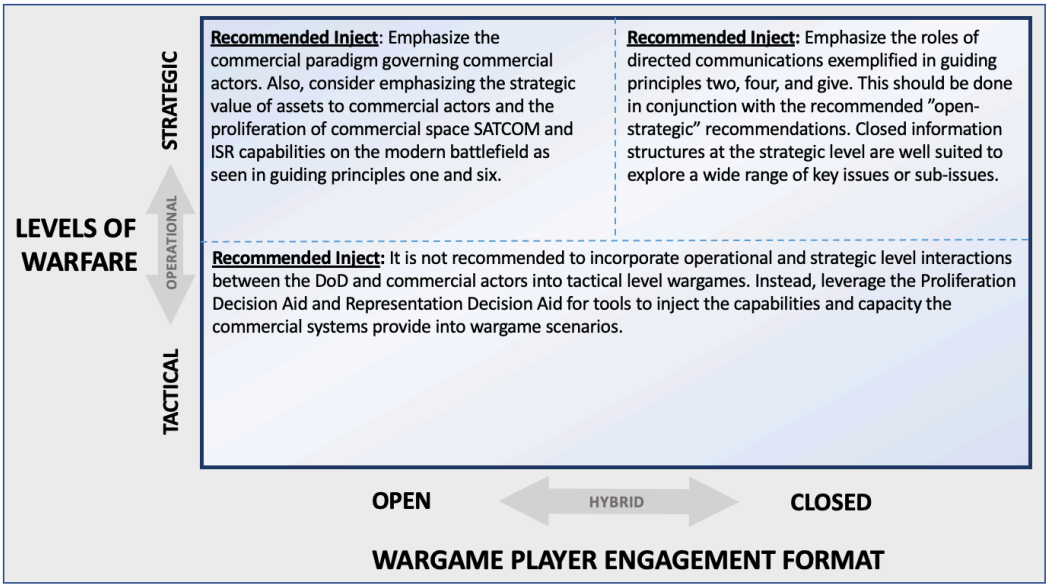
Secondly, the last guiding principle states the proliferation profoundly challenges notions that space-based capabilities can be negated on the modern battlefield. This is a second reality that should affect all actors equally and is readily applicable to open information structure wargames. For example, a seminar-style wargame with an open information structure should consider reminding all players that commercial systems from multiple nationalities already continuously image most of the globe. It would be extremely challenging to interdict the imaging capability provided by a variety of satellites, constellations, companies, and nationalities. Instead, it is more likely that a state actor may only degrade some portion of the commercial satellite ISR, and laws such as "shutter control" may only serve to limit commercial ISR capabilities licensed by that state-actor. Therefore, players in this style of wargame should consider that completely preventing imaging of the battlefield from space is not realistically achievable. Thus, this exemplified yet another reality that is well suited for open information structures while still providing meaningful injects for decision-makers to incorporate into their choices.

Lastly, the commercial paradigm can be emphasized to help guide discussions and player interactions in an open wargame. By giving all players access to commercial perspectives, all players may, in turn, improve their understanding of how to interact with commercial providers in a manner that serves mutual interests. For instance, if players from different and competing countries are vying for commercial services from a single commercial space partner, knowledge of the commercial paradigm will help shape their interactions. In fact, this common knowledge of the commercial paradigm may reveal new forms of influence yet discovered by this research. Ultimately, the incorporation of the commercial paradigm for all players to see allows wargames to both educate players while at the same time pursue analytical objectives.

c. Interaction Decision Aid

The following Interaction Decision Aid, Table 10, summarizes the examples of closed and open information structure formats for use by wargame designers.

Table 10. Interaction Decision Aid



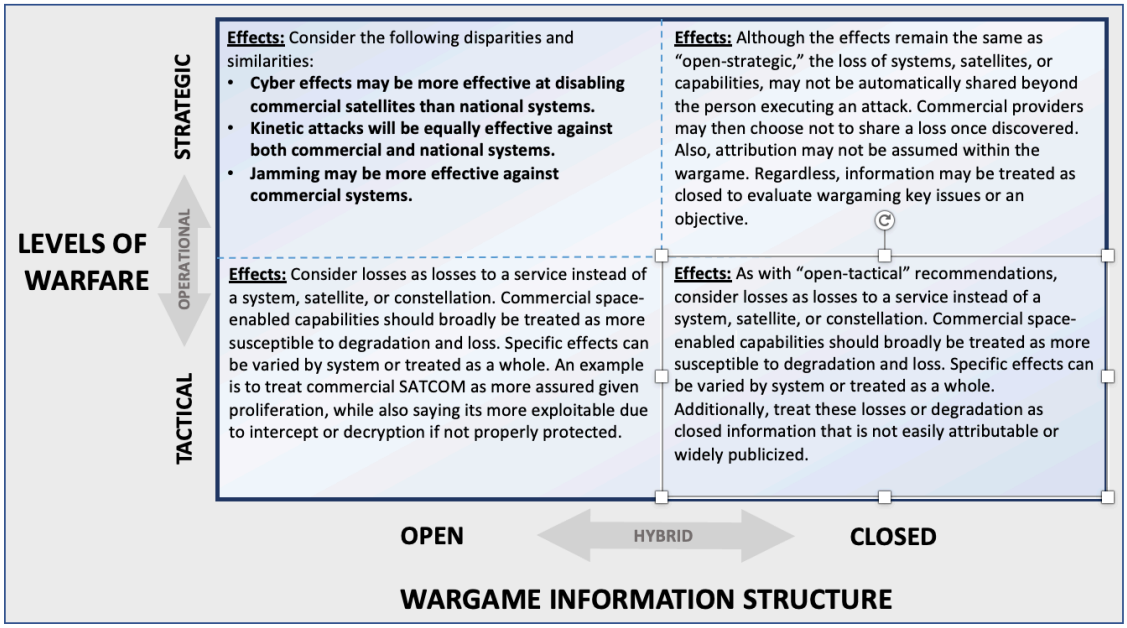
2. Effects

Finally, given the typical lack defensive measures and hardening on commercial spacecraft discussed previously, attacks on commercial spacecraft should be adjudicated in accordance with any known lack of resiliency. In other words, if a wargame incorporates space control operations or models directed energy or cyber-attacks on space architectures in general, then attacks on commercial space actors may result in greater degradation to their architecture than to national systems that are designed for resiliency. Examples of increased degradation might include longer or more widespread losses of service, or it might be permanent loss of a spacecraft instead of a temporary or partial loss. Exceptions to this recommendation include the adjudication of kinetic attacks on an orbiting satellite given that no amount of resiliency or hardening mitigates kinetic impacts at orbital velocities. Additionally, some commercial systems may have advanced cyber security or additional hardening built in, but this exception should be evaluated on a case-by-case basis predicated on detailed knowledge of the satellite's resiliency.

Ultimately, this disparity in effects can easily be adapted across the spectrum of warfare, as shown in Table 11. Also, as previously seen in the other methodologies, this range of effects is appropriately spread along the spectrum of information structure.

Specifically, the loss or degradation of a satellite or its capabilities can, due to the challenges of tracking changes in the space domain, be kept as closed information in some situations [47]. This is especially true if the loss is due to cyber, at which point even the operator of the satellite may have trouble identifying what is occurring. However, more overt attacks such as kinetic ASAT attacks may be known to many interested parties and, thus, could be easily represented in an open information structure. Therefore, information structure remains the proper distinguishing spectrum for this tool. The results are summarized in Table 11.

Table 11. Effect Disparity Decision Aid



Thus, in summary, effects on commercial spacecraft or their broader architectures should incorporate the relative vulnerability of commercial space assets, especially when compared to national systems designed for resiliency and redundancy.

E. CONCLUSION

In conclusion, the incorporation of the commercial paradigm and guiding principles first necessitated identification of a wargaming style that provided the greatest benefit to the DOD wargaming community. Review of existing wargaming efforts and studies

showed that the foundational analytic wargame afforded the greatest utility across the largest spectrum of DOD wargaming efforts. From this context, wargaming methodologies were presented that enabled the accurate modeling of the commercial paradigm and guiding principles for future use by a large spectrum of DOD wargaming efforts. Now, wargame designers can quicky reference these tools to find recommended injects and considerations based upon their specific wargame design with confidence that the injects adhere to the commercial paradigm and guiding principles. To demonstrate their utility, it is now appropriate to evaluate these methodologies within the context of a current Marine Corps turns and rules-based manual wargame known as Assassin's Mace.

VI. ASSASSIN'S MACE CASE STUDY OF PROPOSED PRINCIPLES AND METHODOLOGIES

To evaluate the effectiveness of the wargaming methodologies proposed in this research, the recommendations were applied to the Marine Corps analytic wargame, "Operational Wargame System Game 001: Assassin's Mace—War in the Pacific" (Assassin's Mace) [75]. As part of a wargame held at the Naval Postgraduate School, Assassin's Mace was amended by a wargaming team to address key issues in pursuit of a wargame objective. The following analysis introduces Assassin's Mace and demonstrates how the wargaming methodologies were applied to this DOD analytic wargame based upon the previously discussed factors of the intended level of warfare evaluated and the information structure of the game.

A. ASSASSIN'S MACE INTRODUCTION

The Marine Corps Warfighting Laboratory (MCWL) released "Assassin's Mace" in 2019 in partial response to the *Commandant's Planning Guidance,* published by General Berger, which called for "an invigorated approach to wargaming" within the Marine Corps [76], [77]. Specifically, MCWL developed OWS-1 as a series of games beginning with "Assassin's Mace" focused on the Pacific theater [76]. This series of games is a collection of "table-top wargames that enable rapid player orientation and situational awareness, flexible execution, swift adjudication, and immersive matrixed discussions." In short, Assassin's Mace is a system wargame accessible to a variety Marine Corps Officer backgrounds that is both analytic and educational given its intended use of developing strategic thought for Officers participating in Professional Military Education [75], [76]. The hard-copy version is depicted in Figure 2.

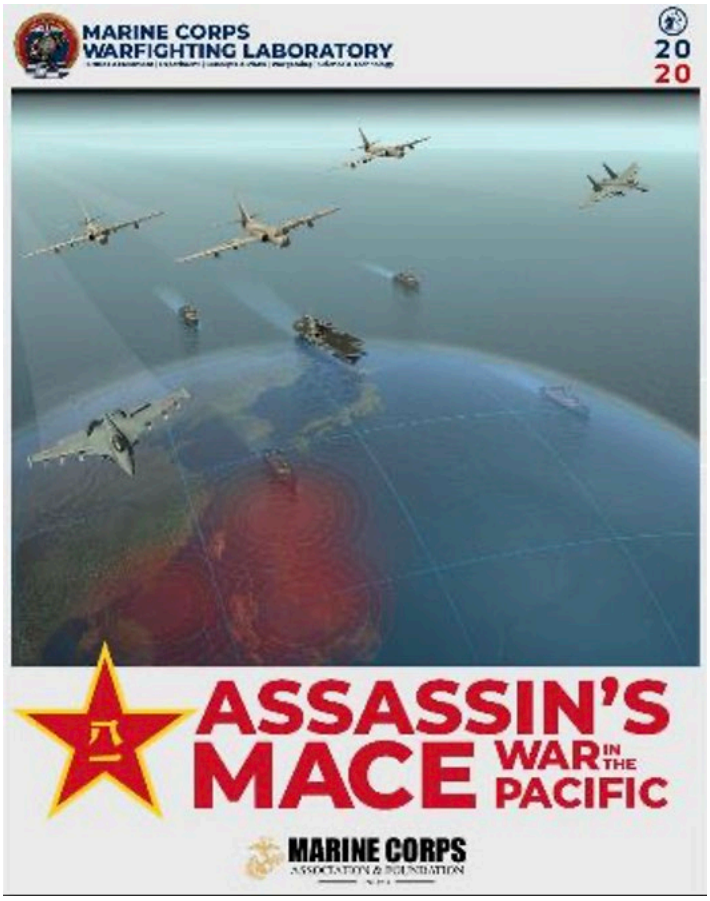


Figure 2. Operational Wargame System Game 001: Assassin's Mace. Source: [75].

The wargame is self-described in its rules manual as a "toolkit to enable scenarios in the 2020 to 2030 timeframe" and "designed to support professional military education and to exercise joint warfighting concepts" [75]. The rules manual further describes the two main uses as "Professional Military Education" and "Concept and Capability Exploration." The level of warfare inherent in the game pieces, adjudication, and rules are described in the rulebook as "high operational level" in pursuit of "strategic objectives." In short, the game facilitates player exploration of concepts and capabilities at the joint campaign level to educate players and support "concept and future force development" objectives.

The game map is specific to the western Pacific region and consists of hexagons aligned to cover the geographic region, national boarders, and major cities of the western

Pacific. The rulebook describes each "hex" as covering approximately 370 km by 370 km, and, apart from difference between land and water, "there is not an attempt to further identify terrain types." Game pieces are grouped by nationality and cover a wide spectrum of air, land, surface, and sub-surface forces associated with conventional modern warfare [78]. A sampling is shown in Figure 3.

Figure 3. Assassin's Mace Game Board and Pieces. Source: [76].

The game is turns-based, and adjudication is accomplished through the use of "multi-sided dice" that provide "a universal adjudication method to resolve detections, attacks, and [Information Operations]/Cyber effects" [78]. Modifiers such as terrain, cyber-attacks, weather, or other forms of influence will cause the die to be "promoted" or "demoted" to higher- or lower-sided die to affect the likelihood of outcomes based on die-based adjudication. Finally, cards and markers are used to modify game pieces and their abilities to incorporate more abstract capabilities such as information operations, cyber-attacks, targetability, and weather effects to name a few [78]. In short, Assassin's Mace is a robust and methodical system wargame well suited for the inclusion of DOD's dependencies on commercial space assets. However, despite its thorough incorporation of terrestrial domains, there is little inclusion of space capabilities or dependencies which

complicated inclusion of these elements, the sum of which are detailed in the following section.

B. ASSASSIN'S MACE SPACE INCORPORATION

Assassin's Mace has little inherent incorporation of space apart from some limited effects and detection considerations. However, the specific details of this limited representation are the starting point from which to amend the game to include commercial space considerations warranting a detailed review starting with its representation of the space domain.

First, Assassin's Mace only incorporates minor representations of the space domain and does not include space-specific assets or game mechanics. Instead, each side possesses a "theater ISR" capability that is proportionally sized to other nation-states represented in the game based upon their relative theater ISR capabilities in the western Pacific. However, this "theater ISR" capability is not strictly a space-based ISR capability and, instead, represents collective theater-wide sensing capabilities assumed to include terrestrial radars, satellites, and other remote sensing capabilities. Most importantly, however, is that "theater ISR" in the context of Assassin's mace doesn't explicitly represent space-based ISR capabilities and has limited value in educating game players about space dependencies that should be considered in their decision-making.

Secondly, space effects are also underrepresented, relying primarily on cards or tokens to modify the effectiveness of theater ISR or communications. Specifically, "theater ISR" can be degraded using a "Cyber Attack" card, as shown in Figure 4.

Figure 4. Assassin's Mace "Degrade ISR" Cyber Attack Card. Source: [78].

This card can be played to reduce the effectiveness of targeted "theater ISR" capabilities in the game, but "theater ISR" is still generic. Moreover, these effects are isolated to one turn representing one day. Additionally, there is no distinction between commercial and national space-based ISR capabilities. Thus, space-specific effects are only marginally represented, and, again, provide little opportunity to educate or inform player decision-maker with respect to space dependencies.

Finally, space-based communications are not explicitly represented in the game. Instead, communications are treated as a generic communication ability that is degraded or protected based on the decision to use "Comms Denial" or "Resilient Comms" tokens to degrade or protect a targeted unit [78]. In these instances, whether or not a unit can communicate is based upon the results of the die-roll adjudication method, with the sizing

of the dice based upon the inherent capabilities plus "Comms Denial" or "Resilient Comms" modifiers [78].

Therefore, in summary, Assassin's Mace does not inherently incorporate space as either a discrete domain, set of assets, effects, or discrete capabilities. Instead, space considerations cannot be attacked, are constantly available, and are of sufficient bandwidth or capacity to meet all demands throughout the course of play [78]. However, this treatment of space is yet another example of a prevalent attitude that should be reconsidered in light of DOD's growing space dependencies.

C. RECOMMENDED ASSASSIN'S MACE CHANGES

To apply the recommended wargaming methodologies, the wargame objectives and key issues were balanced against required changes to include commercial space to avoid recreating significant portions of the wargame's design. Wargame designers should expect to balance a wargame's objective and key issues against a given game design if they are amending a game instead of creating a new design. In this instance, Assassin's Mace, being a developed and nuanced system wargame, required that the commercial space incorporation adjustments be made within the adjudication construct to avoid lengthy redevelopment requirements. Specifically, given that the wargame sponsor requested improvements to Assassin's Mace to incorporate space considerations while also operating on a known timeline, changes that would require significant redesign were avoided while space incorporations that could be quickly applied were preferred. Lastly, expected player experience was considered to ensure incorporations of commercial space considerations remained accessible to a wide range of professional backgrounds while staying consistent with the guiding principles. Thus, considering these considerations, the following game changes were recommended, starting first with game construct changes.

1. Game Construct

Per the guiding principles and recommended methodologies, this research evaluated the wargame design, wargame objective, and key issues for opportunities to increase representation, orientation, and proliferation. The research arrived at the following

recommended injections to increase the wargames incorporation of DOD's dependence and utilization of commercial space partners.

a. Representation

As previously shown, closed wargames at the strategic level with closed information structures are generally well suited to incorporation the largely strategic guiding principles. Specifically, they lend themselves to player representation of commercial actors with the heavily utilization of directed communication game dynamics to evaluate DOD's commercial space dependencies. However, the expected number of players, level of warfare represented, key issues, and player experience with Assassin's Mace all discouraged use of individual player presentation of commercial space actors. Therefore, adjusting game mechanics became the optimal choice based upon the following considerations, starting with the influence caused by the expected number of players.

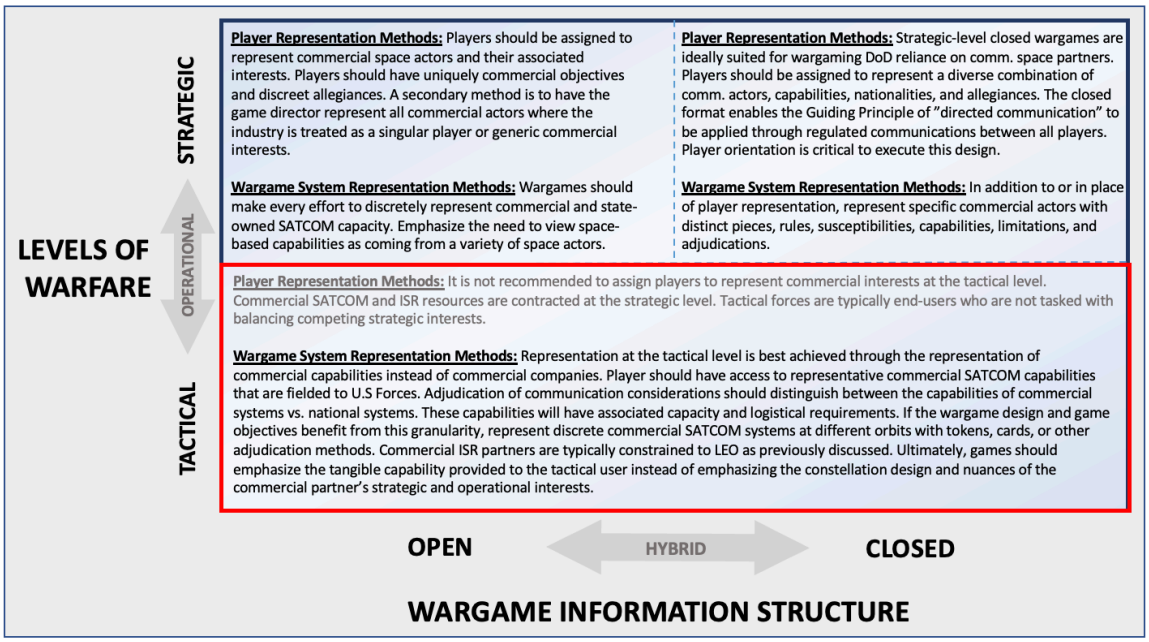
First, the wargame team expected that each side would be played by two or three players, thus making player representation of commercial space actors inappropriate and unbalanced considering the other combat domains were already underrepresented. Instead, players on each side represented task force or functional component commanders. Therefore, the wargame team concluded that a lack of player representation encouraged adjustments to adjudication and pieces.

Secondly, this wargame addressed key issues at the operational level, and the gameplay remained at the "high operational" level described in the Assassin's Mace rulebook. Therefore, strategic representation recommendations were not optimally suited for application in this instance. Specifically, the implied effects of strategic actions on the part of space actors, both commercial and national, were distilled down into the operational and tactical impacts for incorporation into the game.

Lastly, the players participating in the wargame had very little experience with the space domain, space assets, or space capabilities. Therefore, they were not well equipped to represent commercial or national space actors in our wargame. Additionally, since the key issues evaluated the decision-making of terrestrial commanders, it was not advantageous to enforce player representation of space actors at the cost of time and effort

to prepare players for this role. Therefore, the wargame team determined it was best to apply representation techniques from the proposed methodologies that were closer to the tactical recommendations than the strategic recommendations. Table 12 shows the specific proposed "Representation" Decision Aid with the selected section used for Assassin's Mace highlighted in red.

Table 12. Representation Decision Aid—Selected Technique

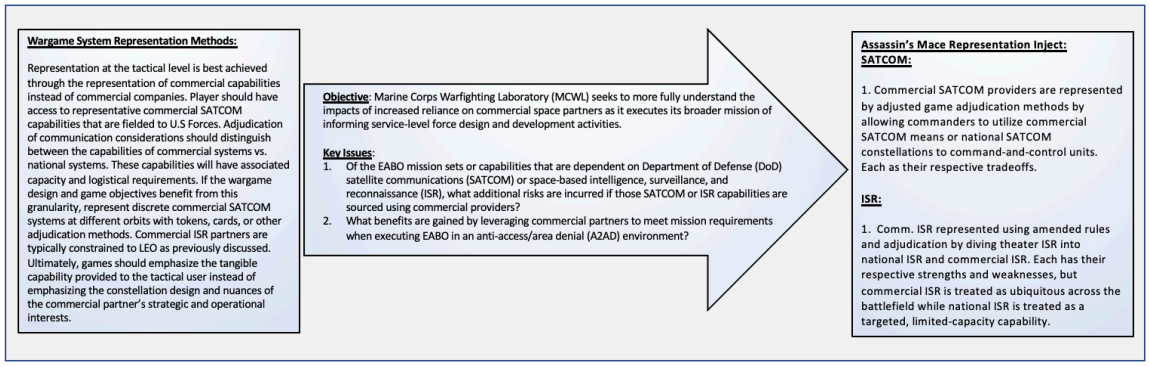


From the above Representation Decision Aid, the "Wargame System Representation Methods" were employed as guidance for how to adjust Assassin's Mace to best represent commercial space into this wargame. Then, as shown in Table 13, the recommendations were evaluated within the context of the wargame objective and key issues to arrive at the selected incorporation methods used in Assassin's Mace. Specifically, SATCOM was modeled by breaking down communication adjudication into traditional communications using national SATCOM systems and commercial SATCOM. Then, commercial SATCOM was assigned a die number that would result in successful communications in most instances based upon probability. However, if it was unsuccessful, then the command was decrypted and provided to the Red Team which is discussed in

detail in a later section. In this instance, the term "unsuccessful" is not used to describe what happened to the communication. Instead, it is used in reference to the result of the adjudication. The "unsuccessful" communication is specifically modeled as a communication that was detected by the adversary and prevented from reaching its intended recipient. This is not a prescriptive model, but rather a plausible example of the consequences of using a representative commercial SATCOM channel that transmits its signals with a higher degree of detection or intercept than national SATCOM systems. Thus, not only was space-based SATCOM incorporated, but it was separated into both national and commercial SATCOM for use in the wargame with implied vulnerabilities.

Additionally, ISR was modeled by differentiating theater ISR into two forms, national theater ISR and commercial theater ISR. National theater ISR was treated as a targeted, limited-capacity capability while commercial theater ISR was treated as ubiquitous. Specifically, national theater ISR could only be applied to individual hexes and total capability was a function of how many national theater ISR cards each team possessed. Commercial theater ISR, was represented as a separate capability that applied equally across all hexes each turn as a means of representing its greater capacity and coverage, a trait discussed in more detail in the proliferation amendments to Assassin's Mace. These results are summarized in Table 13

Table 13. Commercial Representation—Results



In summary, representation was accomplished for Assassin's Mace utilizing adjustments to gameplay mechanics and adjudication. It required the creation of new

pieces, but it did not require major revisions to other game pieces, existing effects, or the game board. Additionally, the effects were easily understood by players with limited space backgrounds while also allowing freedom of decision-making by players to enable productive evaluation of the key issues and the wargame objective.

b. Orientation

Given that the wargame did not incorporate unique commercial actors, either through player representation or game-piece representation, player orientation was not a critical factor for this wargame. Specifically, player orientation is meant to enable productive and principled dynamics within a wargame when explicit commercial actors are represented. However, because this wargame represented commercial capabilities instead of commercial actors consistent with the tactical recommendations in the Representation Decision Aid, players interacted with commercial capabilities instead of commercial actors. Therefore, the only orientation that was completed was an introductory lesson for all players on current DOD reliance on commercial space partners and an introduction to space-based capabilities. Details were provided on the changes to adjudication and gameplay mechanics to inform play decision-making. This allowed the players to make informed choices when electing to utilize commercial ISR and commercial SATCOM over national systems with the intent that this context would produce results that reflected deeper analysis and planning on the part of the players.

c. Proliferation

Proliferation was first evaluated within the context of the game design and wargame key issues. As with representation, the wargaming team concluded Assassin's Mace is better suited to model commercial ISR proliferation using the tactical recommendations for a closed wargame from the Commercial ISR Proliferation Decision Aid. Specifically, Assassin's Mace does not have a sufficient representation of the space domain and space actors to incorporate interactions between strategic commanders and commercial actors as seen in the strategic level recommendations. Instead, a capabilities-focused approach was more suitable, and the tactical recommendations from the Commercial ISR Proliferation Decision Aid were, therefore, more applicable. However, a different conclusion was

reached for commercial SATCOM proliferation. Specifically, the wargaming team concluded that commercial SATCOM proliferation was best incorporated using the strategic recommendations from the Commercial SATCOM Proliferation Decision Aid. This selection was based on the wargame's treatment of command and control which, at the "high operational" level of warfare represented in the game, is modeled as a generic capability instead of a combined set of radios and other communication pathways seen in the tactical level recommendations. Therefore, the proliferation of commercial ISR and SATCOM was incorporated in two ways, starting first with commercial ISR incorporation.

First, for commercial ISR, proliferation was modeled by adjusting the relative capacity of commercial theater ISR to national theater ISR consistent with the tactical recommendations for a closed information structure wargame. Specifically, Assassin's Mace models national theater ISR as a targeted capability based on the preassigned number of national theater ISR tokens allotted to each side at the beginning of the conflict [78]. For example, if the blue team is assigned three national theater ISR tokens, then those tokens can be "targeted" at three different hexes each turn to identify what enemy units are present in those three hexes. Targeting simply denotes that the ISR capability only reveals forces within that hex. Detection is adjudicated through the roll of dice by hex. However, the wargaming team modeled commercial ISR proliferation by allowing the previously discussed commercial theater ISR capability to be applied to all units across the entire gameboard at the beginning of each turn. Therefore, on each turn, adjudication was accomplished for all hexes and all units to reveal either blue or red forces. This represented the new reality that commercial remote sensing capabilities are now widely proliferated across the entire battlespace on a near-continuous basis consistent with the sixth guiding principle. Moreover, the detection of both sides' forces each turn showed how proliferation does, per the guiding principles, work both for and against a commander's security interests on the battlefield. The decisions for commercial ISR proliferation modeling are summarized in Table 14 and Table 15.

Table 14. Commercial ISR Proliferation Decision Aid—Selected Method

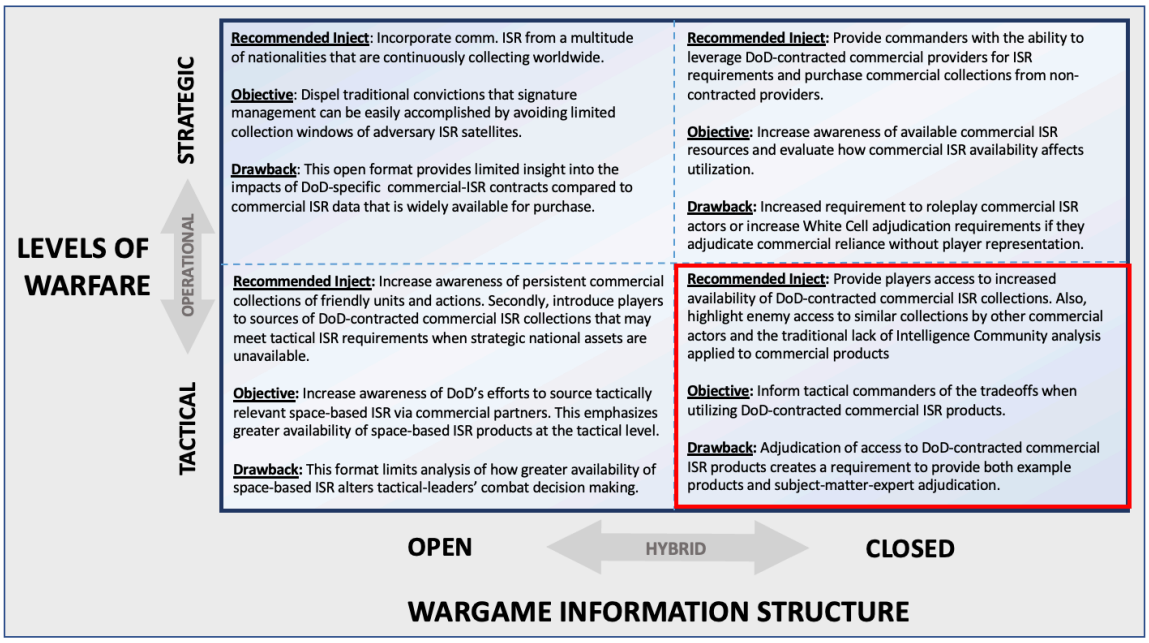
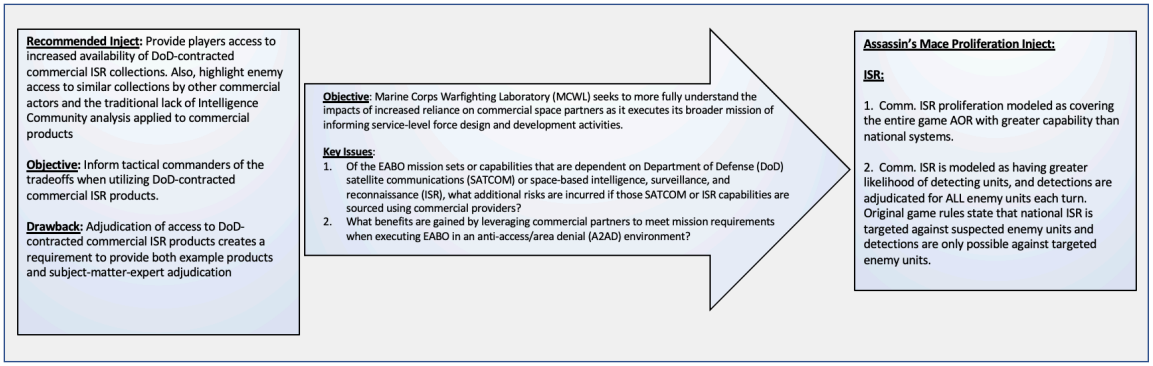


Table 15. Commercial ISR Proliferation—Results



Secondly, commercial SATCOM proliferation was modeled based upon the strategic recommendations for a closed information structure wargame. Specifically, these recommendations encourage the augmentation of command-and-control capabilities through the incorporation of commercial SATCOM pathways that increase the likelihood of successful communication. Therefore, the wargaming team amended communication game mechanics to allow players to use commercial SATCOM by using a "Resilient Commercial Comms" ability. This ability allowed players to employ commercial

SATCOM as a means of communication with their units in addition to a unit's inherent communication ability modeled with the existing communication gameplay mechanics. This ability was assigned a die number that ensured communications would be successful most of the time based on dice adjudication. This redundant form of communication meant that the adversary must target both national SATCOM channels and commercial SATCOM channels to successfully prevent successful command-and-control. This is consistent with the noted diversity and proliferation of commercial SATCOM channels outlined in the guiding principles. A summary of this employment of the Commercial SATCOM Decision Aid and its resulting adjudication changes are summarized in Table 16 and Table 17.

Table 16. Commercial SATCOM Proliferation Decision Aid—Selected Method

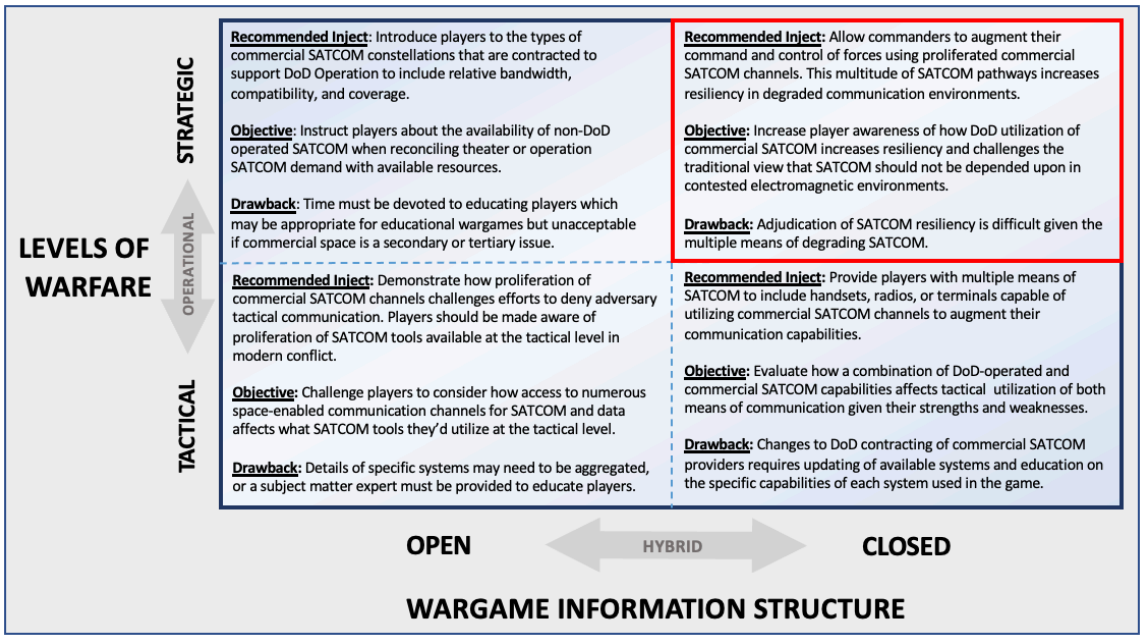
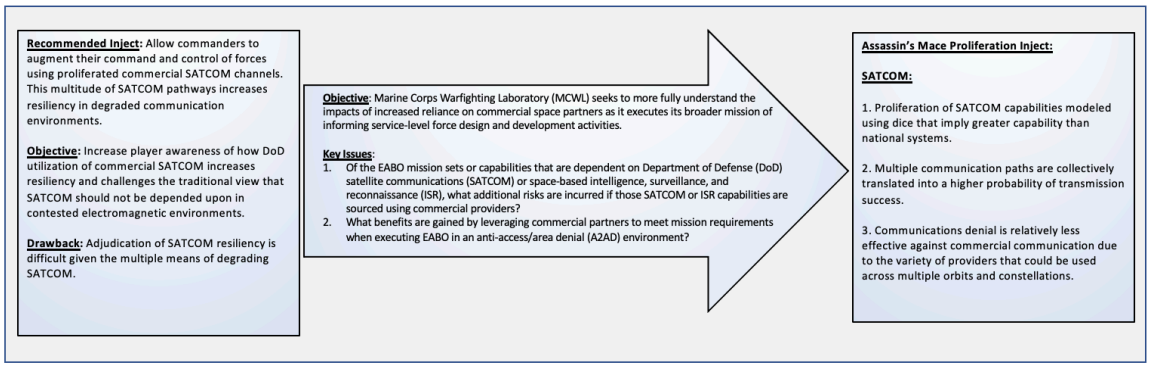


Table 17. Commercial SATCOM Proliferation—Results



In summary, proliferation of commercial ISR and SATCOM was accomplished using both tactical and strategic recommendations. By combining these recommendations, the wargaming team achieved appropriate representations of commercial ISR and commercial SATCOM in a manner that allowed players to choose whether to rely on commercial space-enabled capabilities in both their reconnaissance and command-and-control. In doing so, Assassin's Mace was successfully modified to enable the examination of the key issues to achieve the wargame objective. Thus, with representation, orientation, and proliferation recommendations applied, the following section outlines the changes made to Assassin's Mace to improve game execution.

2. Game Execution

As with the game structure changes, the modifications to game execution were derived from the wargaming methodologies to incorporate commercial space into the player interactions and space-related effects.

a. Interactions

Due to the decision to not represent commercial actors with players or tokens representing commercial actors, there were limited opportunities to inject DOD reliance on commercial space partners into game interactions. Specifically, this wargame did not allow opposing sides to interact with one another directly or to interact with the respective supporting commercial partners. This decision was made because, at the operational level

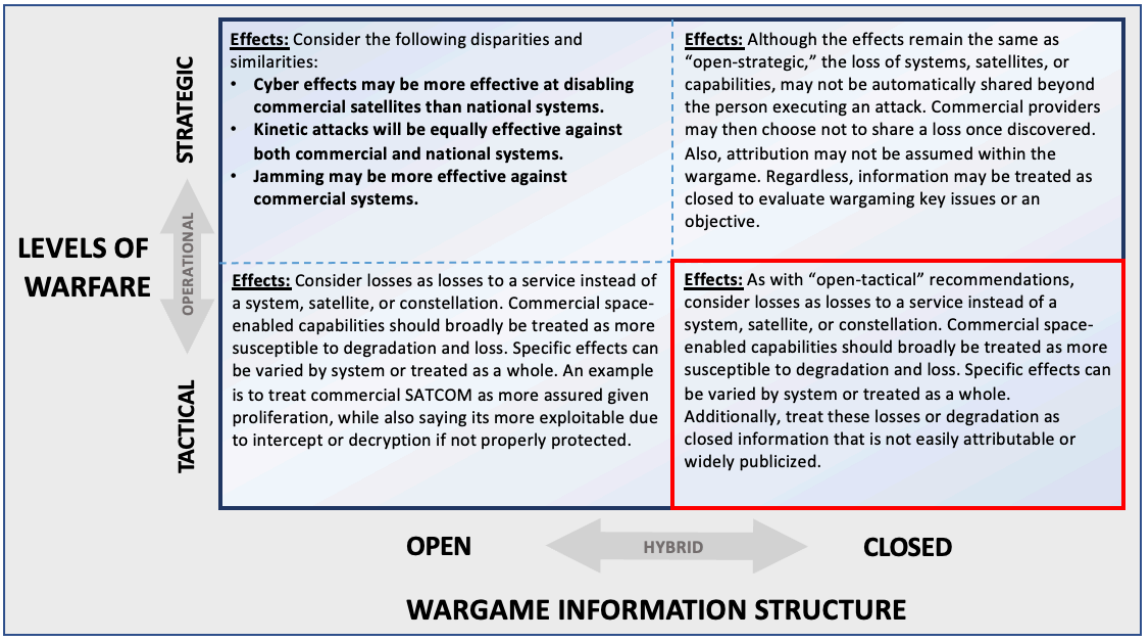
of warfare being represented, the wargaming team decided these interactions did not serve to evaluate the key issues involved. In other words, the wargame sought to identify how access to commercial capabilities influenced how the commander's pursued their operational and strategic objectives. Therefore, the recommendation to incorporate changes to player interactions was not applied to Assassin's Mace. This serves as an example of how choices of how to represent commercial space in the construct of a wargame heavily influences the applicability or suitability of the following recommended changes. In this instance, the choice to represent commercial capabilities instead of commercial entities prevented meaningful inclusion of the recommended interaction changes.

b. Effects

Finally, the wargame team incorporated the unique vulnerabilities and capabilities of commercial systems into game adjudication and game mechanics that enhance the value of the other changes in game construct. Specifically, when Assassin's Mace and its amended game construct were evaluated, the representation and inclusion of proliferation afforded four opportunities to refine these adjustments to reflect commercial strengths and weaknesses more accurately. These four adjustments are derived from the recommended changes for a tactical, closed information structure wargame Effects Decision Aid, and are comprised of two changes to commercial SATCOM and two changes to commercial ISR.

First, since commercial SATCOM was represented as another means of communication for units, the changes to commercial SATCOM's relative strengths and weaknesses were applied to this inclusion method. Specifically, the Commercial Effects Decision Aid, seen in Table 18, recommends treating commercial capabilities as more susceptible to degradation baring any known resiliencies or hardening.

Table 18. Commercial Effects Decision Aid—Selected Method



For this specific inclusion, commercial SATCOM was modeled as having two additional consequences: detection and potential interception. First, if commercial SATCOM was used to command-and-control a unit, then it was revealed to the adversary that a message was sent to that unit. The information of that communication was not revealed, but, as a representative vulnerability of using a commercial SATCOM channel, it was revealed that a communication was sent to that unit. Secondly, if that communication was adjudicated as unsuccessful, it came with the added consequence that the contents of the communication were revealed. If this occurred, the adversary was allowed to know what command was given. Of note, this drawback was not meant to imply that commercial systems use less encryption, but rather this drawback created risks for players when weighing the use of commercial SATCOM channels for command-and-control. Specifically, this drawback represented a generic cyber vulnerability of the commercial SATCOM used in this game to differentiate between the capabilities of national and commercial SATCOM systems. Thus, in summary, commercial SATCOM game mechanics were amended in two critical ways to incorporate representative vulnerabilities

that would reveal the underlying decision-making considerations players relied upon during gameplay.

Modeling of Commercial ISR also utilized two effects-related changes to incorporate commercial strengths and vulnerabilities more accurately. First, commercial theater ISR was treated as four times more vulnerable to the cyber-attack card available to players in the game. Specifically, as shown in Figure 5, cyber-attacks degraded a player's commercial theater ISR by eight counts while national theater ISR capabilities were only degraded by two counts. This change showed players that commercial services, while possessing more capacity and capability in some instances, may also be less resilient in a contested space environment.

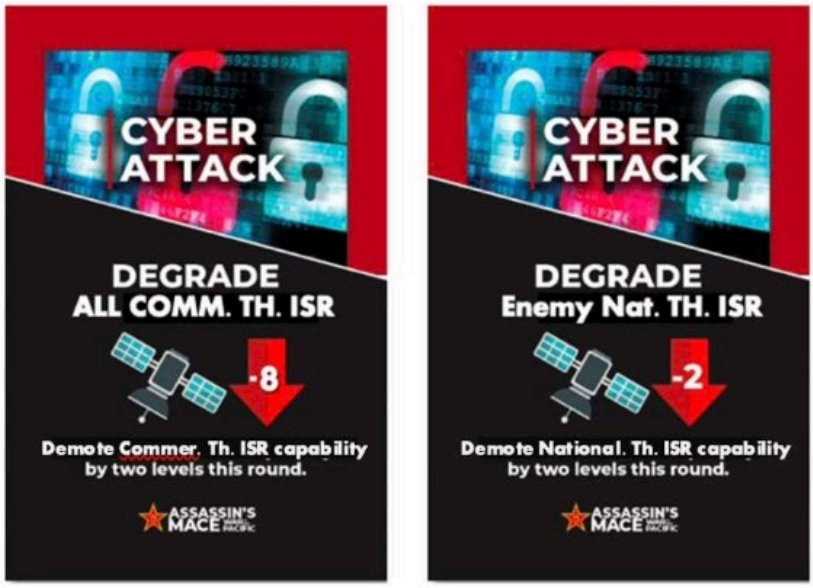


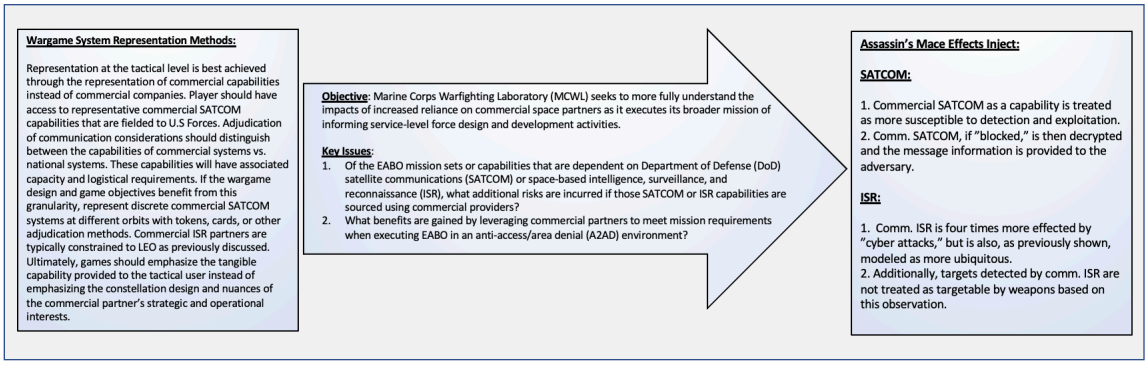
Figure 5. Cyber Attack Card Changes. Adapted from [75].

Lastly, commercial ISR incorporated a final sample weakness designed to distinguish the relative value between national theater ISR and commercial theater ISR products. Specifically, units detected by commercial theater ISR were not targetable once detected unlike units detected using national theater ISR. In other words, Assassin's Mace uses a marker to identify an adversary's units as targetable by weapon systems. This marker

is placed on those units detected by theater ISR in the unamended gameplay. However, the wargaming team elected to not assign the marker to targets detected by commercial theater ISR to simulate that information not being sufficiently detailed or incorporated into friendly targeting cycles to such a degree as to be targetable. Instead, commercial theater ISR could be used to cue national theater ISR or terrestrial systems that could produce targeting-level data. Thus, a relative weakness was injected capitalizing on the distinction between national and commercial theater ISR capabilities.

Thus, in summary, effects were successfully incorporated into the wargame mechanics and adjudication which helped distinguish between the relative strengths and weaknesses of commercial SATCOM and ISR. These results are summarized in Table 19, and they collectively represent highly efficient amendments to Assassin's Mace in pursuit of the sponsor's key issues and wargame objective.

Table 19. Commercial Effects Incorporation - Results



D. CONCLUSION

In conclusion, the amendments to the sponsored Assassin's Mace wargame demonstrated both the utility and limits of the proposed wargaming methodologies for the incorporation of DOD's reliance on commercial space partners. In one sense, the wargame amendments successfully applied the recommended methodologies to Assassin's Mace and enabled the evaluation of the wargame's key issues. However, given that Assassin's Mace was a robust and nuanced system wargame, amendments that were achievable on timeline and with the available players and resources meant that larger changes to the game

to better incorporate the wargaming methodologies could not be pursued. Despite these challenges, however, the wargaming methodologies were confirmed to offer value to game designers and can be successfully applied to existing DOD wargaming efforts to meet wargaming objectives and key issues.

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VII. SUMMARY AND CONCLUSION

This research identified the guiding principles and wargaming methodologies that enable DOD wargaming efforts to incorporate DOD's reliance on commercial partners providing SATCOM and space-based ISR. This thesis demonstrated that DOD analytical wargaming efforts can achieve this by applying the identified commercial paradigm and six guiding principles using the five recommended methods of inject. In doing so, DOD analytical wargames can now methodically incorporate dependencies on commercial space partners in a manner that is consistent with the underlying real-world dynamics and coordinated with concurrent DOD wargaming efforts utilizing these guiding principles and wargame injection methods.

A. SUMMARY

This, collectively, was concluded by first assessing the scope of commercial space capabilities, capacity, and proliferation to demonstrate that commercial space partners operate significant combat-relevant capabilities that meaningfully influence modern combat. These capabilities are of such capacity and number that, regardless of any specific partnerships, their inclusion into modern strategic thinking and, by extension, DOD wargaming, is an imperative.

Then, the thesis reviewed specific U.S. policy and historical relations to achieve two distinct goals. First, these reviews established the context and existing regulatory framework needed to systematically characterize the dynamics that exist between the USG and commercial space partners. Secondly, the review of current policy and the existing relationship showed that current dependencies are already significant and growing, further emphasizing the importance of including this dependency into DOD strategic thinking and, necessarily, DOD wargaming efforts.

With the regulatory context and necessity for inclusion established, this research then introduced the space domain and the basics of space conflict to enable a detailed assessment of challenges faced by commercial actors and, specifically, DOD space partners during times of conflict. Then, with the collective context for commercial space partners

during conflict established, this thesis distilled these challenges into a singular commercial paradigm consisting of four key considerations that commercial space partners must balance with their decision-making:

1. Relations with customers
2. Relations with regulators
3. Current business model
4. Future commercial viability

Based upon the context provided by the commercial paradigm, this thesis evaluated how these commercial considerations could be leveraged to influence a commercial space partner's ability or willingness to support the DOD either during times of conflict or in the future. This research then summarized the results of this analysis into a set of six guiding principles as follows:

1. Assets may hold strategic value to commercial partners
2. Market access cannot be assumed and may be leveraged
3. Current and future profitability must be protected
4. Stakeholders must be known and accounted for
5. The existence of undisclosed influence must be acknowledged
6. Proliferation complicates capability denial

Once this research established the commercial paradigm and guiding principles, it then introduced the craft of wargaming and, more specifically, DOD wargaming efforts. Then, to ensure the recommended wargaming methods would be both broadly applicable and in a pertinent format, the thesis determined that the recommended incorporation methods should be structured for application to analytic wargames. Furthermore, based on the dynamics being modeled, the research concluded that wargame decision aids should use the spectrums of Levels of Warfare from tactical to strategic and wargame "Information Structure" from open to closed for framing the recommendations [71]. Then, the commercial paradigm and guiding principles were synthesized into recommended changes

to the wargame construct and gameplay mechanics. Specifically, wargames seeking to incorporate DOD reliance on commercial SATCOM and space-based ISR should ensure representation, improve player orientation, and increase relative proliferation into the game construct. Then, to improve the fidelity of the gameplay, wargame designs should incorporate the commercial paradigm and directed communications into game interactions between players. Moreover, wargame designs should incorporate the relative resiliencies and susceptibilities of commercial space assets and capabilities into their modeling of space-enabled capabilities.

Finally, this thesis evaluated the effectiveness of these recommendations by applying them to a DOD analytic wargame, Assassin's Mace, as part of a sponsored wargame conducted at the Naval Postgraduate School. This application demonstrated how each of the wargame inject methods could be applied to an existing DOD analytic wargame in pursuit of a known wargame objective with associated key issues. This process revealed that the developed tools are well suited for modeling DOD reliance on commercial space partners in analytical wargames, but many of the modeling recommendations are not easily applied to existing games without also requiring extensive remodeling of the space domain if not already included. Specifically, revising Assassin's Mace to fully incorporate all of the recommended changes would have required significant revision to game pieces and turn mechanics. However, this degree of revision was not needed in this instance to achieve the sponsor's objectives. Instead, the recommended wargame methods did allow substantially improved incorporation with relatively minor adjustments to the wargame design through the pairing of the changes with specific wargame key issues.

B. RECOMMENDATIONS

This thesis revealed that further research is needed to standardize wargame player education and orientation. Specifically, topics such as the space domain, space conflict, satellite imaging, and SATCOM degradation may not be well understood by all wargame participants, especially those representing disciplines less associated with the space domain. Therefore, additional research is needed to refine player orientation tools so that all players are well equipped to participate in wargames incorporating the space domain.

Additionally, DOD wargaming would benefit from standardized data concerning commercial companies, constellations, capabilities, and capacity. This information may already be aggregated to some degree by some DOD wargaming efforts, but wargame designers and players would benefit from additional standardization of the assumptions made about commercial actors and their capabilities across the full spectrum of DOD wargaming. Therefore, if the DOD wishes to further incorporate these topics into their wargames while still maintaining consistency across multiple wargaming efforts, then more research is needed to establish baseline products for the education and orientation of wargame designers and players participating in such wargames.

More research is also recommended to translate the guiding principles identified in this research into more service- or theater-specific considerations. Specifically, if wargames intend to evaluate service- or theater-specific space considerations, additional insights could be achieved by refining the guiding principles and wargaming methodologies into more service- or theater-specific tools.

Lastly, this research constrained itself to LEO through GEO orbits. Growing applications of the cislunar region beyond GEO may require amendments to the proposed tools to account for the unique qualities of cislunar orbits.

C. CONCLUSION

In conclusion, this research was successful in providing a framework for wargame designers that enables the inclusion of DOD's dependency on commercial space partners into DOD wargaming efforts. This, in turn, should allow the DOD to draw more consistent conclusions from its wargames incorporating commercial space due to standardized inclusion founded upon the principles governing the DOD's reliance on commercial space partners.

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