The Peril and Promise of On-Orbit Logistics in Orbital Warfare

by

A Capstone Research Project Proposal Submitted to the Missile Defense Advocacy Alliance and University of Southern California in Partial Fulfillment of the Requirements of the USC SHIELD Executive Program in Global Space and Deterrence

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Abstract

Title: The Peril and Promise of On-orbit Logistics in Orbital Warfare

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The imminent emergence of a viable commercial marketplace for on-orbit refueling and repair will almost certainly change the character of orbital warfare by loosening, if not eliminating, the biggest constraint of maneuverability. How the U.S. government structures its relationship with the commercial actors in this market will significant impact on the operation of U.S. government systems in orbit in competition, crisis, and conflict. This paper examines several potential relationship models to assess points of risk at the higher end of a crisis that often carries over into conflict.

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Definitions

Cislunar	The spherical volume of space extending from geosynchronous orbits to the moon and all Earth-Moon Lagrange Points.
Constellation	A group of satellites performing the same function or interacting among each other to perform a function through their combined effort.
Geosynchronous Orbit	A band of orbits over 36000 kilometers altitude, allowing the satellites to observe the Earth as if there was no rotation.
Lagrange Point	A point of equilibrium between the gravitational influence of two celestial bodies.
Low Earth Orbit	A band of orbits with altitudes between 160 and 2000 kilometers, typically taking 90 minutes to 2 hours to orbit the Earth.
Medium Earth Orbit	A band of orbits situated between Low Earth Orbit and Geosynchronous Orbit
Monopoly	A market structure where there is only one significant seller of a good or service.
Monopsony	A market structure where there is only one significant buyer of a good or service.
Proliferated LEO	A constellation of a high number of satellites, normally in the hundreds to thousands generally emphasizing low cost and speed of deployment.
Rendezvous and Proximity Operations	The deliberate maneuvering of one space vehicle into close proximity to another space vehicle which may or may not have the intention of docking.

Acronyms

CASR	Commercial Augmentation Space Reserve
CRAF	Civil Reserve Air Fleet
DARPA	Defense Advanced Research Projects Agency
EEFI	Essential Elements of Information
GEO	Geosynchronous Orbit
LEO	Low Earth Orbit
MEO	Medium Earth Orbit
OPSEC	Operations Security
PLEO (also pLEO)	Proliferated LEO
PMC	Private Military Company
PRC	People's Republic of China
RPO	Rendezvous and Proximity Operations
U.S.	The United States
USSF	The U.S. Space Force
VISA	Voluntary Intermodal Sealift Agreement

Chapter I: Introduction

A Future Battle of Maneuver

Throughout this paper, certain sections are in *italics*. These sections are short vignettes about potential actions in space during a notional crisis between the U.S. and the People's Republic of China (PRC) over Taiwan.

It was in mid-February at 2030 when space operators across the planet began to worry. In a massive game of cat and mouse, satellites from the United States and the PRC began maneuvering against and away from each other. The reason was obvious: concern of a potential PRC build-up to cross the Taiwan Strait in the calmer waters of early April meant an increased need for surveillance and reconnaissance by U.S. satellites. The PRC responded by seeking to interfere with those missions through a variety of means, including feints of rendezvous and proximity operations against U.S. spy satellites. Meanwhile, with an absolute requirement to maintain custody of deploying U.S. carrier strike groups, PRC satellites were taunted by U.S. space vehicles and unable to complete their primary function without significant maneuvering. Soon the targets spread between both sides as communications, navigation, and timing vehicles experienced not only jamming and spoofing as well as physical interference.

This situation was now a battle of positioning and a challenge to the robustness of the space vehicles. Adjustments, positional changes, and general operational tempo of the satellite busses were happening at a pace never experienced in the past. After three weeks of action, reaction, and counteraction across and between all the orbital regimes, each side realized the maxim that "tactics win battles, logistics win wars" remained true in space. To keep warfighting capabilities going and deny the adversary those same capabilities, significant levels of on-orbit refueling and *maintenance were needed. Otherwise, the space fight would be over before the first landing ships set sail.*

Background of the Problem

The United States and its challengers are increasingly acknowledging space as a warfighting domain (Vision and Priorities of the United States Space Force, 2023). For decades, at least since the first Gulf War, space has been recognized as a key enabler of other warfighting domains through the provision of increased communications capabilities, aid to navigation, and the provision of decision-enabling intelligence (Kolovos, 2017). But now, it is coming into its own as a distinct domain in which war can be waged.

Regardless of domain, since at least the early modern period of the mid-17th century, warfare can be reduced to the aspects of fire and maneuver: the delivering of effects upon an opponent (fire) and gaining a positional advantage that either increases or decreases the efficacy of those effects (maneuver) (Biddle, 2004). Space, as a warfighting domain, differs only in that maneuver itself can be a form of fire: denying an orbital slot to a challenger by occupying first, forcing a challenger to displace and therefore disrupt their mission performance, or inserting a space vehicle within a field of regard to “soak” in transmissions between a challenger satellite and its terrestrial element can create a mission denying effect (Hao et al., 2020). Although space is one of the two most technologically sophisticated warfare domains alongside cyberspace, this primacy on maneuver calls back to the era of early modern positional warfare where battles could be determined without firing a shot simply by maneuvering to hold a superior position and convincing the challenger there was no actual chance to have a battlefield victory (Lynn, 2019).

Whether in the context of war or peace, the largest constraint on maneuver in space is fuel. At current technology levels, it is considered cost-prohibitive to launch a space vehicle with large, excess amounts of fuel much beyond the estimated life cycle need (Pearson, 1989). What if that were to change? Although cost for launch is decreasing, it is highly unlikely that a significant change in chemistry and physics will adjust that fact much beyond the margins. However, it is a near certainty that a market for on-orbit logistics focused on re-fueling and repair of space vehicles will occur. Experiments have occurred in the past, there are significant investments now (Kulu, 2023), and the market is forecast to expand greatly over the next several years. While it is cost prohibitive to launch satellites with large amounts of on-board fuel, many commercial satellite owners are seeing the cost benefit from on-orbit refueling and repair. Although that too will be expensive, it will be cheaper than either increasing initial fuel supplies or launching a replacement vehicle. The capabilities will arrive because a market demand signal is beginning to develop.

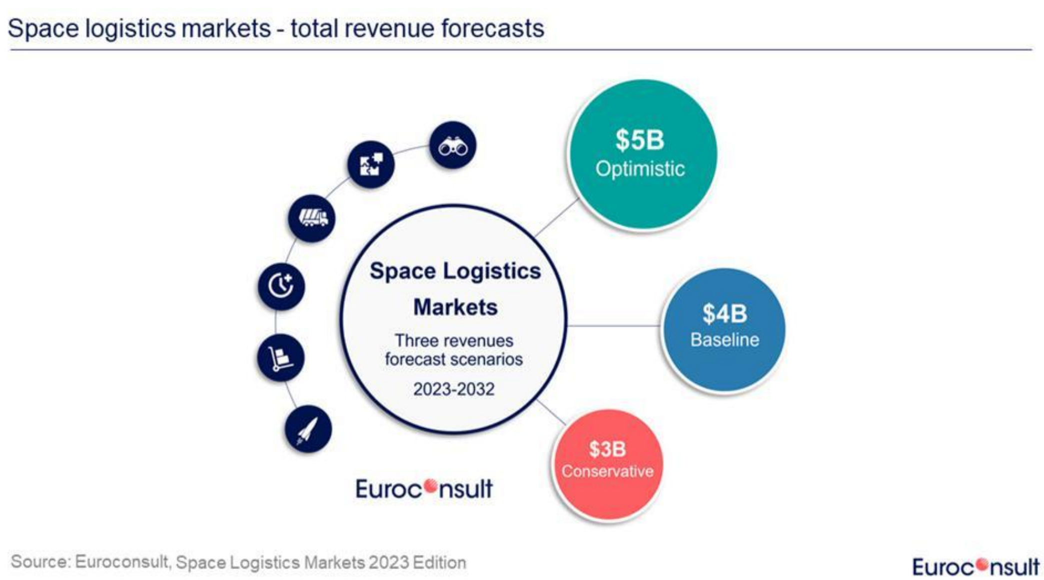

Figure 1. Space Logistics Markets – Total Revenue Forecasts
(Euroconsult, 2023, after para. 9)

In other warfighting domains, the U.S. government generally opts to rely on commercial logistics providers to deliver services to military forces (Dugan, 2014). The reasoning stems from a simple cost analysis: in a world where personnel and monetary resources are limited, contracting out enabling functions tends to allow placing resources toward more core functions. An example of this is the U.S. Army contracts with KBR to provide base support functions, such as power generation, living quarters, and hygiene tents in deployed locations (CBO, 2005). As these functions must occur, contracting for them allows the Army to concentrate personnel toward functions that are more closely aligned to the core mission, which is fighting and winning the nation's wars. Additionally, the argument can be made that while short-term costs are higher than if a military service performed it with organic capability, the longer-term costs are lower when factoring in associated costs with medical treatments and retirement pensions not applicable to contractors.

This paper assumes that space, as a warfighting domain, and the U.S. Space Force, as the military service focused on that domain, will follow this same pattern. However, the nature of space creates or expands certain risks that either do not exist or are of a significantly smaller scale in the domains other than space. These risks include increasing exposure of essential elements of information about capability, dependencies that could become fragile in times of conflict, and the net balance between friendly and challenger capabilities.

All this discussion of warfighting also must account for the changing context of a commercial, non-governmental presence in space. Traditionally a realm exclusive to the government, there has been an explosion of interest by the private sector to not only leverage space to increase commercial success but also enter a new market for commerce (Uwaoma et al., 2023). In the other domains, it can be simple for commercial actors to simply avoid an area of conflict. In most instances, commercial aircraft will avoid the airspace where wars are occurring, and maritime shipping will seek to avoid some routes. Orbital mechanics impacts both belligerents and non-combatants in a fashion that does not grant the same level of flexibility.

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Problem Statement

How should the U.S. government approach establishing logistic support in the space domain to best manage risks generated by contracting out to commercial vendors?

There are several potential models to approach establishing logistic support. Deliberate contemplation and discussion in these early days rather than closer to or during a crisis and conflict in the space domain offers a better opportunity to mitigate risk through informed decision-making. In this specific age, the innovation is less based on the technology for conducting on-orbit logistics, but rather on the policy stance toward creating the logistics support relationships.

Thesis

Deliberate consideration of relational models prior to the full establishment and utilization of a market by the U.S. government can lead to a potentially innovative policy stance. This paper does not discuss competing technologies that may be used for on-orbit refueling or repairs. There are market and engineering forces that will impact the outcome of those competitions. The paper assumes that a preferred technology will arise; the focus is on how the U.S. government uses that technology.

Research Questions

Primary Research Question

How might different policy stances toward private on-orbit logistics impact U.S. space control in conflict?

It should be noted that on-orbit logistics is limited in this paper to only refueling and repair operations. It does not account for launch operations, telemetry, tracking, and control operations, or data storage and processing operations.

Secondary Research Questions

A. Will on-orbit logistics necessarily be commercialized/privatized, and how much will be needed?

B. What role does maneuverability play within warfare and especially U.S. concepts of space control?

C. What policy models exist for the U.S. government to interact with emerging on-orbit logistic supply actors?

D. What role have PMCs played in the past, and what problems have developed from their use?

SHIELD Implications

SHIELD projects should seek to address technology, innovation, and policy. Due to the broad range of technologies being currently developed for this new field, this paper is bounding that aspect of the topic. While these technologies will arrive, it will be beyond the scope of this paper to determine which technologies or executions of technologies will be preferred within the space operations community. That is a function of several market and engineering factors that will be less susceptible to government influence than how the government and vendors interact. The innovation aspect of this paper is within the policy: making deliberate choices and analysis of potential policy models to establish the relationship between the U.S. government and commercial space logistics providers prior to need in conflict, creating decision space rather than waiting until a decision must be made.

Chapter II: Review of Relevant Literature and

Research The Crisis Evolves

As the terrestrial crisis continued to develop, with both sides posturing and justifying their preparation for a potential war over the territorial integrity of Taiwan, the already crowded orbital regimes were becoming ever more active. Each side began conducting RPOs against the space vehicles of their opponent. Knowing that certain orbital slots were more useful and important for one side, the other would seek to rapidly move a vehicle into that position to deny that opportunity and claim that the other side was operating in an unsafe fashion. Owners of commercial vehicles responded, nervous about the potential loss of their slots and of their vehicles, moving their flight paths at a rate they have never considered. The stresses to vehicles of all parties begin to manifest with equipment failures much sooner than what was predicted during their design.

The owners and operators of the flying gas stations, those space vehicles that can provide fuel or repairs begin to see a catastrophic success: the demand for their services is skyrocketing, which should be reflected in outstanding quarterly profits. But can they meet all the demand? From a business perspective, 'it is a wonderful position to be so busy that you must turn away work.

The Emerging On-orbit Logistics Market

On-orbit logistics is poised to become a burgeoning marketplace for investment, as the space industry expands and commercial activities in space proliferate. With the increasing number of satellites, space stations, and plans for lunar and Martian habitats, the demand for on-orbit logistics services is expected to soar (Lissy et al., 2023). Companies like SpaceX, Blue Origin, and Northrop Grumman are already investing in reusable rockets and spacecraft to lower the cost of accessing space, thereby facilitating more frequent missions for logistics purposes

(Sippel et al., 2023). The overall commercial market driver is a simple cost-benefit analysis: although on-orbit logistic services are expensive, it is still less expensive than the complete replacement of a high-value piece of capital machinery in the form of a space vehicle.

This argument even extends to the current trend toward proliferated LEO (pLEO) constellations such as SpaceX's Starlink. While most pLEO concepts envision disposable components, there are parallel discussions about logistic services for these types of constellations from minimizing debris and de-orbiting (Bronson & Gladstone, 2023). It is likely that as more companies deploy these types of constellations, there will be more cost savings in conducting on-orbit refueling and repair in some situations rather than a blanket decision to dispose of vehicles.

The overall technology is not new. In 2007, the Defense Advanced Research Projects Agency (DARPA) experimented with the Orbital Express program aimed at developing a "safe and cost-effective approach to autonomously service satellites in orbit." (Boeing, 2006, para.1) Throughout that year, two small experimental satellites performed several rendezvous and proximity operations (RPOs) to demonstrate the viability of providing refueling and repair operations. It should be noted that no fuel was transferred in these experiments, but the concept was proven to be technically feasible.

The commercial market is already beginning to anticipate the opportunities for on-orbit logistics, whether to take advantage of services or to provide those services. Government investment is beginning to flow (Erwin, 2023). General market forecasts for space logistics show an eye-watering acceleration of potential profit over the next few years (see Figure 2). But where money flows, human conflict tends to also happen.

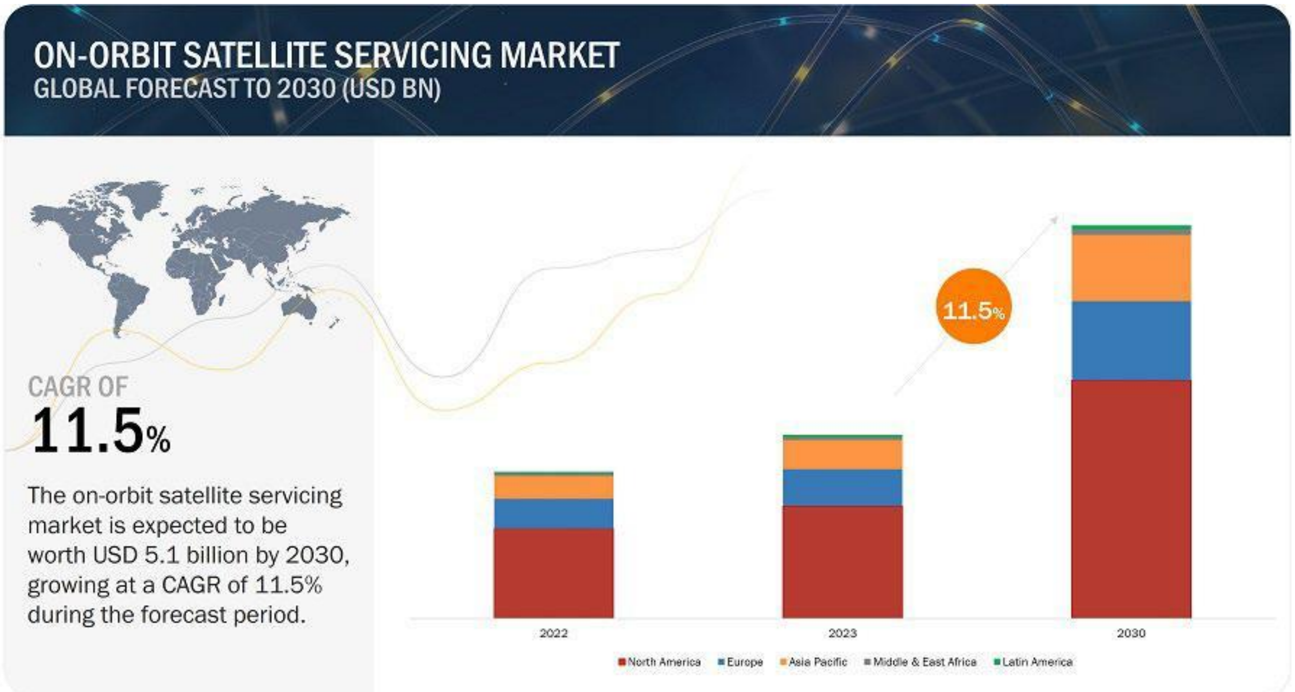

Figure 2. On-Orbit Satellite Servicing Market (MarketsandMarkets.com, 2023)[1]

Conflict in Space

There has not yet been a full conflict in space. Four states have tested weapons against satellites (Stroikos, 2023), and one state has fired a weapon in anger against a ballistic missile about to re-enter the atmosphere (Giveh, 2023). It is wishful to think that as more states become space-faring, terrestrial conflicts will not extend to space. Human history has so far demonstrated that conflict follows human expansion into a new domain. That is likely to hold true even if humans are only placing proxies in the form of unmanned space vehicles to execute the fight. Assuming conflict will occur between state actors in space means that we must attempt to understand how the character of war may be unique to this specific domain.

1 https://www.marketsandmarkets.com/Market-Reports/on-orbit-satellite-servicing-market-206789424.html

Each domain offers slightly different characteristics of warfare at the tactical, operational, and strategic levels. Yet there are two commonalities across all domains and time. These commonalities are somewhat reductive, but they are firepower and maneuver. Firepower is the ability to negatively affect an opponent by the application of energy. Maneuver is placing oneself in a position of advantage or placing oneself to deny a position of advantage to an opponent (Biddle, 2004). Modern society often frames firepower with gunpowder and explosives, however, even the contact of a bladed weapon on a body demonstrates the application of energy: the point of a sword thrust into an opponent delivers energy in the piercing just as much as a cannon ball fired from a deck mounted cannon is delivering energy as it careens into an enemy ship. It is at its core about motion.

Space, whether as a warfighting domain or not, is about motion. Orbital mechanics and physics mean that motion is always first and foremost. A space vehicle in a geostationary orbit, a subset within the GEO orbital regime, appears to hang in the same spot over the Earth but is traveling approximately 3 kilometers per second (ESA, 2020). This means that in warfighting, maneuver is the dominant aspect. The ability to get into an orbital slot or maintain a station and position is necessary to perform a mission or, conversely, deny your opponent the ability to perform their mission if they need to be within that particular orbit. This is like Corbett's concept of fleet-in-being, where simply positioning a fleet in a specific maritime location can prevent an opponent from establishing a desired dominance or superiority of that body of water (Corbett, 1911). Through this lens, maneuver itself becomes a form of firepower in the space domain. The application of energy to gain an orbital position before an opponent, to force an opponent out of a position, or to interpose a space vehicle between an opponent and its target, such as a ground station, requires the transfer and expenditure of energy for a specific purpose of conducting a mission or denying an opponent the ability to perform a mission.

But energy, at least in the form of thrust and fuel needed to make that push, has always been the weak link in the chain—the limiting factor for space vehicles. To shift from one orbital regime to another, or to shift from a cislunar pathway to a terrestrial center orbital regime requires significant expenditure of energy and for decades has not been considered viable. It has been cost-prohibitive up to this point to perform such maneuvers on a useful scale, and so space vehicle design has generally been structured around the orbital regime where the vehicle will operate.

The emerging market described previously would remove that constraint and open a whole new realm of maneuvering possibilities. Orbital mechanics will not change, but the removal of fuel constraints will make orbital mechanics a consideration, not a limit. This perspective sets the stage for warfighting concepts that include both offensive and defensive maneuvering and shifting between orbital regimes. These options can be pursued if the supporting logistics are in place; logistics are the key enabler for such concepts. Without the fuel, nothing moves.

The PRC has determined that it should have these refueling and repair capabilities as an organic capability (Burke, 2024). The entering assumption of this paper is that the U.S. government will not pursue a similar pathway. Instead, it is assumed that while the U.S. government may acquire some organic refueling and repair capabilities, it will not be at a level to be self-sustaining. Instead, the U.S. government will pursue a pathway like other domains and contract out these logistic services, which raises the question of how should the U.S. government approach this contracting. There are multiple models of support contracting that the U.S.

government has or could use for these capabilities. Each model establishes different forms of risk, some acceptable, and some not acceptable.

Models of Interaction

Three distinct models of interacting with the commercial market space exist, have scholarly literature attached to them, and can be placed within a space context. The first model is traditional, market-driven acquisitions in support of government activities, much like the way U.S. space capabilities are currently procured. The second model is private military corporations, especially those that perform or provide services up to and including combat operations for a government employer. The third model is establishing a voluntary, cooperative program with logistics providers like the Civil Reserve Air Fleet (CRAF), the Voluntary Intermodal Sealift Agreement (VISA), or the nascent Commercial Augmentation Space Reserve (CASR).

Traditional, Market-driven Acquisition and Procurement

Traditionally in space flight, the U.S. government has assumed a monopsony. That is, there is a single or massively dominant purchaser of goods and services within an industry. In this case, the monopsony is held by the U.S. government (Park, 2023). While commercial, private satellites have existed for over fifty years, as a percentage of the population, they have remained small. This environment suggests that almost all launch, terrestrial logistics, and support were purchased by a single customer, the U.S. government. However, that is changing not only with an increasing number of space-faring nations but also with a larger commercial sector owning privately held space vehicles (UCS, 2023).

Despite these environmental changes in the marketplace where the monopsony may be de-throned, this default policy model is how the U.S. government engages with the space industry. As such, this structure serves as the baseline model for this paper. From a principal-agent perspective, this model modifies several basic assumptions: the agent will only deny the service to the principal due to capacity constraints and not due to any agent preference, objective, or an option to provide service to a more preferred principal. It also assumes that a special case of adverse selection, in which the agent agrees to a non-favorable price for the service based on incomplete information about true cost or due to a lack of other principals with whom to create an agreement does not exist.

Private Military Companies

Private military companies (PMCs) are independent businesses that offer a variety of services related to warfare and conflict, often taking on the duties and responsibilities otherwise done by conventional military forces, such as logistics, strategic planning, training, and security. While PMCs have existed for hundreds of years, modern PMCs have seen a significant resurgence over the past thirty years.

With the end of the Cold War, the geopolitical landscape began to generate a variety of novel challenges while military budgets shrank. With the concomitant surplus of military equipment and discharged soldiers, a market opportunity arose (Singer, 2001). States, especially the United States, often concluded that paying a higher short-term rate for a service provided by a PMC was preferable to the longer-term cost of having and maintaining an organic capability. Logistics support for ground forces is a prime example: in the 1990s, the U.S. Army reduced the size and scope of its logistics units, focusing active-duty capability on the tactical and operational edge (Kidwell, 2011). This process meant operations, such as all the peacekeeping efforts in the Balkans and Operations Enduring Freedom and Iraqi Freedom, required PMCs to provide much of the logistics support: building and maintaining temporary housing, the feeding of thousands of military personnel, etc.

PMCs mitigate if not outright close risks in capability areas for military forces otherwise not wanting to maintain a capability, which is a classic use case for the principal-agent model. The costs, in the short term, are quite high because the agent takes on significant risk: capabilities and tasks placed and performed in or near combat have the real risk of loss of life or equipment. The high cost charged to the principal mitigates this risk to the agent.

Yet, PMCs are also costly to oversee for the principal. Incidents involving Blackwater in Iraq demonstrated this concern to the U.S. government in terms of loss of life among both Blackwater contractors and Iraqi civilians. The U.S. realized that their policy positions, based on the baseline model laid out in the previous section, were ’not sufficient for PMCs, mainly because oversight was not structured to address the potential for combat losses or engagement by PMCs (Palmer, 2018). This model then acknowledges the need for increased oversight by the U.S. government regarding the behaviors of the agents to ensure that the agents are not dragging the principal into a different, non-mandated direction, as Blackwater did to the U.S., resulting in the first Battle of Fallujah (Ballard, 2006).

Contingent Civil Reserve

In 1952, the United States government mobilized a significant number of civilian aircraft to assist with the Berlin Airlift. Following this endeavor, the Civil Reserve Air Fleet (CRAF), also known as the United States Mobility Reserves, was established to systematically support military needs during national emergencies or when airlift demands surpass military aircraft capacities. The CRAF consists of both international and national (domestic) segments. The international segment is further categorized into long and short-range, while the national segment varies based on mission requirements (Command, 2023).

CRAF aircraft bolster the capabilities of the Air Mobility Command's fleet of C-5s and C-17s, primarily supporting long-range transatlantic operations. Additionally, short-range (medium) aircraft fulfill passenger and cargo requirements for intra-theater airlift operations. In exchange for contractual agreements and a commitment to allocate a minimum of 40% of passenger and 15% of cargo capacity from the U.S. registered cargo fleet, participating companies in the CRAF program benefit from peacetime airlift business opportunities facilitated by the U.S. Government (Command, 2023).

Since its inception, the Civil Reserve Air Fleet (CRAF) has played pivotal roles during Operation Desert Shield, Operation Iraqi Freedom, and Operation Allies Refuge in Afghanistan. In 2010, Secretary of Defense Robert Gates emphasized the imperative for stringent scrutiny of military expenditures, noting, "Military spending on things large and small can and should expect closer, harsher scrutiny… the gusher has been turned off, and will stay off for a good period of time...It's a simple matter of math" (Shanker, 2010).

Today, defense spending, particularly concerning space assets, faces similar scrutiny. This continues to this day in the National Space Strategy:

- "Develop Government space systems only when in the national interest and no suitable or cost-effective United States commercial or, as appropriate, international commercial capability or service is available or could be available in time to meet Government requirements" (National Space Policy, 2020, pg. 20).
- "Prioritize partnerships with commercial industry to meet Government requirements through the modification of existing commercial space capabilities and services when potential system modifications represent a cost-effective and timely acquisition approach

for the Government and are consistent with system and mission-security practices and principles" (National Space Policy, 2020, pg. 20).

- "Pursue opportunities for transferring routine operational space functions to the commercial space sector where beneficial and cost-effective and consistent with legal, security, or safety needs" (National Space Policy, 2020, pg. 21).

To address this set of concerns, the U.S. Space Force is working to create CASR, the Commercial Augmentation Space Reserve, as a solution aligning with the President's space policy objectives. Advocates highlight the diminishing dependencies on traditional capability development channels and the reduction in reliance on exclusive technology. It claims to foster robust partnerships with the commercial sector through facilitating data and personnel exchanges (King, 2023). The claims by CASR supporters of portfolio diversification and optimization of utilization of military assets under the purview of combatant commanders are taken at face value for this paper.

From a model perspective, this aligns well with principal-agent theory, seemingly the same as the traditional method. However, because execution is sporadic or contingent only on the declaration by the principal, oversight and enforcement must take on different facets. Additional consideration must be made for hypothetical situations that may make the execution of the contract non-viable for the agents and for situations that may cause the agent to back out of the previously penned agreement.

Conclusion

With the three models in hand, a set of criteria can be established, and each model can be judged for levels and types of risk created. Defining the criteria and the underlying theoretical framework is presented in the following chapter.

Chapter III: Research Methodology

Research Approach

This paper is grounded in principal-agent theory. A principal, the U.S. government in this case, which is either unwilling or unable to develop an organic capability for on-orbit refueling and repair, creates a contractual relationship with an agent within the potential market of on-orbit logistic providers. The principal provides resources, and the agent in return provides the good or service requested. For purposes of this research, there is a special case that must be considered, which is moral hazard (Braun & Guston, 2003).

It is assumed in the base situation that both the principal and agent are oriented toward an objective identified by the principal and that the agent is using provided resources to achieve that objective. The special case of moral hazard is the condition where the agent diverts resources provided by the principal toward its preferred objectives rather than the contracted objective. To prevent or correct this behavior, the contract should include mechanisms for the principal to perform oversight of agent performance and enforcement mechanisms if the condition of moral hazard begins to emerge (Dutta & Radner, 1994).

This theory creates a lens to address four key factors to compare how each of the relational, or contractual, models may unfold to identify individual strengths and weaknesses. In turn, it creates a consistent comparative space to assess which, if any, model poses a clear advantage for the U.S. government.

Operational Security

The first factor deals with the potential exposure of essential information about a friendly capability that may be revealed through contractual on-orbit logistic activity. The doctrinal concept of critical unclassified information establishes that certain aspects of information may provide insight about current and future operations that a commander may otherwise need to hold as private information to gain an advantage over an enemy (CJCS, 2012). The ability to dynamically maneuver a space vehicle and the logistic support needed to perform that maneuver fall into that category. It speaks to both the potential current limits of an observed space vehicle as well as potential future actions by an actor with that space vehicle.

Keeping the exposure of the essential elements as low as possible in almost all cases is the preference of the principal. There may be some instances where revelation is useful for deterrence, but this paper considers that as a special case, not the norm. For a commercial provider of logistic services, the preference is to advertise the provision of support. It transmits a positive message to shareholders that profits are likely to be high and potentially generate more business. There is a clear misalignment between the principal and agent.

This misalignment can change from model to model, and certain models provide a greater opportunity for the principal to explicitly address their equities within the contracting process. In the analysis, this factor has the shorthand label of OPSEC (operations security).

Monopsony to Monopoly

The second factor deals with the potential to increase moral hazard when the principal establishes a fixed dependency on a single or limited set of agents. Although the space domain has been primarily a monopsony, with the U.S. government being the primary purchaser, the situation can quickly shift to monopoly if decisions are made to only rely upon a single vendor. There can be an inversion of the power dynamics within the contract binding the principal solely to an agent. There have been two high-profile instances just within 2023. The Wagner semi-coup within Russia (Gurbanov, 2023) and Space X limiting the U.S.-paid-for Starlink access to the Ukrainian forces targeting of invading Russian forces (Henderson & Lisk, 2023) demonstrate the potential hazards. The shorthand for this factor in the analysis is Dependency.

Crowded Out

The third actor also deals with the potential collapse of a monopsony into a true market. If a variety of principals appears to seek the goods or services of a pool of agents, there is a dilemma for the agent on principal selection. This situation assumes that the agent pool is large and diverse enough so that a monopoly is not formed, but that the collective output of the pool does not fully satisfy the market demand. Such scenarios often result in one of two (or both) conditions: that a principal or principals will be unable to contract for any services, or a bidding war will occur driving up costs to an unreasonable rate. This predicament is different from a moral hazard problem, as it illustrates the multiple-principal problem. An agent is presented with a choice among principals to establish a contractual relationship, and so by extension, the agent can break a relationship with the knowledge that another principal may be found (Hu et al., 2023).

In the case of on-orbit logistics in times of crisis or conflict, this scenario offers an offensive opportunity. A government, seeking to deny any potential challenger also needing logistic support, could attempt to shift the true market back to a monopsony for the specific purpose of denying a challenger from gaining needed support. This consequence would hinder the opponent’s ability to maneuver within the domain, placing their plans in other domains at serious risk. The shorthand for this factor in the analysis is Scarcity.

Rising Cost

The fourth factor is quite simple: agents may demand increased resources due to the changing environmental conditions in times of conflict. While the symptoms of increased cost can be the same as the previous factor, the logic behind it is quite different. When the contract between principal and agent is made, each party has some understanding of the costs based on the contextual conditions. Crisis and conflict between space-faring powers, however, have not yet manifested. Neither side, principal nor agent, truly knows what the costs will be in terms of risk to capital assets. As the potential for crisis and conflict becomes more real, there is significant potential that an agent could determine that a principal is an unattractive partner and either refuse engagement or break a contract. This situation is especially true if a challenger declares that any space vehicle, even if privately owned, is a legitimate target in times of conflict.

This dilemma creates a significant defensive quandary for government actors. As the reverse of the previous factor where all services may be bought up, this factor simply denies a principal access to the market because working with them is deemed to be too great a risk, much like a careless driver who is now uninsurable because of too many accidents. The shorthand for this factor is Premium.

Research Process

This paper relied almost exclusively on secondary source material with some personal insights being gleaned from off-the-record discussions with personnel associated with some U.S. government efforts. Any insights gleaned were only included when a secondary source could be found to anchor as a citation.

Chapter IV: The Analysis

Introduction

This chapter examines each of the three models against all four factors in times of crisis and conflict. Each model is presented with a vignette of how that model may play out in the scenario presented at the start of the paper. Then, how the model weighs against each factor is considered.

Traditional, Market-Driven Acquisition and Procurement

Weeks of shuttle diplomacy and many late-night debates within the UN Security Council resulted in no easing of tensions in the Taiwan Strait or above the Earth. Incidents of spoofing, jamming, and aggressive RPOs continued to mount. Dynamic operations burned fuel supplies, as keeping U.S. high-value assets reaction ready to avoid PRC interference became a top priority. This struggle was indeed a boon for the service providers, and their announcements of newly gained government funds and successful operations supporting U.S. satellites flooded their social media feeds, assuring shareholders that their fiscal health was strong.

Of course, that changed days before the invasion commenced. Every vendor providing on-orbit logistics to the U.S. government suffered massive cyber-attacks, from data deletion to full loss of telemetry, tracking, and command (TT&C). With no opportunity for logistics support for an unknown time in the early moments of the conflict, U.S. space assets were sitting ducks for PRC interference, unable to provide necessary support to the other military services trying to fend off an invasion.

This model, the baseline, is simply the continuation of current practices. The U.S. government remains the primary, almost sole purchaser of on-orbit services. However, providers will constantly seek to increase their customer base and assure their investors that their business model is successful. This condition means continual media presence and announcements of business successes, creating a great deal of risk within the OPSEC factor. How the diversity of potential vendors will manifest is not quite as clear. Currently, the U.S. government appears to be favoring start-ups in many space fields, including logistics. This type of behavior tends to indicate that Dependency will be a low risk, and there will be multiple potential vendors with whom to contract. However, the U.S. government in dealing with space has fallen into a dependency situation before with launch, broken up only by the recent entrance of newer launch vendors such as Space X, and may fall into it again with pLEO with a heavy reliance on Starlink and Starshield (Feldstein, 2023). Should Dependency have a low level of risk, then Scarcity is likely to covary in the opposite direction if predictions about an ever-increasing demand from the commercial space vehicle sector grow as well. A larger potential set of customers for any given vendor will give them freedom to pick and choose with whom they do business, and as a crisis moves into conflict, the government actors actively participating in that conflict may not be an attractive client. This context is mirrored in the Premium factor, where vendors who do not simply break a contractual relationship are likely to demand significant resources from the U.S. government. These demands may be much more than just fees, but as challengers are already speaking about the validity of targeting private space vehicles used by a government entity in a conflict (Gadkari, 2023), there will likely be requirements to protect and defend resources, such as increased cyber defenses provided by the government or even reimbursement for logistics needs by the vendor: paying a premium not only for the re-fueling but also for the re-fueling needs of the re-fueled to avoid attack by another actor. All in all, this model shows likely high levels of risk to the U.S. government in a conflict in three of the four factors, with only Dependency needing little mitigation (Table 1).

Market-Driven	OPSEC	Dependency	Scarcity	Premium

Table 1. Risk Summary of Market Driven

Model **Private Military Companies**

Even while the diplomatic corps around the world tried to stave off a war between the U.S. and PRC over Taiwan, both sides continued their terrestrial preparations and continually sparred in LEO and GEO. As the weeks wore on, the activities above the atmosphere became increasingly aggressive between the players. Then, the number of players expanded when PRC satellites began aggressive RPOs against not only U.S. government space vehicles but also against those of U.S.-based companies. Some of those companies lost their on-orbit assets. Others, especially those providing refueling and repair to government systems, fared better; their movements and actions closely coordinated with the larger U.S. Space Force fleets.

When the invasion began, the opening moves occurred in space with a blitz of reversible and non-reversible electronic attacks and attempted kinetic strikes from the PRC. The blow was severe, but manageable and recoverable with the U.S. preserving sufficient capability on-orbit to support decision-making and operations in all the other domains, enabling them to blunt the larger attack.

The PMC model is an aggressive change to traditional U.S. attitudes toward space. This transition would make the enactment of this model difficult, but not impossible, and raises the question of how it performs against the four factors. The risk level in OPSEC is likely to be low. The incentives to publicly advertise the relationship and activities in support of the U.S. government are not prevalent. Incentives can be built into the contracted relationship to explicitly hamper discussion of the relationship. Dependency is likely to have a high level of risk, as it is unlikely that many vendors would be willing to accept the higher levels of risk during conflict or any constraining requirements created by a contract seeking to keep OPSEC factors low. Scarcity again co-varies with Dependency, going low as Dependency goes high due to similar logic. Vendors that have determined they will engage in this form of relationship with the U.S. government are unlikely to disengage when conflict breaks out. Premium will also remain high but with a special benefit. Contracts built under this model are almost certainly going to reflect generous compensation for the increased risk to agents in times of conflict as well as the allocation of potential protect-and-defend resources provided by the government to the vendor. Yet, the vendor may also develop their defensive tactics, techniques, procedures, or even capabilities, which may turn out to be best practice and provide overall increased capability to the U.S. government. In total, this model is more likely than not more expensive than any of the others. However, the operational risk and potential benefits in times of conflict are quite attractive (Table 2).

PMC	OPSEC	Dependency	Scarcity	Premium

Table 2. Risk Summary of PMC Model

Contingent Civil Reserve

After the first month of increased, aggressive actions in orbit between U.S. and PRC space vehicles, each seeking to gain insight into deployments and potential mobilizations for an invasion, the U.S. conducted a partial mobilization of CASR. This partial mobilization focused exclusively on logistics capabilities, ensuring that U.S. constellations could continue to maneuver and perform their missions during the heightened tension. As the crisis kept unfolding and an increasing number of commercial vendors began to increase their maneuvers in reaction to both U.S. and PRC actions, the overall demand for services from multiple potential customers *grew. However, the CASR mobilization hamstrung many vendors, leaving them looking wistfully at lost profits, as potential new customers got their services from competitors.*

When the invasion began, CASR vendors found themselves lumped alongside U.S. assets in being targeted by offensive PRC actions. The cost to the vendors, in terms of actual and potential profit and asset loss, became too great, and many vendors began to remove themselves from the CASR agreement.

The CASR model shares many similarities with the baseline model; it can be considered a branch of that model. Yet, the outputs of the factors are different. OPSEC is somewhat mitigated as participation in CASR does not require continual advertisement to generate business or assure investors. As a contingent service, this model only becomes applicable when enacted. Dependency increases, as there will be little-to-no ability to pursue services outside the CASR agreement, subjecting the U.S. government to a small set of potential vendors. Scarcity and Premium are likely to covary in the same direction in this model, with both being high. Because the other domain examples, CRAF and VISA, have not been tested in a conflict environment where assets are endangered and entrance into the agreements and subsequent contracts are voluntary, it is not unreasonable that vendors might back out at an inopportune time or demand significant additional resources to mitigate the assumed risk. This model, although a variation on the baseline inverts the issues with OPSEC in a positive fashion but loses ground in dependency (Table 3).

CASR	OPSEC	Dependency	Scarcity	Premium

Table 3. Risk Summary of CASR Model

Conclusion and Future Research

Putting the three models side-by-side, no single model leaps forth as having a clear advantage (Table 4). Each one has inherent drawbacks and benefits. From a simple, evenly weighted comparison perspective, the PMC models offers the least total amount of risk. However, that determination is a highly flawed conclusion. Risk is inherently associated with value, and so there must be some differentiation and weighting among the factors. When examined from a policymaker's perspective, some factors will be more important than others. Unfortunately, these values will differ between policymakers and over time even within the same policymaker.

Market-Driven	OPSEC	Dependency	Scarcity	Premium
PMC	OPSEC	Dependency	Scarcity	Premium
CASR	OPSEC	Dependency	Scarcity	Premium

Table 4. Risk Comparison of All Three Models

This dynamic opens a clear door for future research on this topic. An obvious pathway to build on this would be to survey a wide swath of policymakers to gain insight into what a likely realistic weighting of factors may be. This evaluation would allow for a new analysis of each model under the weighted conditions to see if one model does become a clear front-runner.

Several covarying relationships were identified in examining models. However, in most cases, the same type of covarying did not carry from one model to another. This examination would be a fertile area for additional research to isolate the logical mechanisms to determine how or if that relationship might be broken. This investigation could allow for modification of a given model to isolate high-risk factors and implement mitigations without impacting the formerly covarying factor. That would also open the door for developing a hybrid model, taking the most desirable factors from different models and creating a new method.

What can be concluded from this research is that no one model can be recommended without some hesitation or caveat about the weaknesses of the model. However, as it is more likely than not that the U.S. government will have to engage with commercial vendors for on-orbit re-fueling and repair very soon, it is recommended that serious thought be placed into which model will be used rather than simply act as it has in the past.

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