CENTER FOR SPACE POLICY AND STRATEGY

APRIL 2020

SLASH THE TRASH: INCENTIVIZING DEORBIT

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Summary

There is likely to be a surge of satellites launched into space over the next decade, which means the risk of collisions in space will rise along with risks to the sustainability of the space environment from debris. How can the sustainability of the space domain be protected in a looming new era of increasingly congested space? How can the international space community reduce these risks and make them more manageable? One vital method is for satellite owners and operators to voluntarily comply with the already internationally agreed-upon guideline to deorbit satellites no longer than 25 years after the end of their mission. This paper outlines five distinct concepts to incentivize compliance with the "25-year rule" and provides a framework for analyzing the merits of each concept. It focuses on commercial satellites in low Earth orbit but could be applied more broadly.

Introduction

Since the Space Age began more than 60 years ago, almost 9,000 satellites have been placed in orbit, with about 5,150 still there and about 2,207 of those still operational as of October 2019.[1] In 2019, commercial companies proposed satellite constellations ranging from around 1,000 to 30,000 satellites each, totaling 46,000 or more new satellites in orbit over the next decade. This potential rise in the number of satellites in such a short period of time means the risk of collisions in space will rise. The resulting space debris, along with the new vehicles themselves, will affect the overall sustainability of the space environment. While it is unlikely that all the planned satellites will be launched, we are on the cusp of a fundamental change in the space environment.

Some satellites function for decades but many cease to be useful after only months or a few years. "Dead" satellites, or satellites that have reached end-of-mission life, can remain in valuable and densely populated orbit regions and present major risks to the space environment—all related to debris. Dead satellites can collide with other satellites—dead or alive—generating debris.[2] Additionally, a dead satellite can break up when old batteries or leftover propellant explode, creating a cloud of expanding space debris. The bigger the satellite, the more debris that can be produced from an explosion or a collision. Debris is dangerous to both satellites still performing their mission and to other debris objects. Similarly, debris does not discriminate between targets from the commercial or government sector.

For decades, the international community has been aware of the growing risk to orbital operations caused by space debris. One of the most important principles created internationally is from the Inter-Agency Debris Coordination Committee (IADC) and is drawn from the 2002 *IADC Space Debris Mitigation Guidelines*, which recommends that satellite operators should remove spacecraft and orbital stages from useful and densely populated orbit regions no longer than 25 years after mission completion.[3] It started as a 25-year guideline that has been incorporated into some regulation and, hence, is often colloquially referred to as the "25-year rule." This rule helps operators be responsible users of space by protecting and sustaining the operational environment for all users.

Analysts and scientists argue that the simplest and most efficient way to mitigate the growth of space debris is for satellite operators to increase the rate of compliance with the 25-year rule. Unfortunately, compliance rates have been poor,[4] and there is growing need for drastic improvement. In addition to the imminent boom in the number of satellites, an increasing diversity exists in both the size and capability of satellites and satellite constellations. The current approach will not scale to the expected increases from satellite constellations consisting of hundreds or thousands of satellites. Nor does the current approach account for the short mission lives of CubeSats, which represent a growing sector of the satellite industry. In fact, a 2015 NASA report found that one out of every five CubeSats launched between 2003 and 2014 violates international deorbiting guidelines.[5] The projected increase in collision risk could be mitigated by complying with the 25-year rule and reducing the overall number of years in orbit after the end-of-mission life, especially when considering relatively short mission lifetimes.

Commercial satellite owners and operators need better incentives to comply with the 25-year deorbit rule and reduce the overall number of years that dead satellites occupy the most crowded orbits. Five distinct concepts to incentivize voluntary compliance to deorbit and a framework for evaluating them or any other voluntary deorbit concept are discussed herein.

Deorbiting a Satellite from LEO

This discussion focuses on low Earth orbit (LEO) satellites, but similar concepts could be applied to other orbits. Satellites in LEO are used for remote sensing, Earth observation, human spaceflight, and more. LEO is the most crowded orbit.

Satellite operators use two primary means to deorbit a satellite from LEO. Satellites below 600 km will naturally deorbit within 25 years due to drag from the atmosphere. This is very efficient for operators since they do not have to take any action or incur any costs; however, it still poses a risk to other satellites in operation as the unguided satellite passes through lower altitudes.

On the other hand, satellites above 600 km generally do not deorbit naturally within the 25-year time frame and require direct action to comply. In fact, this is where the greatest concentration of LEO satellites resides—from 800 to 1,000 km.[6] Complying with the 25-year rule generally requires a guidance system and the use of thrusters or deployment of a drag enhancement device to lower the orbit. Satellites are not required to have this capability and controlled reentry comes with costs. Many satellites can complete their mission without these capabilities and without the added expense in terms of satellite complexity, weight of thrusters and propellant, or drag enhancement devices. Designing a satellite with such added weight and complexity simply to crash it into the atmosphere at the end of

An ***uncontrolled reentry*** is when a spacecraft's orbit naturally decays through lower orbits until reentry. The reentry location is undetermined beforehand and poses possible risk to people and property if components survive reentry. This is more the case for upper stages than for satellites.

A ***controlled reentry*** is when the spacecraft fires its thrusters to place it on a trajectory to avoid objects in lower orbits and reenter—usually in an unpopulated region in the South Pacific.

Controlled reentry is the preferred means to deorbit but requires functioning guidance and control systems with thrusters.

its mission provides no direct gain for the owner or operator in terms of accomplishing the satellite's mission or in generating revenue. Meanwhile, some satellites have thrusters and propellant to enable their functionality and make them profitable. Using the propellant to deorbit—to crash and burn—then, reduces the profit made from that satellite. Without economic or other incentives for timely, controlled reentry, operator compliance with the 25-year rule for orbits above 600 km will likely remain low. See Figure 1 for how long it typically takes satellites to naturally deorbit as a function of their altitude.

Benchmark Guidelines

Space activities occur in an inherently international context. The 1967 United Nations (UN) Outer Space Treaty[7] establishes that all states are equally free to use space and have the right of freedom of access to space. It also establishes that no state can claim sovereignty over any part of space and prohibits the testing and placement of weapons of mass destruction in space. As of January 2019, 132 countries have either ratified or signed the treaty.

The 1972 UN Space Liability Convention[8] makes a country liable for damage caused by objects launched from its soil. As of January 2019, 116 countries have either ratified or signed the treaty. Many of them developed corresponding domestic licensing regulations with varying levels of attention given to mitigate debris and reduce chances of collisions. For example, the *U.S. Government Orbital Debris Mitigation Standard Practices* established in 2001, and updated in 2019, has a 25-year deorbit rule similar to the French *Space Operations Act* from 2010. Both the U.S. guideline and the French law state that a satellite or launcher element shall reenter the Earth's atmosphere no more than 25 years after its end of mission date naturally or by performing a controlled reentry.[9]

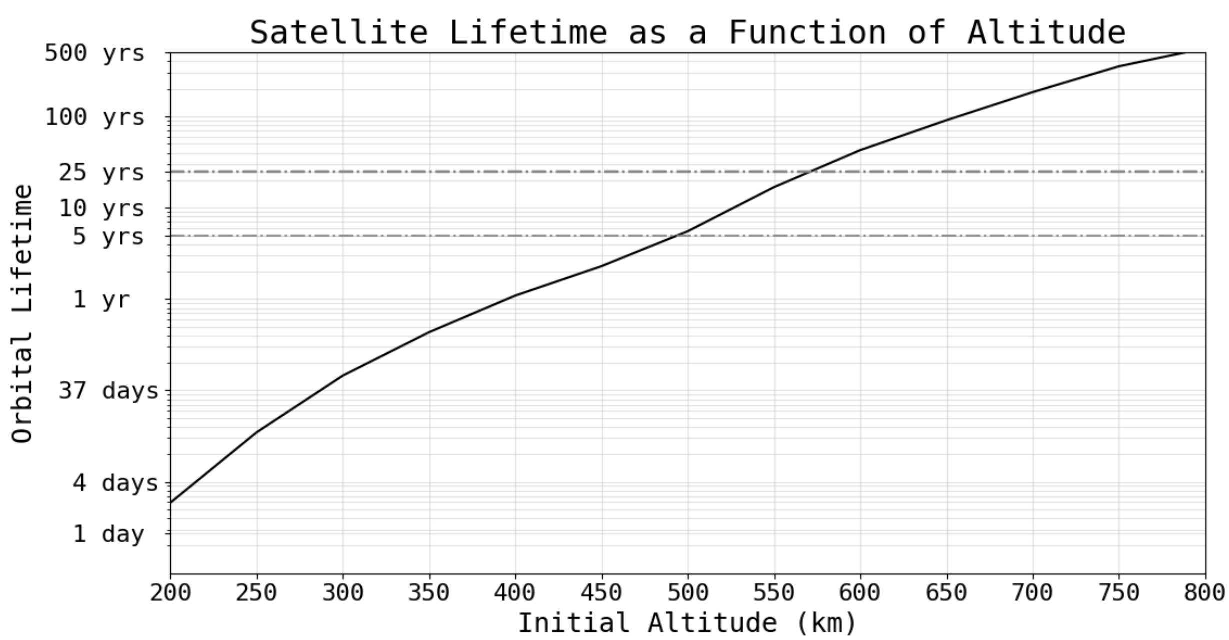

Figure 1: Approximate time it takes a satellite to naturally decay given a starting altitude. *Specific reentry times depend on size and other parameters.*

As mentioned previously, the IADC debris guidelines came into being in 2002 and were used as a basis for the 2007 UN Space Debris Mitigation Guidelines. In 2019, the International Organization for Standardization (ISO) issued standard 24113, which aims for a 90 percent disposal success rate. Important to note is that these most recent attempts to limit debris are *nonbinding* agreements, and organizations and governments are encouraged to use them when mission planning. At a minimum, they are politically binding. Besides the Outer Space Treaty and the Liability Convention, there are no international, legally binding agreements that restrict or mandate actions in space, including deorbiting.

Although scholars are divided on the topic, high value, widely used regions of space such as LEO could be viewed in economic terms as a *common pool resource*.[10] Common pool resources are typically defined as goods that are "rival," meaning that one actor's consumption of the good prevents another from also consuming it, and which are relatively "non-exclusive," meaning that it is costly to prevent others from consuming them. Key orbital regimes can be susceptible to overuse, where all stakeholders will have diminished benefits if each pursues maximum activity at minimum cost in their own narrow self-interest, largely due to the increased risk of collisions creating debris that will reduce the statistical life of other missions. The Outer Space Treaty gives all states equal rights to access space and conduct missions there. Classic examples of common pool resources in the economic literature are open ocean fish stocks and underground water sources that cross borders.

Existing international treaties and guidelines, as well as domestic laws, have been useful in avoiding some of the classic tragedies of the commons in space but may not be sufficient. With large increases in activity planned in LEO, considering additional methods to effectively manage that orbit is timely. Indeed, many satellite companies desire an international solution to develop and enforce end-of-mission requirements according to a 2015 report on space debris.[11] Interviews with more than 80 commercial satellite operators show they understand the consequences of overuse and indicate that companies might be willing to bear some costs to maintain the space environment. The commercial satellite sector functions like other commerce in a competitive global marketplace; that is, it crosses borders and is incentivized by maximizing profit. A single country cannot set deorbit requirements without potentially losing commerce to other countries as owners and operators seek to avoid the higher costs of compliance (e.g., shorter mission life, satellite propellant, thrusters, and complexity) by moving elsewhere. This also encourages new spacefaring countries to not regulate as heavily or follow costly, voluntary international norms as they try to attract space commerce to their shores. Analyzing key orbital regimes through a common pool resource lens provides some ideas on several paths forward.

A Framework for Evaluating Voluntary Compliance Concepts

Scholars, most notably Elinor Ostrom, have shown that a consistent set of design elements matter greatly in the design of successful management regimes for common pool resources.[12] This paper suggests that Ostrom's framework is applicable to incentivizing deorbit within the 25-year rule parameters.[13] Table 1 represents a subset of Ostrom's design elements that are most relevant to incentivizing voluntary compliance with the deorbit rule. This set of design elements informs the framework for assessing incentivizing concepts.

Table 1: Common Pool Resource Management: Most Applicable Design Elements

- All stakeholders affected by the management regime are allowed to participate in its rulemaking.
- Penalties for rules violations exist to minimize cheating and free-riders. Penalties for violations should start very low but progressively become stronger if a user repeatedly violates a rule.
- A mechanism for rapid, low cost, dispute resolution exists, and is considered credible by stakeholders.
- Participants are not locked into participating in the management regime. They could exit the management regime if desired. Similarly, they may rejoin when they perceive it to be in their interest.
- Costs are distributed fairly.
- The condition of the resource is monitored by those that are considered credible by stakeholders. Such an entity may include users and other stakeholders.
- Users of the resource are monitored for compliance with the rules by a monitor considered credible by the users. Users and other stakeholders may provide this monitoring function.
- The fairness of resource allocation, management decisions, and dispute resolution are monitored by those considered credible by the users. Users and other stakeholders may provide this monitoring function.
- Good communication among stakeholders is a prerequisite because it facilitates trust and increases cooperation among participants.
- Complete, accurate, and timely information sharing among stakeholders is crucial for verifying all the elements of a resource management regime.

With these design elements in mind, the framework for evaluating voluntary compliance concepts consists of four categories:

1. ***Control*** – the ability of satellite owners and operators to have a significant level of control over the development, monitoring, and enforcement of rules in the pursuit of space sustainability. Bringing owners and operators into the management and rule-making process increases their understanding and support for the rules and further reduces pushback when it comes to enforcing them. Stakeholders may also be free to exit the system, for example, if they feel cheated.

2. ***Financial*** – the economic cost. Satellite owners and operators are more likely to comply if it would lead to reduction in cost. However, economic cost also refers to costs being fairly distributed among owners and operators, "a level playing field" so to speak. As Ostrom points out, stakeholders are much more likely to comply with deorbit rules if the costs are spread fairly. Managing progressively more severe penalties for repeated violations is also important.

3. ***Social*** – the reputation among stakeholders and peers. When managing common pool resources, elements that improve a stakeholder's reputation can be key. Ostrom argues that when participants' reputations are known to others, the likelihood of cooperation increases.[14] Social capital applied in this context refers to the public, potential investors, and customers having a positive impression of a satellite company. Social capital can be built with peers, the media, investors, governmental entities, or the public at

large. Owners and operators who show a commitment to sustain space and protect future endeavors in space can reap direct benefits in terms of increased investment, positive "brand" recognition and media coverage, and increased public and governmental support. Alternatively, both government and commercial operators who damage the space environment for other users may be socially, reputationally, (and financially) castigated. States ultimately carry the responsibility to "authorize and continuously supervise" commercial activities as required by the Outer Space Treaty (Article 6), so a state's reputation in the international community is also at stake.

4. ***Rules*** – Minimization of the burden for stakeholders to comply is fundamental to any *voluntary* incentivized compliance system. Rules can come from governmental or organizational entities—even a voluntary system should not overly burden participants. Thus, this is different from *Control*, which tells who (government, private markets) is making the rules. In terms of government-imposed rules, if the country in which owners or operators are based has a lengthy, expensive licensing process, they might seek to move their companies to a country with more lenient rules. Owners and operators often recognize the need for some governmental regulation or rules in order to create regulatory certainty with their investors. Striking the right balance is the trick.

Five Concepts to Incentivize Deorbit

There are several models for managing common pool resources, starting with either direct government management or private market alternatives. Private markets are created when governmental authorities parcel out a common pool resource at the start, then allow a marketplace to develop in which private stakeholders can pursue their self-interest within government-defined rights and enforcement of contracts.

However, Ostrom argues that many successful common pool resource management institutions are a rich blend of "private-like" and "public-like" institutions. They are neither exclusively private institutions or markets nor completely government institutions. She refers to these blended institutions as *clubs*.[15] A club (or consortium, cooperative, or coalition) can include both private and governmental stakeholders who are free to join so long as they abide by the rules and may leave at any time. It should be noted that these also require a "government hand" to create the conditions that allow such clubs to be implemented and lend legitimacy to their authority. Using these approaches, five concepts to incentivize voluntary compliance with the 25-year deorbit rule are outlined here. While not an exhaustive list, it shows a range of concepts using these models. The concepts are not mutually exclusive—a combination of them could be considered to yield the best result—but they will be examined separately.

Assumptions

The following assumptions (in no particular order) were applied to the management concepts:

- All concepts are technically feasible (i.e., they use existing technologies).
- Concepts can use existing international treaties or laws; however, new structures may be needed and could be implemented using regular international negotiation channels.
- Concepts can begin as domestic constructs; however, they may be extended internationally.
- Concepts may require development of domestic policy, rules, regulations or legislation.

1. Direct Government Management

The current model involves direct management by governments and governing bodies that voluntarily abide by international agreements and guidelines and then shore them up with domestic laws, licensing procedures, and enforcement. This domestic enforcement can come from governing bodies such as that from the European Space Agency that requires companies with whom they contract to follow ISO standard 24113, which includes the 25-year rule. Nations will often create more stringent guidelines, using the standards as a starting point.

The current model is unevenly distributed around the globe. Since not all spacefaring countries have the same laws, a risk exists to "race to the bottom," where the nation with the least environmentally responsible regulations becomes the home of choice for space operators, similar to how Liberia or Panama became the preferred countries for registering ocean-going vessels.

2. Mandatory Satellite Collision Insurance

Presently, satellite insurance serves to lessen the owner's and operator's financial risk for launch plus one year on orbit. However, working to extend this private insurance market to include collision risk would encourage voluntary debris mitigation compliance. Launch-providing countries could require collision insurance for the entirety of a satellite's time on-orbit and provide incentives to "good steward" companies. Similar to good driver discounts for auto insurance, satellite collision insurance would incentivize satellites to deorbit in a timely manner to reduce collision risk with higher premiums for those owners and operators that do not comply. For operators that deorbit well *before* the 25-year mark, insurance companies may offer even lower premiums. This is especially important for reducing the number of overall years that a satellite is on orbit and benefits operators of CubeSats with very short mission lives. This could lead to a financial incentive for satellite companies since space insurance is the third highest program cost to satellite operations after satellite and launch services.[16]

A requirement for on-orbit insurance is already being explored. The 2008 French Space Law contains an insurance requirement for on-orbit risks. In 2018, the United Kingdom passed the *Space Industry Act*. Section 38 of the act requires holders of on-orbit operations licenses to have third-party liability insurance. However, insurance typically does not go past launch plus one year on orbit since this period has the highest rate of incidents for satellites. For this model to be financially equitable all spacefaring nations must adopt concurrent insurance requirements for all commercial satellite operators.

3. Industry Consortium

An industry consortium (or club, as Ostrom would call it) is a bottom-up approach that creates buy-in from stakeholders and enables voluntary, consensus-based standards, guidelines, and best practices for safe deorbiting. A successful industry consortium needs participation from major companies that own and operate the majority of commercial satellites around the world to foster equity and support for the system. This concept also offers some degree of social benefit to member owners and operators as well as perks of membership. Membership is voluntary, so it offers a degree of control as well.

There are several analogous efforts in the works that could function as a model for building a space industry consortium. The Consortium for the Execution of Rendezvous and Servicing Operations (CONFERS)[17] is actively trying to create industry consensus standards and norms of behavior for on-orbit satellite servicing. The Space Safety Coalition is taking a lead in protecting the sustainability of the space domain. The Space Data Association shares information on orbital positions and notifies commercial and government members of collision risk. Multiple consortia can coexist, covering a broad spectrum of activities. Governments, governing bodies, and major operators could provide funding or regulatory frameworks and contract enforcement mechanisms to enable new consortiums and to assist in the development and legitimization of their charters.

4. Sustainability Rating, Certifications, and Awards

An independent, unbiased entity that awards participants with a space sustainability rating could also incentivize voluntary deorbiting. The awarding entity, which may be a consortium**,** could provide space sustainability ratings, certifications or awards to owners and operators that comply or favorably exceed best practice guidelines and rules. Similar models are used to incentivize environmentally sustainable practices across many industries such as the airlines, construction, fashion, home furnishings, and food. Voluntary compliance creates buy-in, establishes credibility, and offers social capital and reputational benefits to adopters, without forced regulation, although there may be membership dues, branding fees, and other associated costs associated with this concept. In the long run, sustainability ratings might contribute to the development of positive norms of behavior.

In May 2019, the World Economic Forum (WEF) designated a consortium of companies, universities, and agencies to develop a system to rate the sustainability of space systems to incentivize responsible behavior in space.[18] As with other concepts, this offers a platform to incentivize deorbit *before the 25-year rule* for added reward, which will further reduce the number of years in orbit post-mission.

5. Deorbit Year Trading Scheme

Under this concept, a privatized market is set up so that satellite owners and operators can trade "credits" with each other. Credits are earned by deorbiting satellites earlier than an established time cap with compliance being monitored by an international entity. Credits could be used toward future deorbit years or, if a satellite owner or operator could not deorbit within the caps, they could either "buy" credits from other owners and operators in a regulated marketplace or be penalized. This concept requires both government regulation to establish the rules and international cooperation to create the marketplace, verify deorbits, and establish dispute resolution procedures.

A slightly different approach would function like a bottle deposit. In this formulation, a satellite owner puts funds in escrow that will only be returned upon successful and timely deorbit. If the satellite fails and is stranded past a predesignated time, a third party may collect the deposit by deorbiting the spacecraft; i.e., active debris removal. Commercial companies like Astroscale are already pursuing active debris removal methods as a business service. This concept may be more successful on a domestic or regional level since the financial management on an international level would be very complex.

Similar to the "cap and trade" carbon trading concept for offsetting climate change, a deorbit year trading scheme would create an economic, market-

Additional Considerations

Regardless of which incentivizing concept, or combination of concepts, is employed, it should be as adaptable and flexible as possible. It needs to adapt to macro changes in technology—relevant on timescales of 10-plus years. It also needs flexibility to account for different technological approaches implemented by owners and operators.

Customized deorbit guidelines are an example of added flexibility that can be based on parameters such as expected lifetime, altitude, inclination, mass, ability to maneuver, and other characteristics. They also allow owners and operators to be innovative and efficient when developing deorbit plans. This could be a timely approach given the likely proliferation of large constellations and nonmaneuverable CubeSats.

based incentive for satellite owners and operators to deorbit satellites before the deorbit deadline. The Kyoto Protocol and Paris Accords on Carbon Dioxide emissions offer ideas and lessons for the implementation of analogous trading schemes. It should be noted that for this concept to promote a level playing field, governments from around the world would need to work together to establish an international deorbit rule trading market.

Concept Assessment with the Proposed Framework

The four metrics in the framework—control, financial, social, and rules—can be applied in different ways to assess the concepts. Example ideas of how to utilize them are presented below. Note: The concepts laid out here are not prescriptive and, thus, can only be assessed so far and relative to each other.

Figure 2 shows how two of the metrics—rules and (owner/operator) control—can create a useful tradespace to evaluate how to balance government requirements with owner and operator leadership and control. The current model, Direct Government Management, located in the top left of the figure, is highly regulated and has low stakeholder control. In the United States, owners and operators are given the opportunity to comment on rulemaking such as the Federal Communications Commission's 2018 call for comments on rules to mitigate space debris.[19] However, industry must ultimately comply with government-imposed domestic deorbit rules and regulations to launch from the United States. The exact locations of the other concepts are dependent on specific implementation designs. Figure 2 highlights the regions in which they would likely reside.

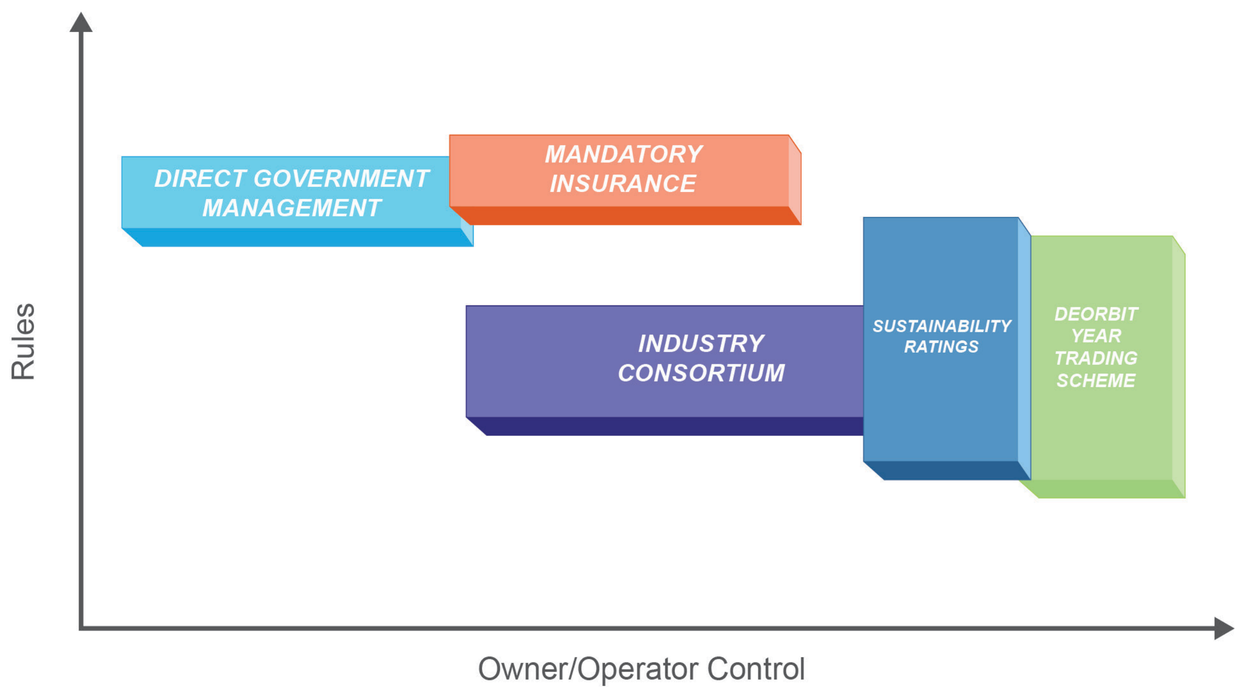

Figure 2: Example assessment of the rules-control tradespace.

Figure 3 is an example of how to explore the range of a single metric. Both Direct Government Management and Mandatory Insurance offer little opportunity for building social capital. With insurance, the social capital would be indirect. An improved owner and operator deorbit track record would improve a company's reputation as a secondary benefit to lower insurance costs. A Consortium could incentivize compliance via peer (social) pressure. Membership in a given Consortium could be viewed as a positive status and offer exclusive benefits. For example, the Space Data Association offers its members improved access to collision avoidance data and screening of flight plans. With the Trading Scheme, owners and operators who are frequently able to sell deorbit year credits would gain a positive reputation, which would be an incentive to comply. However, like Mandatory Insurance, the gain in social capital would be a secondary benefit in comparison to the primary motive of reduced expenses. This creates a positive feedback loop with the economic cost incentive as mentioned for previous designs.

Figure 4 is an example of exploring a particular aspect of one of the metrics—the fairness of the cost burden. The current model of Direct Government Management is less likely to have fairly distributed costs due to the potential for an unlevel playing field by which owners and operators based in different countries with different regulations pay different associated costs.[20] Likewise, consistent domestic enforcement and penalties for noncompliance are unclear creating uncertainty for owners and operators about the fairness of potential penalties. Consortiums can require fair cost burden sharing to the participating members, but, ultimately, the costs will depend on the rules decided on by the consortium. A Trading Scheme allows for the most flexibility and stakeholder control over costs.

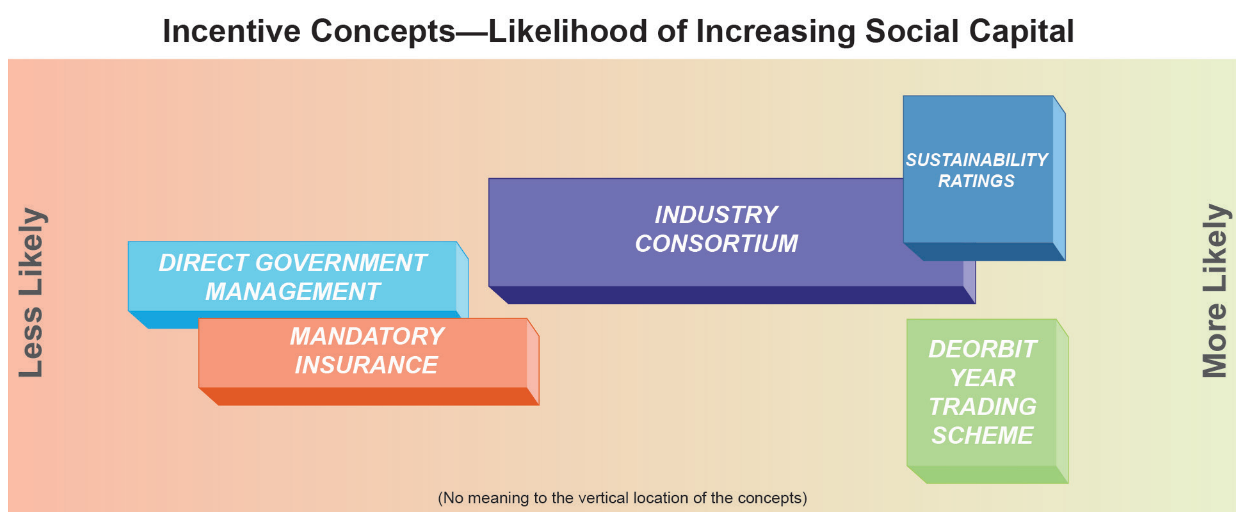

Figure 3: Example of assessing the concepts using one of the metrics. *The concepts are relatively scored based on how likely they would increase the social capital of owners/operators. There is no meaning to the vertical location of the concepts.*

Incentive Concepts—Stakeholder Perception of Cost Fairness

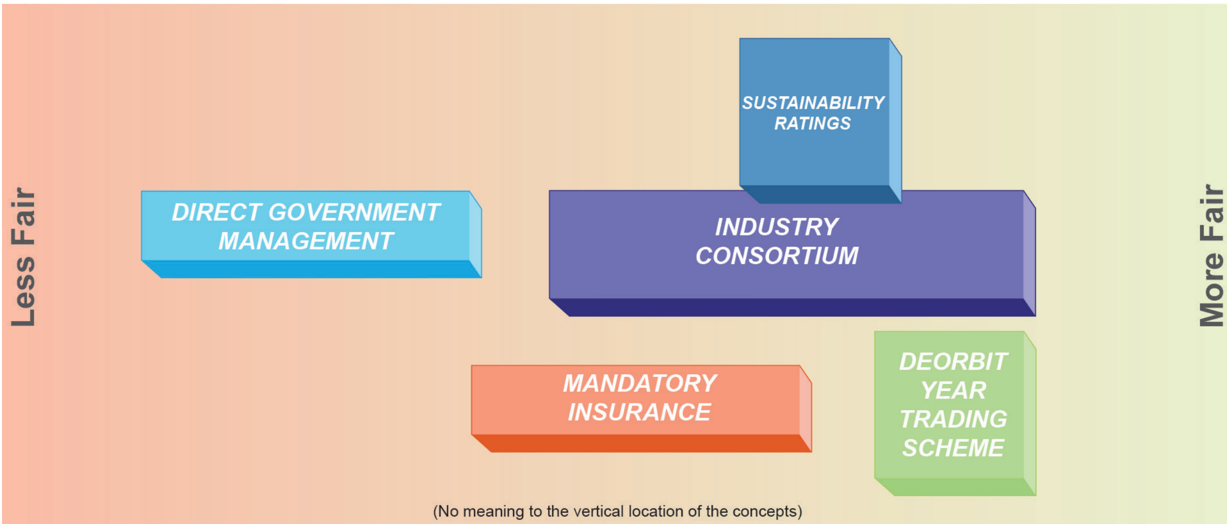

Figure 4. Example of assessing an aspect of one of the metrics. *How fair are stakeholders likely to feel the cost burden of the concepts are relative to each other? There is no meaning to the vertical location of the concepts.*

Conclusion

Each of the concepts outlined above have merit, and there is no need to pick just one to implement. A hybrid approach is likely the best approach. The main objective is to sustain the space environment for current and future users, commercial and government, by lessening the chance of debilitating collisions, especially in the useful, already crowded LEO. Voluntary compliance to the 25-year rule or more stringent deorbit rules is the most logical choice since space operations are done on an international scale, beyond borders and individual governments. When considering space through a common pool resource lens, the free market and financial incentives play a role but are balanced with necessary regulation and oversight. Any voluntary compliance concept, be it collision insurance, an industry consortium or a sustainability rating system, will still need some level of government involvement. Commercial space is at an exciting time in history, and, to continue on this socially and financially beneficial curve, our shared resource must be carefully managed to keep it safe and productive for all users.

Acknowledgments

The authors would like to thank the following people for their help in completing this paper: Marlon Sorge, Steve Jordon Tomaszewski, Ted Muelhaupt, and Roger Thompson of The Aerospace Corporation, and Chris Kunstadter of AXA XL.

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[20] In 2018, Swarm Technologies, a Silicon Valley Startup, flew four picosatellites on an Indian Polar Satellite Launch Vehicle. The FCC had not approved their application a month earlier, but they launched from India anyway. This event garnered much outrage from the space community as it highlights the lack of consistent regulation across international borders.