Expanding LEO Capacity Through Orbital Classification Frameworks

Ruth E. Stilwell[1], Diane Howard[2], Darren McKnight[3], Nate Dailey and Alex Luttmann[4]

[1] Aerospace Policy Solutions, LLC, Lauderdale-by-the-Sea, Florida, USA

[2] sur l'espace, PLLC, Ft. Lauderdale, Florida, USA

[3]LeoLabs, 4795 Meadow Wood Lane, Chantilly, VA 20120 USA

[4]MITRE, McLean, Virgina, USA

Low Earth Orbit (LEO) is an increasingly complex domain, challenging its international governance framework. Decades of work to improve safety in orbit has focused on the ongoing issue of orbital debris but the emerging challenges posed by the growth in large constellations and increasing demand for space services necessitate the consideration of new policy-based frameworks. International fora, like the Inter-Agency Space Debris Coordination Committee (IADC), have produced consensus guidelines for the mitigation of space debris. This model illustrates that harmonized approaches may be available to address common concerns of space safety. The IADC's first internationally adopted guidance document, the "IADC Guidelines" was presented to the Scientific and Technical Sub Committee (STSC) of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) in 2003 as part of the official work program and was endorsed by the UN General Assembly in December of 2007. The guideline approach used by IADC to address the issue of space debris can provide a roadmap for the development of an orbital classification framework to facilitate the safe expansion of orbital capacity in LEO. This paper suggests a policy-based approach to performance requirements for active space objects in described orbits based on definable risk metrics. Orbital carrying capacity at its core is a safety metric, improvements in collision avoidance capability, including SSA and maneuverability, can increase the carrying capacity of a specific orbit, but may be constrained by the least capable actors. A policy-based framework that establishes guidelines for minimum entry requirements for particular orbits reduces the inadvertent capacity effects of least capable actors.

While space debris remains a pressing issue for space safety, rapid growth in the number of objects in LEO and corresponding projections for increasingly dramatic future growth, has drawn attention to the question of orbital carrying capacity. Researchers are examining how orbital carrying capacity should be defined and quantified. Various approaches, like the Space Environment Capacity Concept, are emerging. The panoply of available approaches can be filtered by how we collectively consider the problem of orbital capacity. Do we consider that there is a finite number of objects that a particular orbit can accommodate, and therefore growth must be constrained to prevent over-exploitation? Or do we consider that growth is both inevitable and desirable and we should consider policy choices that seek to increase available capacity to ensure safety and sustainability of LEO? This paper assumes the latter and presents a potential framework derived from the aviation experience of airspace capacity, using an orbital classification approach to create guidelines for entry requirements for operations in, and transits through, defined altitudes based on congestion and collision risk [Figure 1]. These guidelines could assist both operators and States in the development and approval of space missions. This work builds on the emergent behaviors of space operators in high density or high-risk orbits to

[1] Executive Director, AIAA Member.
[2] Principle, AIAA Member.
[4] Chief Strategist, AIAA Member.

codify a framework of best practices, organized under a globally harmonized model that is well known and accepted in the aviation domain. The orbital classification concept is a first step, designed to facilitate the work of experts in defining the orbital bands with common risk characteristics and identifying the entry requirements and external elements (i.e. available of SSA performance) appropriate to mitigate the risk of increased activity.

This paper relies on the experience of the aviation community in developing airspace classification as a tool to increase both airspace capacity and safety but recognizes the distinct differences in both the physical characteristics and governance structures of the aviation and space domains. It does not seek to impose a global structure of space traffic control but rather recognizes that the response to similar challenges created by the growth in commercial and competitive activity may be instructive. The principles of Article I of the Outer Space Treaty, that outer space "shall be free for exploration and use by all States without discrimination" coupled with the vastness of space itself, led to a somewhat laissez-faire approach to the development of standards of behavior in space. Early commercial aviation enjoyed the same unconstrained access to airspace, until specific, high-profile collisions created the awareness that while the sky remained vast, increasing growth in high demand areas carried with it increasing and unsustainable collision risk. For the space community, the consequence of two significant events, the 2007 Fengyun ASAT test and the 2009 Iridium 33 and Cosmos 2251 collision, each creating large amounts of persistent debris, triggered similar awareness. The new debris risk environment accelerated improvements in Space Situational Awareness (SSA) and conjunction alerting to prevent collisions with debris and debris mitigation requirements began to emerge. Similarly, collisions between aircraft led to improvements in surveillance, aircraft performance, and safety alerting and equipment, but importantly, increased demand also led to the organization and structure of the airspace itself.

As a matter of public policy, the issues of orbital carrying capacity and those of space debris diverge sharply at this point. While space debris is broadly recognized as a common threat across the space community, carrying capacity is not. Additionally, approaches to creating capacity definitions and thresholds are similarly divergent. From some perspectives, over-exploitation of individual orbits can be viewed as a problem created by a small number of actors, within even a smaller number of supervising States. This is an immediate, and arguably short-sighted view. Growth in commercial space activity and the value of space services has global consequences as competition for access to space is accelerating in every region. Efforts to artificially constrain growth in one space faring State or region may incentivize others to fill the gap. An approach that would have a dominant State or region seek to impose limitations on access by future space actors, deriving disproportionate benefits based on a principle of future value assigned to the first to exploit, undermines the foundational principle of the Outer Space Treaty. However, establishing performance criteria for operation in already congested or high-risk orbits designed to preserve the safety and sustainability for current and future actors satisfies the principle of "without discrimination" codified in the treaty. Further, the orbital classification approach can be used to identify low risk orbits to ensure access to space remains available to all categories of operator, particularly non-commercial activities where higher performance requirements may impose an unnecessary barrier to entry.

While space debris remains a pressing issue, the rapid increase in the number of satellites in LEO since 2019 and the emergence of novel in-space activities has added both congestion and complexity to the domain. At the same time, space operations have become more capable. Maneuverability of spacecraft is more common than it once was, in-space transportation services are emerging, space surveillance and space situational awareness has increased dramatically over the last decade, and sustainability principles of reusability and recycling are increasingly adopted by the space community. Forward-looking constructs, like orbital classification, should take advantage of the opportunities presented by this changing landscape. This paper proposes a framework that allows the organization of the orbital domain to react to the changing demands on it.

I. Introduction

Orbital capacity is used as a generic term to describe the ability of Earth's orbital environment to accommodate satellites, space debris, and transiting objects without compromising safety, functionality, or sustainability. However, even these descriptive terms are subjective. The rapidly increasing pace of space activities, including the deployment of large constellations, has brought attention to the concept of orbital capacity as a potentially limiting factor in the growth of the space sector. However, it is apparent from other domains, particularly in aviation, that improvements in safety behaviors can serve to increase the capacity of defined airspace volumes [1]. Conversely, failure to improve safety behaviors limits the usable capacity of an orbit. Safety and capacity are not divorced partners; they are inextricably linked.

This work builds on and refines the concept of Orbital Classification using feedback received on earlier research into a proposed framework including “Applying an Aviation Analogy to Sustained Space Operations” presented at the 9th IAA Space Traffic Management Conference [2], “Space Debris Policy and the Small Satellite Community” presented at AIAA/OSU Conference on Small Satellites [3] and “Integrating Orbital Carrying Capacity into International Policy Constructs: Leveraging Best Practices From Aviation's Risk-Based Norms” presented at the 75th International Astronautical Congress [4]. Previous work focused on describing maneuverability requirements based on risk characteristics in defined orbits as a starting point for an orbital classification framework (Table 1).

Table 1: A notional LEO classification framework accounts for orbital persistence, size of existing constellations, and background debris collision hazard to suggest maneuverability requirements

<table>
<tr><th rowspan="2">Class</th><th colspan="3">Altitude (Persistence)</th><th colspan="3">Constellation Size Present</th><th colspan="3">Debris Background Level (i.e., spatial density, objects/km³)</th><th rowspan="2"></th><th colspan="6">Maneuverability Required</th></tr>
<tr><th>Low <400km</th><th>Med 400- 650km</th><th>High >650km</th><th>Low >10</th><th>Med >100</th><th>High >1000</th><th>Low <1E-9</th><th>Med 1E-9 to 1E-8</th><th>High >1E-8</th><th>0</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr>
<tr><td>A Congested</td><td colspan="3">X</td><td></td><td></td><td>X</td><td colspan="3">X</td><td></td><td></td><td></td><td></td><td></td><td></td><td>X</td></tr>
<tr><td>B Persistent</td><td></td><td colspan="2">X</td><td colspan="2">X</td><td></td><td></td><td colspan="2">X</td><td></td><td></td><td></td><td></td><td></td><td>X</td><td>X</td></tr>
<tr><td>C Occupied</td><td></td><td>X</td><td></td><td colspan="2">X</td><td></td><td></td><td colspan="2">X</td><td></td><td></td><td></td><td></td><td>X</td><td>X</td><td></td></tr>
<tr><td>D Lightly Occupied</td><td colspan="2">X</td><td></td><td colspan="2">X</td><td></td><td colspan="2">X</td><td></td><td></td><td></td><td>X</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>E Below Manned Spaceflight</td><td>X</td><td></td><td></td><td>X</td><td></td><td></td><td>X</td><td></td><td></td><td></td><td>X</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Subsequent research identified a more comprehensive list of capabilities and best practices that can serve as a more robust framework. These include information sharing, post mission disposal, and space situational awareness. This research illustrated that the large satellite community is well ahead of regulatory authorities in identifying and documenting best practices, however it is unclear how and if smaller operators are included in formal discussions.

II. Industry developed best practices are far ahead of regulatory frameworks

Operators of large constellations have a vested interest in the sustainable use of space and have not only recognized a need for common principles for safety and operational behaviors but have taken action to codify and document industry best practices. Facilitated by AIAA, a coalition of satellite operators including Iridium, OneWeb, and SpaceX, published the document “Satellite Orbital Safety Best Practices” detailing, among others, specific practices for behavior on orbit [5]:

- PRACTICE C-1: **Maintain quality O/O predicted ephemerides and spacecraft status information and submit/update this information regularly to the CA screening authority**
- PRACTICE C-2: **Perform CA risk assessment to identify high-risk conjunctions that require mitigation**

- PRACTICE C-3: **Pursue adequate mitigation actions to avoid high-risk conjunctions**
- PRACTICE D-1: **Actively and expeditiously manage the deorbit of LEO satellites that are reaching the end of their useful mission life**

In addition to formally produced documents, large constellation operators have begun informal activities to "deconflict" their planned orbital shells. This behavior stands in stark contrast to the characterizations of space as wild frontier where conflict between competing international interests is inevitable. To the contrary, the emerging behavior is far more pragmatic and solution-oriented than a superficial view would assume.

Embedded within these practices are underlying principles of information sharing, data integrity, risk tolerance, and sustainable use. This is one of many documents labeled as "best practices" or handbooks, including "NASA Spacecraft Conjunction Assessment and Collision Avoidance (CARA) Best Practices Handbook" [6], Secure World Foundation's "Handbook for New Actors in Space" [7], the US Space Force "Spaceflight Safety Handbook" [8], and the Space Safety Coalition's, "Best Practices for the Sustainability of Space Operations" [9]. The emergence of these types of documents from industry, Non-Government Organizations (NGO), and individual agencies point to an emerging need to institutionalize common principles. It is important to note there is significant heterogenicity in the space operator community, limiting the reach of individual documents.

Industry action to promote best standards is a laudable first step but cannot replace broader institutional action to codify safe behavior based on the risk in specific orbital shells. Broader efforts to establish domain wide goals may lack sufficient granularity to motivate compliance. Concerns over regulatory capture or orbital dominance are legitimate but should not override the foundational principle that preventing collisions on orbit is in the common interest.

III. Emerging LEO Neighborhoods

To some extent, low Earth orbit (LEO) has begun to striate into "neighborhoods" differentiated by the concentration of object types (Table 2).

Table 2: Low Earth Orbit "Neighborhoods" demographics highlight the drastically different situations in LEO (source: LeoLabs LeoCat biweekly update 5/29/2025)

<table>
<tr><th>Current Neighborhood</th><th>altitudes</th><th>occupancy</th><th>persistence</th></tr>
<tr><td>Human spaceflight and Cube Sats</td><td>350-450km</td><td>Large space stations, operational non-maneuverable cubesats</td><td>atmospheric drag removes fragments and intact hardware within weeks to months</td></tr>
<tr><td>Low-LEO constellations</td><td>500-600km</td><td>High density of operational spacecraft with high capability to avoid collision with other spacecraft or debris</td><td>atmospheric drag cleanses this region of derelict debris fragments within years and intact hardware within decade</td></tr>
<tr><td>Mid-LEO constellations</td><td>700-800km</td><td>One major constellation, significant amount of fragmentation debris from previous breakup events</td><td>drag does little to remove fragmentation debris from this region (i.e. will persist for decades)</td></tr>
<tr><td>"Bad neighborhood"</td><td>800-900km</td><td>Large number of debris and high mass objects – 20% of LEO mass</td><td rowspan="3">Debris will persist for centuries</td></tr>
<tr><td>High collision risk</td><td>900-1100km</td><td>High spatial density of derelict objects including rocket bodies</td></tr>
<tr><td>High-LEO constellations</td><td>1150-1250 km</td><td>Low risk unless a fragmentation event occurs</td></tr>
</table>

The LEO classification approach seeks to accommodate operators with varying capability levels by structuring the entry requirements for specific orbital shells to maximize the orbital capacity in high demand orbits while ensuring that access to orbit remains available to less capable users. This has been an effective construct in global aviation for several decades, using enhanced safety requirements to accommodate high demand. For LEO, growth, without a framework for orbital appropriate behavior, risks reaching orbital capacity limits prematurely. These emerging neighborhoods illustrate how early inaction has limited the viability of certain orbits. Recent public discussions by SpaceX have emphasized their intentions to move to lower altitudes (e.g., move shells above 500 km to altitudes below 400 km) to avoid other less responsible operators and the more persistent debris population [10].

On the other end of the spectrum, consider the 800-900km "bad neighborhood" where more than 75% of the objects are the result of fragmentation events (compared to 47% in LEO overall). Only 76 of more than 2,900 objects in this orbital band are operational satellites [4]. This is the lowest occupancy by operational satellites of any of the defined neighborhoods indicating that this high-risk environment is not desirable. The Mid-LEO corridor at 700-800km is equally instructive as the collision event in 2009 dramatically and persistently changed the environment and elevated the global level of concern and investment in the prevention of debris generating events. Given the societal benefits and increasing dependence on services provided to the Earth from space, there is a shared interest in ensuring that orbits remain viable, desirable, and sustainable.

IV.Concept refinement

The paper "Integrating Orbital Carrying Capacity into International Policy Constructs: Leveraging best practices from aviation's risk-based norms" established an early notional construct based on maneuverability requirements [4]. Subsequent research has indicated that additional capabilities and behaviors should be considered, particularly in highly congested orbits. This paper focuses specifically on notional orbital Class A (highly congested), to examine the value of establishing minimum capabilities and behaviors for space operators in a given orbital shell.

A. Case Study: Notional Class A

The first step in the concept refinement activity is to isolate each notional class and develop candidate entry requirements. Since the large constellation operator community has documented best practices, this will serve as a starting point for Class A (highly congested). Other classifications, potentially with lower entry requirements are needed, but the proliferated orbits represent a near-term opportunity to demonstrate potential benefits of action. In addition, the major users of these orbits have begun to shape best practices that can provide a template to the regulatory community.

The best-case scenario assumes all actors meet the industry's best practices defined in the AIAA facilitated document, including data quality and precision, information sharing, SSA participation, and collision avoidance capability [5]. Degraded cases will consider the impacts of non-complaint operations in the Class A shell, including the burden they impose on complaint actors. The findings from this ongoing activity will be reported at the International Astronautical Congress in Fall 2025.

1. Economic analysis

Limited growth in satellite services, caused by higher collision risk in low Earth orbit (LEO), has economic consequences that reach far beyond the space industry. These consequences impact various sectors that depend on satellite data and services. A MITRE internal research and development (IR&D) study, completed as part of efforts to quantify the economic consequences of orbital congestion, examined the dependence of Fortune 500 and Fortune 100 companies on satellite technology and the financial impacts of potential disruptions caused by orbital capacity limitations. This analysis supported the orbital classification framework proposed in this paper, which potentially contributed to mitigating collision risks through policy-based performance requirements, thereby preserving orbital capacity and ensuring the sustainability of space-based services critical to global economies.

The IR&D study utilized a comprehensive dataset of annual financial metrics from Bloomberg for Fortune 500 companies over the period from December 31, 1994, to December 31, 2024. The metrics included market capitalization, stock price, price-to-earnings (P/E) ratio, revenue, gross profit, and year-to-date total return. For each company, annual filings were analyzed to determine reliance on satellite technology, defined by three criteria: (1) operation or manufacture of satellites or satellite components (e.g., Northrop Grumman, Lockheed Martin), (2) use of data from Earth observation or remote sensing satellites (e.g., Exxon, Chevron), or (3) reliance on signals from position, navigation, and timing satellites, such as GPS (e.g., Ford, Delta Airlines). This binary indicator of satellite reliance enabled a comparative analysis of financial performance between satellite-dependent and non-dependent companies.

The econometric model employed was a fixed-effects regression, specified as:

$$\log(Y\_it) = \beta\_1 * SatelliteReliance\_it + \beta\_2 * TimeTrend + NAICS\_i + \alpha\_t + \varepsilon\_it,$$

Where Y_it represented the financial metric (e.g., market capitalization, revenue) for company I in year t (1994 to 2024), SatelliteReliance_it was an indicator equal to one if the company relied on satellite technology, TimeTrend captured linear temporal effects, NAICS_i denoted four-digit industry fixed effects, α_t represented year fixed effects to control for macroeconomic conditions, and ε_it was the error term. The coefficient β_1 measured the average difference in the dependent variable between satellite-reliant and non-reliant companies, controlling for industry and temporal factors. Standard errors were clustered at the yearly level to account for temporal correlation.

Regression results for the Fortune 500 sample demonstrated significant financial advantages for satellite-reliant companies. On average, these companies exhibited a market capitalization 70.3% higher (approximately $24.4 billion), a stock price 23.9% higher (roughly $108.8), a P/E ratio 8.4% higher, revenue 19.5% higher (approximately $4.1 billion), and gross profit 43.9% higher (roughly $2.9 billion) compared to non-reliant counterparts. For the Fortune 100 subset, the effects were more pronounced: market capitalization was 248.3% higher (approximately $262 billion), stock price 37.8% higher (roughly $723), P/E ratio 33.9% higher, revenue 37.3% higher (roughly $24.2 billion), and gross profit 101.5% higher (approximately $20.2 billion). These findings, statistically significant at the 1% or 5% levels, underscored the importance of satellite technology in driving financial performance across diverse industries.

To evaluate the potential economic risks posed by orbital congestion, this research calculated the financial consequences of theoretical disruptions to satellite services. For a one-week outage, a Fortune 500 company reliant on satellites faced an average revenue decline of $78.6 million (7/365 * $4.1 billion) and a gross profit decline of $55.6 million (7/365 * $2.9 billion). For a Fortune 100 company, the impacts were substantially larger: a revenue decline of $464.1 million (7/365 * $24.2 billion) and a gross profit decline of $387.4 million (7/365 * $20.2 billion). A one-month outage amplified these effects, with Fortune 500 companies facing an average revenue decline of $337.0 million (30/365 * $4.1 billion) and a gross profit decline of $238.4 million (30/365 * $2.9 billion). In comparison, Fortune 100 companies experienced a revenue decline of $2.0 billion (30/365 * $24.2 billion) and a gross profit decline of $1.7 billion (30/365 * $20.2 billion). These estimates highlighted the significant economic consequences of disruptions to satellite services, which could have resulted from increased collision risks in congested or high-risk orbits.

This analysis reinforced the orbital classification framework by highlighting the broader economic implications of maintaining safe and sustainable access to Low Earth Orbit (LEO). The framework establishes performance-based entry requirements for specific orbital shells, reducing collision risks by ensuring that operators in high-demand orbits met minimum standards for maneuverability, space situational awareness, and information sharing. Mitigating the dangers posed by non-compliant or less capable actors preserves orbital capacity, safeguarding the economic benefits derived from satellite services. A policy-driven strategy to avoid potential disruptions with far-reaching impacts on international markets is vital, particularly given major corporations' significant financial reliance on these services.

International cooperation is foundational to this economic analysis, not merely acknowledged but a central element. The study examined the global economic landscape, demonstrating that collaborative frameworks are essential for addressing current challenges and national efforts alone are insufficient. This conclusion is reinforced by the investigation of governance structures, which examines models for facilitating international economic coordination. It analyzes the interplay between institutions, policies, and agreements, understanding how governance can foster economic stability and growth. The analysis examines the historical evolution of cooperation, drawing on past experiences, and highlights the cyclical nature of global trends, underscoring the enduring need for collaboration. Potential obstacles, such as divergent interests, are acknowledged, with strategies proposed to overcome them. Ultimately, the research argues for prioritizing and strengthening international cooperation as a cornerstone for sound economic policy and sustainable global development. The significant financial impacts of potential outages emphasized the shared interest in preventing debris-generating events and ensuring equitable access to orbital resources. Integrating industry best practices, such as those documented by large constellation operators, into a globally harmonized orbital classification system, will enhance safety and capacity while supporting the continued growth of satellite-dependent industries. Subsequent MITRE research will expand this analysis to quantify the costs of compliance with proposed performance requirements. It will assess their feasibility for operators of varying capabilities, ensuring that the framework strikes a balance between safety and accessibility.

2. Safety and capacity

The effects of non-complaint entrants on collision probability will serve to develop metrics that will feed into other research on orbital capacity. The foundational basis for the orbital classification model is to leverage policy frameworks to reduce collision risk and focus resources on areas where the greatest benefits can be derived. Aviation provides a relevant lesson here as well. Investments in capacity enhancing tools and requirements are demand driven. Low density airspace does not justify high barriers to entry, conversely, a requirement to accommodate lowest equipped operators in high density airspace imposes significant limitations on all actors in the airspace. To use a metaphor, it is like driving a golf cart on the highway. The existence of the less capable actor in a high demand environment reduces the overall capacity and introduces a potential safety hazard. The effect of reducing orbital capacity is not only a constraint on opportunities for growth in the space economy, but it also has consequences for resilience in the delivery of space-dependent services.

3. Information sharing as a debris mitigation tool

Operating in a shared environment carries an obligation to share basic information that may also increase with the density of operations in a given orbit. For a Class A orbital environment, where LEO is proliferated with operational space objects, a minimum viable set of shared information (MVI) specific to the orbital class should be developed that may go beyond the existing required data sets for the two-line elements (TLE) that allow external entities to calculate position and velocity. This MVI should enable more precise prediction of potential conjunctions and future states than is required for lower density orbits. The amount and quality of shared information serves to reduce the uncertainty (and associated safety buffer required) in a potential conjunction and can serve to reduce the overall number of conjunction alerts issued. Additional information does not need to include data that is considered proprietary or business sensitive. For example, industry's best practices include sharing information on the satellite's ability to take collision avoidance mitigation action but does not anticipate a need to share technical information on how the avoidance action is achieved [5].

V.Paths to implementation

Traditional regulatory approaches have limitations for the international orbital domain and may not be the most effective mechanisms for developing and implementing a scalable orbital classification approach. However, the common interest and mutual benefit in avoiding debris-generating events in space may create diplomatic pathways to facilitate implementation.

The use of orbits is governed by a complex interplay of international treaties, national laws, and technical guidelines and involves multiple international intergovernmental organizations such as the United Nations Committee on Peaceful Uses of Outer Space (UNCOPUOS), the United Nations Office of Outer Space Affairs (UNOOSA) which serves as its Secretariat, and the International Telecommunications Union (ITU), a specialized United Nations agency that manages orbital slot assignments through its Master International Frequency Register.

Binding frameworks relevant to this discussion are found in the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty or OST), Convention on International Liability for Damage Caused by Space Objects (LC), and the Convention on Registration of Objects Launched into Outer Space (RC), some notable highlights of which are described below.

The OST comprises the foundational legal framework for space activities. There are several principles implicated by the proposed use of operator capabilities as a discriminator for placement of a mission in an orbital location. For instance, access to, and the exploration and use of, space is considered the province of all humankind (Article I) and outer space cannot be claimed by any nation (Article II). Activities in space must be conducted for peaceful purposes (Article IV). State governments are internationally responsible for national space activities, including those performed by the private sector (Article VI). States are internationally liable for damage caused by their space objects (Article VII) and directed to avoid harmful contamination of space by use of space including orbital domains (Article IX) and conduct their space activities with due regard for the corresponding interests of other States Parties to the OST.

The LC establishes international liability for damage caused by space objects whether in orbit, in airspace, or on Earth (Articles II & III) and the RC requires States to register space objects with the United Nations (Article II) and provides transparency and accountability for objects placed in orbit (Articles IV & V). Additionally, upon request by the United Nations, States Parties with monitoring and tracking capability are to provide information to the greatest extent feasible about space objects causing damage to another State Party's space object or persons (Article VI).

UNOOSA, the ITU, and the Inter-Agency Space Debris Coordination Committee (IADC) also have equities with respect to orbital behavior. UNOOSA oversees implementation of the space treaties and promotes international cooperation. It serves as the Secretariat for UNCOPUOS which developed those treaties as well as non-binding guidelines such as the Long-term Sustainability of Outer Space Activities Guidelines which address debris mitigation, preservation of the orbital environment, and the responsible use of orbits. UNCOPUOS' Space Debris Mitigation

Guidelines are based upon the work of the IADC, which is comprised of space agencies and provides technical guidelines for debris mitigation, post-mission disposal, and collision avoidance while in orbit.

The ITU ensures equitable access to orbital resources by regulating the use of radio frequencies and orbital slots for satellites. It allocates geostationary orbital positions and spectrum to prevent interference. The ITU regulations are binding.

In addition to international treaties and guidelines and the international organizations that draft or promulgate them, countries have also enacted domestic laws to authorize and supervise space activities in their jurisdictions in fulfillment of the Outer Space Treaty's Article VI and in accordance with their national interests. A few examples include the United States' Commercial Space Launch Act and its progeny, authorizing and supervising launch and reentries from and to the United States and by U.S. nationals from anywhere else in the world; the Federal Communications Commission managing U.S. commercial spectrum use and some orbital and end-of-life aspects of a licensee's mission; and the Department of Commerce's Office of Space Commerce which regulates private sector remote sensing systems.

In the European Union, Member States often have individual space laws while the EU has been working on its overarching EU Space Act for some years. The EU promotes sustainable use of orbits through initiatives such as the Space Traffic Management Framework. The European Space Agency coordinates space activities but does not regulate them. China regulates its space activities through its national laws and policies which emphasize treaty compliance and international cooperation. The Russian Federation oversees space activities through Roscosmos and with national legislation, also focusing on treaty compliance. The Indian Space Research Organization (ISRO) manages India's space activities with its Department of Space which oversees satellite launches and orbital use recently finalized its Space Activities Bill which is currently being circulated among stakeholder ministries. This legislation will regulate private sector activities. Other countries with national space agencies and legal frameworks include *inter alia* Japan, Canada, and Brazil.

Several frameworks attempting to either curate existing practices or articulate new policy frameworks have emerged in addition to those iterated above. These include space traffic policies developed in the United States, the EU, and some other nations to address collision risks, debris mitigation, and coordination of orbital activities. The Space Safety Coalition, an international group of stakeholders, put forward its Best Practices in 2019. The Satellite Orbital Safety Best Practices compiled by Iridium Communications, OneWeb, and SpaceX with the American Institute of Aeronautics and Astronautics. Academia was presented in 2022. Recently in 2025, the University of Cologne published its Cologne Manual on Space Traffic hoping to establish an internationally coordinated framework to ensure safe, secure, and sustainable space operations with practical recommendations for voluntary guidelines.

Challenges and gaps have surfaced over the years. LEO is crowded. The rapid increase in the satellite population has created congested conditions as described in the earlier sections of this paper. While some initiatives have produced debris mitigation guidelines, including the UNCOPUOS Guidelines, these lack enforcement mechanisms unless included in domestic legislation.

There is a growing concern among new entrants, including developing nations, who face challenges in accessing orbital resources now or fear they will in the future. Some have decried fragmentation. This has resulted in some academic interest in centralized regulations for the use of orbits or to direct operator behavior, but that viewpoint is not embraced by most spacefaring nations at this time. There is also a public perception that no constructive headway has been made to address the impacts of congestion, but this perspective is not aligned with actual practices and standards development efforts which are underway at the International Standards Organization, IADC, in UNCOPOUS subcommittees, and the ITU, as well as regionally and domestically. Discussion surrounding weaponization of space and the use of orbits for military purposes has become more overt.

This section of the paper began with the observation that the current regulatory and oversight framework likely does not provide guidance for managing the increasingly congested LEO domain nor does it provide effective mechanisms allowing growth to scale. However, a bottom-up operations-based approach to ordering activities must be aligned with the foundation described above. It simply needs to take it further.

For example, most sustainability efforts are primarily focused on end-of-life for satellites to avoid further congestion. This differs from approaches delineating how better to operate within an already congested area. Current operator practice reveals the early striation of satellites into "neighborhoods" differentiated by the object type. For the practice of linking capabilities to a particular orbital location to be embraced by the international community, it must be decoupled from any concepts of ownership or claim. Instead, this approach must be aligned with access and use. Further, countries need to lean forward into support and incentives for these emerging operations-based practices. While the OST provides space freedoms of access for exploration and use for all of humankind, it is States Parties that have the obligation to ensure that operators' practices at an individual entity level are compliant with the OST's directives and it is States Parties that are ultimately internationally responsible and liable for those operators' practices.

Owner operators, both governmental and non-governmental, have an opportunity to share their practices for decision formulation when maneuvering. Data sharing is a first step, but it is not the final step. The interest all users have in a more stable operating environment – and the opportunity for sustainable growth for all users -- is a common interest and one that can and should be built upon diplomatically. There is mutual benefit in avoiding debris-generating events in space.

VI. Conclusion

Activities across segments of the civil space community, including those in industry, academia, and the non-profit sector, indicate the recognition of significant gaps in the development of institutionalized standards and guidance material for best practices in orbit with a particular focus on LEO. Industry documents reflect the increasing capability of commercial space actors to avoid collisions. The emergence of orbital neighborhoods illustrates that different risk profiles in different orbital shells indicates that entry requirements for individual orbits should be tailored the risk profile. A single “one size fits all” approach to standards of behavior in LEO is suboptimal. It is also evident that standards based on the location of the operation, rather than the type of operator, create better opportunities to maximize orbital safety and capacity. An orbital classification approach can serve to identify and communicate appropriate behaviors and standards in a manner that recognizes the varying characteristics of different orbital “neighborhoods” and creates standards to optimize orbital carrying capacity while accommodating access for different levels of operational capability.

VII.References

[1] R. Stilwell, D. McKnight, Z. Malekos-Smith and N. Dailey, "Integrating Orbital Carrying Capacity into International Poliicy Constructs: Leveraging best practices from aviations rusk-based norms," in *75th Interational Astronautical Congress* , Milan, 2024.

[2] R. Stilwell and D. McKnight, "Applying an Aviation Analogy to Sustained Safe Space Operations," in *9th Space Traffic Management Conference*, Austin, 2023.

[3] R. Stilwell and D. McKnight, "SSC23-P1-29 Space Debris Policy and the Small Satellite Community: Applying an aviation analogy to sustains safe space operations," in *AIAA/USU Conference on Small Satellites*, Logan, 2023.

[4] R. Stilwell, D. McKnight, N. Dailey and Z. Malekos-Smith , "Integrating Orbital Carrying Capacity into INternational Policy Constructs: Leverging Best Practices from Aviation's Risk-Based Norms," in *Proceedings of the International Astronautical Congress*, Milan , 2024.

[5] AIAA, facilitator, "Satellite Orbital Safety Best Practices," AIAA, 2022.

[6] NASA Office of the Chief Engineer, "NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook," National Aeronautics and Space Administration, 2003.

[7] Secure World Foundation, Handbook for New Actors in Space, 2nd edition, Washington, DC: Secure World Foundation, 2024.

[8] 18th & 19th Space Defense Squadron (Space-track.org), "Spaceflight Safety Handbook for Satellite Operators Version 1.7," Combined Force Space Component Command, Vandenberg, 2023.

[9] L. Riesbeck and D. Oltrogge, "2023 Updated Space Safety Coalition Best Practices for the Sustainability of Space Operations," in *2nd Orbital Debris Conference Papers 2023*, Sugar Land, TX, 2023.

[10] L. Space Exploration Holdings, *FCC Application Public Notice,* 2024.

[11] *Treaty on Principles Governing the Activities of States in the Exploration and Use of outer Space, including the Moon and Other Celestial Bodies,* London, Moscow, Washington (in triplicate) , 1967.

[12] European Space Policy Institute, "ESPI REport 82 - Space Environment Capacity - Full Report," European Space Policy Institute, Vienna, 2022.

[13] M. Yakovlev, "The "IADC Space Debris Mitigation Guidelines" and Supporting Documents," in *Proceedings of the Fourth European Conference on Space Debris*, Darmstadt, 2003.

[14] United Nations Office for Outer Space Affairs , "Space Debris Mitigation Guidelines of the Committee," United Nations, Vienna, 2010.

[15] P. D. Stephan Hobe, "The Cologne Manual on Space Traffic Management," Co-operation project between the Institute of Air Law, Space Law and Cyber Law at the University of Cologne and the German Aerospace Center (DLR), Cologne, 2025.