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P&I Club Membership As Potential Incentivization For Adherence To Best Space Traffic Management Practices: A Maritime Analogue

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P&I CLUB MEMBERSHIP AS POTENTIAL INCENTIVIZATION FOR ADHERENCE TO BEST SPACE TRAFFIC MANAGEMENT PRACTICES: A MARITIME ANALOGUE

by

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This thesis, submitted by Cristin M. Finnigan, in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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This thesis is being submitted by the appointed advisory committee as having met all of the requirements of the School of Graduate Studies at the University of North Dakota and is hereby approved.

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Cristin Finnigan
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ABSTRACT

It has been said that the space environment is becoming so accessible, we are at risk of depleting it as a resource, thereby risking society's space-dependent functions. Law, regulations, policies, and guidelines exist to guide entities to act to preserve the space environment. However, best space traffic management (STM) practice implementation and regulatory compliance could be costly and resource-intensive, especially for a small business. Some entities may not undertake innovative space endeavors at all, or worse, ignore laws, regulations, policies, and guidelines.

A question arises of how space actors could be persuaded to work toward meeting STM laws, regulations, policies, and guidelines and perhaps take on potentially costly practices to follow them. This thesis attempts to answer whether liability apportionment and risk-pooling through a space protection and indemnity (P&I) club membership could benefit a space actor enough to drive implementation of best space traffic management practices where actors could be more likely to adhere to laws, regulations, policies, and guidelines.

The study is limited to one example model space P&I club in the U.S. as a foundation for a potential larger international group in the future. The study assumes both insurance and P&I calls can be based on publicly available financial information, though need for more detailed information on insurance premiums and P&I calls is needed to create a fine-tuned model. The study also assumes a potential space P&I club member would be subject to U.S. law, regulations, and policy. Methods include document and policy analysis, interviews with space insurance and risk management subject matter experts, and cost analyses. Arguably, a case does indeed exist

wherein a potential space P&I club membership could benefit a space actor enough to encourage implementation of best space traffic management practices. However, it would be best used as part of the bigger STM picture alongside existing regulations and policies. Still, a P&I club membership could provide a significant enough benefit where actors could be more likely to adhere to regulations and policies, which would, in turn, have a positive impact on keeping the space environment sustainable for current and future activities.

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Introduction and Background

It has been stated many times throughout the conversation surrounding space traffic management (STM) that outer space is "becoming increasingly congested and contested,"[1] and "our global space environment is on a path of suffering a *Tragedy of the Commons*."[2] The tragedy of the commons "refers to a situation in which individuals with access to a shared resource (also called a common) act in their own interest and, in doing so, ultimately deplete the resource.[3] 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) provides "outer space… shall be free for exploration and use by all States without discrimination of any kind…."[4] In other words, particularly when addressing matters of outer space and especially as launch and spacecraft technological capability becomes more and more accessible even to small entities (such as new space startups) and students, space activity could be perceived as leading us into a tragedy of the commons situation in the outer space environment.

In June 2018, President Donald Trump signed Space Policy Directive 3 (SPD3), a space traffic management (STM) policy setting forth principles, goals, and guidelines to help ensure

[1] The White House. Space Policy Directive-3, National Space Traffic Management Policy [hereinafter *SPD3*]. Washington, D.C.: The Director of the Office of Science and Technology Policy, 2018: 3. Accessed August 15, 2019. https://www.whitehouse.gov/presidential-actions/space-policy-directive-3-national-space-traffic-management-policy/.

[2] *Reopening the American Frontier: Promoting Partnerships Between Commercial Space and the U.S. Government to Advance Exploration and Settlement: Hearing Before the Senate Subcomm. on Space, Science, and Competitiveness*, 115 Cong. (2017) (stat ement of Moriba Jah, Associate Professor, Aerospace Engineering and Engineering Mechanics, Cockell School of Engineering, The University of Texas at Austin) [hereinafter *Statement*], 5, accessed March 31, 2018. https://www.commerce.senate.gov/public/_cache/files/c2f571ea-f105-411a-8f86-da2e2745cc68/270AD245868C44DB055E3BA358E752C8.dr.-moriba-jah-testimony-1-.pdf

[3] Alexandra Spiliakos, "Tragedy of the Commons: What it is and 5 Examples," February 6, 2019, https://online.hbs.edu/blog/post/tragedy-of-the-commons-impact-on-sustainability-issues.

[4] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other Celestial Bodies [hereinafter *OST*] art. I, Jan. 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205.

the use of outer space can continue in a safe and sustainable way. SPD3 defines STM as "the planning, coordination, and on-orbit synchronization of activities to enhance the safety, stability, and sustainability of operations in the space environment."[5] The International Academy of Astronautics (IAA) defines space traffic management as "the set of technical and regulatory provisions for promoting safe access into outer space, operations in outer space and return from outer space to Earth free from physical or radio-frequency interference."[6] "Safe" space access and operations encompass several key areas, including but not limited to mitigation of orbital debris and best practices to prevent it, advancement of space situational awareness (SSA) and greater sharing of pertinent data, and monitoring and tracking of space objects and prevention of conjunctions and collisions. SPD3 defines SSA as "the knowledge and characterization of space objects and their operational environment to support safe, stable, and sustainable space activities."[7]

While international and U.S. domestic entities and governing bodies have drafted policies and best practices to help manage space traffic, there are still many holes to be filled as to the actual logistics of how STM can (and should) be carried out. Some facets of STM to consider include identification, tracking, and monitoring; collision avoidance; and long-term sustainability of our space environment by keeping our "orbital highways" clean. But the question arises regarding specifics of how we implement strategies and tactics to manage our spacecraft's paths on orbit.

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[5] *SPD3,* 3.

[6] International Academy of Astronautics, *Cosmic Study on Space Traffic Management*, 2006, https://iaaweb.org/iaa/Studies/spacetraffic.pdf.

[7] *SPD3*, 3.

And what about the risk involved? Harrington describes risk as "fundamentally an external danger."[8] Merriam-Webster defines risk as

> 1: possibility of loss or injury; 2: someone or something that creates or suggests a hazard; 3a : the chance of loss or the perils to the subject matter of an insurance contract, also: the degree of probability of such loss; b: a person or thing that is a specified hazard to an insurer; c: an insurance hazard from a specified cause or source… ."[9]

According to Julie Wertz, a team "must figure out how to best apply [its] limited resources to maximize [its] chance of success" in getting a mission design "to work in the way it is planned to achieve the mission objectives."[10] Therefore, teams have "formalized the idea of risk," which in its essence is as follows: "*Risk*, *R*, is defined as the product of the probability of a negative event occurring, *P*, and the impact, or consequence, of that event, *I*."[11] Once risks are identified (which could be accomplished using lessons learned or through the expertise of individuals who designed/are designing the system), Wertz states they should be documented and should include a "risk statement," or a statement in the form of "'if event, then consequence.'"[12] These risk identifications and statements can then be captured qualitatively, for example in a "fever chart," or a matrix that frames a scale for probability and impact of the identified potential risk.[13] The matrix could contain any number of rows and columns, and "typical sizes include 3 x 3, 4 x 4, or 5 x 5."[14] The description in each cell can be qualitative, such as "'High, Medium, Low" or 'Very

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[8] Andrea Harrington, *Space Insurance and the Law: Maximizing Private Activities in Outer Space* (Cheltenham: Edward Elgar Publishing Limited, 2021), 15.
[9] Merriam-Webster Definition of Risk https://www.merriam-webster.com/dictionary/risk accessed 3/12/2022
[10] Julie Wertz, *Space Mission Engineering: The New SMAD*, eds. James R. Wertz, David F. Everett, and Jeffery J. Puschell (Hawthorne: Microcosm Press, 2011), 767.
[11] Wertz, 767.
[12] Wertz, 770.
[13] Wertz, 770.
[14] Wertz, 771.

Likely, Somewhat Likely, Not Likely, Very Unlikely.'"[15] As an example, one type of hazard to an insurer that is typically called out as exclusions in insurance policies is a war risk. It could be argued that a war risk may be very unlikely, but would have a very high negative impact to a spacecraft/mission (and would send ripple effects to everyday life on Earth). In terms of liability and insurance, an act of war will be examined pertaining to exclusions from space insurance coverage and supplemental P&I club coverage.

As a more in-depth introduction, in the current state of our outer space environment, different types of spacecraft reside in different orbits depending on their purposes. The International Space Station (ISS), Hubble Space Telescope (HST), some Earth observation/remote sensing satellites, spy satellites, and communication satellite constellations, exist in low Earth orbit (LEO). Navigation satellites and the Iridium satellite constellation reside in medium Earth orbit (MEO). Other Earth observation satellites are in polar orbit.[16] Most commercial communications satellites are in Geosynchronous Earth orbit (GEO) at 36,000 km altitude, and many of these satellites reside in orbital slots over the Equator.

The United States Department of Defense (DOD) arguably has the most comprehensive database containing spacecraft status and activity. The database was once overseen by USSTRATCOM and Joint Space Operations Center (JSpOC) (subsequently, Combined Space Operations Center [CSpOC]) and has now been transferred to the responsibility of U.S. Space Command, specifically the 18th Space Control Squadron (18 SPCS) at Vandenburg Air Force

[15] Wertz, 771.
[16] Alex Ellery, Joerg Kreisel, and Bernd Sommer. "The case for robotic on-orbit servicing of spacecraft: Spacecraft reliability is a myth." *Acta Astronautica* 63 (2008): 632.
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Base in California.[17] Per Sandra Erwin in SpaceNews, 18 SPCS has made "improvements in space debris tracking" and has optimized processes to provide "'more meaningful' data on approximately 25,000 space objects tracked by the U.S. military,"[18] and while this is the case, tracking and monitoring space traffic is consuming a significant part of DOD resources. An examination of whether a commercial entity could bear some of the burden may be advisable, but the tracking and monitoring tasks are still costly and resource-intensive, which may cause industry actors to balk.

One of the goals of SPD3 is to "enable [science and technology] research and development to support the practical applications of [space situational awareness] and STM."[19] As stated above, tracking and monitoring activity in and of itself is costly and consumes significant resources; adding the weight of research and development (R&D) to the mix would likely greatly increase the required funds and resources needed to successfully accomplish an ongoing tracking and monitoring system.

How can some of the burden be shared to encourage private/commercial spacecraft owner/operators to implement these strategies and tactics? According to a position paper drafted by the National Space Society (NSS), advanced technological capability such as active debris removal (ADR) that could fulfill SPD3's (and other policies' and guidelines' recommendations) may not be within reach of certain actors, possibly including developing countries or small businesses. As a result, the NSS recommends "a way to enable market forces to help service the

[17] Sandra Erwin, "U.S. Space Command announces improvements in space debris tracking," *SpaceNews*, September 24, 2020, https://spacenews.com/u-s-space-command-announces-improvements-in-space-debris-tracking/.
[18] Erwin, 2020.
[19] *SPD3*, 4.

debris problem," and "propose[s] funding for liability compensation through mechanisms such as protection and indemnity (P&I) space clubs in collaboration with other stakeholders."[20]

The NSS position paper specifically addresses a possible space P&I club only with regard to ADR and space salvage, using maritime salvage as its analogue. Due to the vast nature of the appeal of incentivization and relief of some financial and other burden for implementing other STM best practices overall, combined with recent space sustainability initiatives, US regulation, and traditional insurance policies, the NSS' proposed approach for forming a space P&I club could apply to a much broader spectrum of STM activities and solutions. The space P&I club could "carry out liability apportionment and compensation agreements with national governments, underwriters, investors, etc.,"[21] so members would receive some benefit from implementing best practices, as well as some relief from bearing the full burden of potentially costly and risky STM activity. If this approach combining industry and standardization of best practices is put in place, it could make the current/existing fragmented STM guidelines more standard and coherent, thus making a significant impact on how quickly we can get to work on the operational matters of managing space traffic. If a space P&I club membership could potentially provide enough benefit, financial or otherwise, a space actor could be incentivized to implement best STM practices by incorporating STM technology or compliance measures, such as end-of-life (EOL) disposal, etc., using that benefit to motivate the action.

A key aspect in managing space traffic is orbital debris. STM and orbital debris are not interchangeable terms, though they are very much tied together. Orbital debris is defined by the Inter-Agency Space Debris Coordination Committee (IADC) as "all man made objects including

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[20] "Space Debris Removal, Salvage, and Use: Maritime Lessons" [hereinafter, "NSS"], *National Space Society*, 5, accessed July 26, 2020, https://space.nss.org/wp-content/uploads/NSS-Position-Paper-Space-Debris-Removal-2019.pdf.

[21] NSS, 5.

fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non functional."[22] SPD3 defines orbital debris as "any human-made space object orbiting Earth that no longer serves any useful purpose."[23] Much of the focus of the regulations, policies, and guidelines discussed in this paper aims to address mitigation (possibly even removal) of orbital debris and facilitating capabilities and technologies to do so.

While SPD3 lays a strong framework, as of December 2020, the world had (arguably) not yet seen the start of paving a solid path toward a solution for managing space traffic – domestically or globally. In the United States, alongside SPD3, the Orbital Debris Mitigation Standard Practices (ODMSP) (last updated in 2019) provides exactly that: best *practices* for STM overall, but, as its name makes clear, mainly addressing orbital debris. SPD3 and ODMSP are intended to work in concert to manage space traffic, mitigate risk of spacecraft conjunctions or collisions, and plant the seed for future active debris remediation (ADR).

As stated above, while these guidelines and best practices essentially have the same goals, solid STM efforts have not gained much momentum. Finding solutions that will meet each goal is difficult and complex. For example, a State or private organization with greater financial ability and resources to address STM issues, even if the entity was not acting dubiously, might be seen as placing its own interests ahead of focusing on solving the problem for the greater good. With regard to governance, it may be preferable that one entity is responsible for providing standard policies, guidelines, and best practices in the multiple facets of STM to prevent fragmented and arguably, in some cases, ineffective and out-of-date guidelines from governments, agencies, and organizations.

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[22] IADC Space Debris Mitigation Guidelines [hereinafter "SDMG"], Inter-Agency Space Debris Coordination Committee, IADC-02-01 Revision 2, March, 2020.

[23] *SPD3,* 3.

Purpose/Objectives

STM is a broad, multi-faceted, much-discussed, and much-debated issue, and while policies, guidelines, and best practices are periodically updated and released, society so far has only taken incremental steps to put the "rules of the orbital road" in place. This study aims to propose one potential avenue to provide additional relief in some of the burden and complexity of implementation of best STM practices, which is potentially very costly, by facilitating sharing of the burden of liability and risk by space activity stakeholders. This sharing of liability and risk could be accomplished-through membership in a space P&I club. It should be noted that P&I club membership is *supplemental* to traditional insurance where P&I clubs may "pick up" coverage for what would typically be excluded from conventional policies.

Statement of the Problem

Due to the risky and costly nature of STM implementation, as described above, industry actors may balk at adhering to policy, guidelines, and best practices, and they may push back – or they may opt to not adhere at all. This do-nothing approach only propagates the problem of fragmented management of the growing volume of space traffic. How, then, might industry actors, or at least a subset thereof, be encouraged to act toward meeting STM policy and guidelines such as SPD3 and FCC satellite licensing regulations? The question this paper attempts to answer is whether liability apportionment and risk-pooling through a potential space protection and indemnity (P&I) club membership would benefit U.S. spacecraft owner operators enough for them to implement best STM practices set forth in existing regulations, policies, and guidelines, namely SPD3 and FCC satellite licensing regulations. The study will examine an existing maritime P&I club and how it might be used as an analog for a space P&I club, and whether a space P&I club membership would benefit a U.S.-based spacecraft owner/operator to account for recommended best STM practices in its space activity. Further, the nature of liability apportionment and risk-pooling as part of a potential space P&I club membership and whether liability apportionment and risk-pooling within that P&I club membership provide benefit to spacecraft owner/operators is examined. From there, the question of whether the potential benefit of a space P&I club membership is greater than the cost of being part of the club is analyzed and discussed, thus attempting to determine if potential space P&I club membership is favorable to spacecraft owner/operators with regard to these assets.

Additionally, the study attempts to answer whether adherence to existing laws, regulations, policies, and guidelines is a benefit stemming from P&I club membership and, if so, whether the benefit of adhering to them is greater than the cost. In other words, would potential space P&I club membership drive better behaviors in space activity that could gradually lead to helping manage space traffic in a cleaner manner and helping mitigate and/or remediate orbital debris?

Scope

The topics of STM and space insurance are vast and affect global society. However, this study is limited to a maritime P&I club in the U.S., of which there is only one: American Steamship Owners Mutual Protection and Indemnity Association, Inc, otherwise known as The American Club.[24] The spacecraft owner/operators in this study are limited to those that have publicly available financial information within annual reports, statements, and on their websites. This study specifically focuses on entities that have active satellite constellations that reside on LEO because orbits within LEO are of most present concern due to its accessibility, increasingly

[24] *The American Club*, accessed March 13, 2022, https://www.american-club.com.

crowded nature, and the number of accidents that have occurred and potentially will occur in the future.[25] Additionally, technology demonstrations have already been performed in attempts to service, deorbit, repair, and/or refuel LEO satellites that would help clean up at least one of our orbits and ideally facilitate safer and more efficient STM practices.

Additionally, the scope of the study addresses existing international treaties and conventions as the space environment is inherently open to all States; U.S. Space Policy, legislation, regulatory and regulatory licensing requirements; and other existing guidelines and best practices the U.S. (including NASA) has/have adopted. Stakeholders within the scope of the study would include theoretical space P&I club members (namely spacecraft owner/operators), the United States Government (USG), a traditional space insurer, and third parties to whom damage will have occurred on orbit as well as on the Earth's surface. On a wider scale, the overall "collective stakeholder" is society as a whole, as we have become very dependent on many space-based resources.

Assumptions

Some assumptions are required within this study since some information, such as space insurance policy premium rates and P&I club call rates, are proprietary in nature, and not all company financial data are publicly available. Additionally, assumptions for models discussed in this research are necessary to keep the study within scope. This study assumes that:

a) The spacecraft owner/operator is based in the United States
b) The spacecraft owner/operator currently carries traditional insurance policy/coverage typical for that particular spacecraft

[25] Michael S. Dodge, "The Divergent and Evolving Legal Pathways of Future Space Traffic Management Collaboration," *Space Traffic Management Conference* 14 (2015): 1.

c) The cost of a space P&I club membership is proportional based on tonnage of spacecraft, similar to a maritime P&I club

d) There were zero accidents in the prior year for the model space P&I club, thus resulting in a "flat" starting balance

e) An occurrence giving rise to a claim would be excluded from a traditional spacecraft insurance policy and would trigger P&I "insurance" coverage

f) The occurrence involved material that was non-biological in nature

g) The cost of the above-referenced occurrence would not fall under the responsible party's contractual limitation of liability provision

h) Until the time of occurrence, the spacecraft involved had been operating for a full year and had been generating a full year's revenue

Method

The methods used to investigate this question were qualitative. They were chosen due to the fact that the researcher was able to collect qualitative data, including a general cost analysis (discussed below) and concurrently, integrate the data, and then compare the data to "confirm or disconfirm the… results", which is beneficial in answering the particular questions posed here.[26] The qualitative research portions consisted of: 1) examination of documents, 2) examination of audiovisual and digital materials, 3) a case study of a U.S.-based maritime P&I club to be used as an analog for a space P&I club, and 4) interviews with two subject matter experts on space insurance and space activity/satellite mission risk management. Further, the research consisted of collection and analysis of financial data from: 1) commercial satellite owner/operators with

[26] John W. Creswell and J. David Creswell, *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (Los Angeles: SAGE Publications, Inc., 2018), 220.

publicly available financial information, 2) membership dues for a maritime P&I club, 3) financial information regarding the satellite industry, 4) financial information from loss of satellite and insurance claims. The exact financial data for each commercial entity are not fully known because much of it is proprietary information, but an estimate was made based on information that is publicly available.

The research began with selecting the relevant types of material to be reviewed, starting with examination of documents. The first types of documents examined were public documents in the forms of international treaties, policies, and guidelines pertinent to and addressing STM; and US legislation, regulation, policies, guidelines, and agency reports addressing same. Information from government documents pertaining to STM guidelines and best practices was gathered and specific recommended guidelines and best practices that appear throughout material as trends were selected for study.

The second types of documents examined were documents available to the public in the forms of up-to-date news stories and magazine articles regarding the current status and activity surrounding STM. It could be stated that a third type of examined documents include the material in the literature review within this study, which encompasses other researchers' studies and an overarching conversation about STM, orbital debris, on-orbit satellite servicing (OOS), and P&I clubs tied together by cost, risk, and liability of implementation of STM best practices.

The next step was to determine which audiovisual and digital materials would be examined. It was discovered that in addition to government documents setting forth guidelines and best practices and news articles discussing these guidelines and best practices, live discussion was occurring in U.S. House of Representatives and Senate committee and subcommittee hearings and in radio shows and podcasts. U.S Congressional hearings were selected based on the specific space-related committee/subcommittee conducting the hearing and the topic(s) of discussion, and whether STM was a talking point anywhere within that discussion. Podcast and radio show episodes were first selected based on their reliability as sources via researcher as key instrument.[27] The researcher personally knows one podcast host and two subject matter experts (SMEs) in the area of STM and has validated their background. The two SMEs have been guests on a podcast hosted by an individual familiar to the researcher and on a separate radio show. Each podcast and radio show episode was entirely focused on STM or an element thereof, and each consisted of in-depth value-added interviews with the guest SME. Audiovisual and digital materials pertaining to STM from Congressional hearings and guest SMEs on podcasts or radio shows based on live conversation and debate were gathered. The fact that the SMEs are personally known to the author is acknowledged. To help prevent any potential bias in studying material involving the SMEs, a wide spectrum of opinions from other sources/industry experts was reviewed to gather a broad range of information from sources of varying experience and backgrounds.

Direct interviews were conducted with SMEs in the areas of space insurance and commercial space mission risk management. Interview subjects were chosen based on experience in actual operations and/or risk cases handled, and University of North Dakota Institutional Review Board approval was obtained to conduct the interviews. Chris Kunstadter, Global Head of Space at AXA XL insurance was selected based on his extensive experience working in the insurance industry, specifically with space insurance policies. Second, Charles Thornton, Director, Aerospace Risk Management at Northrop Grumman was chosen based on his extensive experience working for a large company in the aerospace industry that has

[27] Creswell and Creswell, 181.

successfully developed, demonstrated, and provides OOS, thus he would be able to speak to some of the development of such a mission and some of the specific risks involved.

Research material selection also consisted of determining which relevant peer-reviewed journal articles pertaining to any of the elements of this study would be examined, including but not limited to: STM; accompanying risk, cost, or liability; OOS; and/or STM-related legislation and policy. These journal articles make up the literature review herein and recur as points of discussion throughout this paper.

Then the commercial entities to be used in the study were selected. The entities: Northrop Grumman, OneWeb, SpaceX, Swarm Technologies, AXA XL, The American Club, and The Shipowners' Club, were also part of cost analyses in that their financial data were used as analogs for what economic effect a space P&I club membership might have on a commercial satellite owner/operator, but their selection as the analogs was based on certain specific criteria. OneWeb was selected because 1) its financial data regarding assets, losses, and revenue are available through its annual report, and 2) its spacecraft constellation resides in LEO. SpaceX was chosen for a similar reason: its pricing information for its launch vehicle is available on its website and was incorporated into the potential cost for a theoretical space mission.

Swarm Technologies was chosen because it was a small business and provided a service using a constellation of very small CubeSats which is part of the focus of whom a P&I club membership may benefit. It was also chosen due to its activity under which it was scrutinized and ultimately fined by the FCC for serious regulatory violations, which is studied in light of existing US regulatory and policy regime. Northrop Grumman was chosen because it has developed and demonstrated OOS missions that can be used as examples of innovative technology recommended in the US Space Policy and other guidelines to help mitigate orbital debris and thus, arguably, facilitate a safer and more efficient STM system. AXA XL was chosen because one of the subject matter experts with whom the researcher spoke is its Global Head of Space, and he was able to directly provide certain (non-proprietary and non-confidential) information regarding space insurance policies, coverage, and exclusions. The American Club was selected because it is a US-based maritime P&I club and it includes detailed information on its operations, bylaws, and financial information on its website. It was chosen specifically to be used as an analogue for a potential US-based space P&I Club. The Shipowners' Club was chosen strictly because information pertaining to the spectrum of its membership is publicly available on its website.

Additionally, this specific selection of commercial entities is included because their history, overview, and profile of each entity were available and were examined to gather information about their activities and everyday business. A due diligence qualitative assessment of the commercial entities was important to the study because they each needed to meet requirements to ensure they were good candidates to be used as models. Each entity's documents, statements, and reports were examined, including types of services offered, how each entity functions, who their respective targeted markets are, and each entity's overall goals and visions. The entity documents created a narrative that allowed a bigger picture to be envisioned and the foundation of space-specific models based on existing companies to be laid.

Financial data from OneWeb, Swarm Technologies, EnduroSat, and maritime P&I clubs (namely, The American Club and The Shipowners' Club) were gathered, specifically revenue brought in from services provided by satellite companies and P&I clubs in the form of subscriptions and memberships. Secondly, these entities' expenses and losses were examined to approximate amount of capital expenditures on typical commercial communications satellites and losses due to claims, respectively. This information was taken from each entity's publicly available cost and pricing information, annual/financial statements, and websites. Once this information was obtained, costs of satellites for each spacecraft company were approximated based on number of satellites (according to stated asset, number of satellites launched, and purchase data). (The importance of the cost of a satellite comes into play in determining how potential accidents would affect various businesses, insurance policy costs, and P&I club membership calls.) P&I club membership dues were approximated by the number of members, amount of tonnage, and revenue brought in during the course of one fiscal year, according to the clubs' annual statements. Losses due to claims were also examined, the figures taken from the same annual statements.

Financial information regarding servicing missions that are currently being developed was gathered through annual statements, news reports and press releases. Contracts between commercial entities, namely Orbital ATK (now Northrop Grumman) and Intelsat, were not able to be quantitatively parsed out, so the contracts between NASA and SSL for Restore-L and DARPA and SSL for RSGS were examined to gather approximate costs for pieces of the spacecraft. It was determined that four major components make up an OOS satellite: the spacecraft bus, a number of mission tools (toolkit), robotic arms, and launch vehicles.[28] The approximate cost of the spacecraft bus was acquired from the contract awarded to SSL from NASA for the Restore-L mission, and the cost of the robotic arm was acquired from the contract awarded to SSL from DARPA. The launch vehicle cost was acquired from SpaceX's website. The cost of the toolkit is not readily available, so this figure was approximated by using the cost

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[28] Angel Flores-Abad, Ou Ma, Khanh Pham, Steve Ulrich, "A review of space robotics technologies for on-orbit servicing," *Progress in Aerospace Sciences* 68, (2014): 2.

of the spacecraft bus as a minimum (it is assumed that the toolkit will cost at least as much as the spacecraft bus).

Further, information on dollar value of an industrial working maritime craft – in this case, a 95-foot tug boat, was gathered, as well as information on its gross tonnage and approximate mass based on its displacement. These figures were worked with averages and approximations of publicly available financial data and an estimated range of possible annual insurance premiums were estimated. The annual premium estimates were used to determine potential spacecraft insurance policy rates based on the cost analyses of a potential OOS mission, pricing information on websites, and information taken from financial statements. The same process was used to approximate what a potential space P&I club call would be for a spacecraft owner/operator.

The above information was compiled and explored the following areas: problem areas of STM; importance of the space environment in daily life; STM-related law/policy, regulations, guidelines; space business operational and financial information; STM technical capability and implementation; space insurance and risk management subject matter expertise; space insurance policy coverage; and potential space supplemental P&I club coverage based on a maritime P&I club as an analogue. Based on a broad, yet detailed, spectrum of information, supporting exposition was created as to each area's importance and relevance within STM, policy, risk management, business, and how P&I club membership could help support a space company in each of these areas. Subsequently, it was determined whether supplemental coverage in a potential space P&I club would incentivize a space actor to implement best STM practices.

Literature Review

The sources reviewed in this study address the following: reasons behind the need for implementing STM; a discussion of pertinent STM legislation, policies, guidelines, recommendations, and best practices; current STM activity and status; some of the technical methods proposed and tested to support STM; and the potential benefits and shortcomings of maritime P&I clubs. Subsequently, the overarching discussion was analyzed and included in the Analysis and Discussion of this study.

The literature indicates trends of discussion about several subtopics within various areas of STM. Ongoing updates and discussion about STM activity is important because it is a fluid, ever-changing subject, and experts continue to come up with solutions based on the best information we have at present. STM-related law and policy discussion is relevant and important because it explores how owner/operators might support policies and guidelines by building specific engineering/hardware into their spacecraft. Costly technical STM-related components and implementations on spacecraft in combination with potentially very risky on-orbit maneuvers is a step for introducing the potential for P&I clubs' mechanism to alleviate some of the risk taken on by spacecraft owner/operators.

Jakhu, et al. explain, "[s]pace debris seriously threatens the sustainability of space utilization since it is considered to be an emerging navigation hazard to functional or operating satellites."[29] Some studies have shown LEO is rapidly approaching the "tipping point" at which our space-based capabilities may begin to decrease and the Kessler Syndrome might become

[29] Ram S. Jakhu, Yaw Otu M. Nyampong, and Tommaso Sgobba, "Regulatory framework and organization for space debris removal and on orbit servicing of satellites," *Journal of Space Safety Engineering*, 4 (2017): 130.

reality,[30] and some believe we have already reached it.[31] As Hunter notes, space capabilities "play a role in everything from buying gas to national defense."[32] If the number of objects in orbit around the Earth becomes too great, we risk losing those capabilities to damage from collisions, or we may potentially not be able to launch satellites in the future to continue services because there is too much risk of damage from collisions with other craft – space would have simply become too crowded. Hunter notes further that "[d]isruption in access to space-reliant services potentially range from minor inconveniences to catastrophic global economic collapse."[33]

Hunter states since the Iridium-Cosmos collision, conjunction notifications, or alerts that certain spacecraft may "cross paths" and potentially strike one another, have increased dramatically.[34] In 2011, JSpOC (now SCPS 18) "made 4,331 notifications to satellite owners/operators regarding potential conjunctions,"[35] and Jakhu, et al. note the number of collision avoidance maneuvers has also increased.[36] Recently, Jah explained in a BBC podcast that one collision occurs every couple years on average, but we have recent evidence that collisions are happening more frequently.[37] More frequent collisions will lead to the formation of more debris.

Jah believes the biggest problem preventing us from having a "more robust space traffic monitoring and management capability" is the fact that we do not globally share observational

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[30] Thomas K. Percy and D. Brian Landrum, "Investigation of national policy shifts to impact orbital debris environments," *Space Policy*, 30 (2014): 24.

[31] Jakhu, Nyampong, and Sgobba, 129.

[32] Stephen Hunter, "How to reach an International Civil Aviation Organization role in Space Traffic Management," *Space Traffic Management Conference* (2014): 4.

[33] Hunter, 4.

[34] Hunter, 7.

[35] Hunter, 7.

[36] Jakhu, Nyampong, and Sgobba, 130.

[37] Ronald Pease and Moriba Jah, "Space Junk," Produced by BBC, *Science in Action,* March 25, 2018. Podcast, MP3 audio, 27:00. Accessed April 1, 2018. http://www.bbc.co.uk/programmes/w3csvrhc.

RSO data as a community.[38] There are some reasons we are not able to share information with other States, such as national security, intellectual property, or regulations such as ITAR, but SSA experts say "the more eyes watching objects in space, the more accurately governments and commercial operators can predict orbits for their spacecraft, and in turn, the better they can predict the likelihood of a collision."[39]

Jah and Hunter both address the fact that USSTRATCOM/JSpOC (now 18 SCPS) was already overburdened by maintaining its database of "resident space objects" (RSOs). Hunter explains when Space Fence became operational, the number of catalogued items would increase "from the tens-of-thousands to the hundreds-of-thousands range and current processing systems and manpower would be quickly overcome by the magnitude of data available to be analyzed."[40]

To address the myriad of issues with regard to STM, there have been a great number of proposed solutions. Michael S. Dodge states

> [o]n the one hand, this produces a dilemma, in that there are STM efforts underway by various States that are externally inconsistent with one another, even though they share the goal of safe management of space assets. On the other, systems in place by space actors can serve as ready-made exemplars of methodologies that could, if properly modified, inform the creation of eventual international STM norms.[41]

One possible solution is for an international organization to be created via a "new treaty negotiated specifically for the purpose of ADR and OOS," drawing comparisons to the formation of the International Telecommunications Satellite Organization (INTELSAT) and the International Maritime Satellite Organization (INMARSAT).[42] Jakhu, et al. state this new

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[38] *Statement*, 7.

[39] Caleb Henry, "Space situational awareness experts urge Russia to join orbital neighborhood watch," *SpaceNews*, March 16, 2018, http://spacenews.com/space-situational-awareness-experts-urge-russia-to-join-orbital-neighborhood-watch/.

[40] Hunter, 6.

[41] Dodge, 5.

[42] Jakhu, Nyampong, and Sgobba, 132.

international organization could negotiate with States on whose registry a piece of orbital debris is listed regarding potential ADR or OOS.[43] The international organization could have the right of jurisdiction and control transferred to them, and be authorized to perform ADR or OOS services.[44] If the object being serviced is damaged during the process, the international organization would have cross-waivers of liability in place that allow it to settle.[45] Additionally, any concerns regarding intellectual property, State-specific regulations in place intended to protect national security (such as ITAR), or the potential weaponization of spacecraft through ADR or OOS would be transparently explained through diplomatic channels before the activity takes place, thus, Jakhu, et al. theorize, alleviating fears that the ADR or OOS activity would be performed in bad faith.[46]

However, it has been stated that there is little interest in forming new space treaties in the current political climate, and, according to professor emerita at the University of Mississippi School of Law, Joanne Gabrynowicz, "'[national] legislation and regulation is the only plausible avenue for modernizing the legal framework in outer space right now.'"[47] Because addressing the orbital debris is a matter of urgency, domestic solutions may help in the short-term while concurrent development on a long-term international solution occurs.[48] Further, the theory of a "clearinghouse of information collected by government and corporate interests… and sharing critical information… could also be extended to an international non-governmental organization."[49]

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[43] Jakhu, Nyampong, and Sgobba, 132.
[44] Jakhu, Nyampong, and Sgobba, 132.
[45] Jakhu, Nyampong, and Sgobba, 132.
[46] Jakhu, Nyampong, and Sgobba, 132.
[47] Jason Krause, "The Outer Space Treaty turns 50: can it survive a new space race?" *ABA Journal* 103.4 (2017): 44, accessed December 13, 2017, http://link.galegroup.com/apps/doc/A492536879/EAIM?u=ndacad_58202zund&sid=EAIM&xid=e45fc5c3.
[48] Dodge, 14.
[49] Dodge, 14.

Jah suggests a civilian STM organization would best provide these services (including tracking of RSOs as well as execution of ADR, discussed further below); Hunter recommends a similar single point-of-contact "store-front" approach, but it appears logical that the best solution for tracking and monitoring would be if States were to pool resources and create a ubiquitous catalog of known objects. One possible approach to an STM solution, as Percy and Landrum theorizes, is to "allow an international standards organization, such as ISO, to enact *Industry Standards* against the creation of space debris."[50] It is in the aerospace industry's best interest to maintain a "clean environment" in space, so a company that does not comply with the set standards would fail to remain competitive.[51] Dodge notes that similarly, trade organizations, such as the International Air Transport Association, have had positive impact on the behavior of airlines, so it is logical to believe a trade organization dealing with "collision avoidance, traffic guidance, and other on-orbit activities... could arise to obviate present STM difficulties."[52]

How would an entity be held to complying with established policy, guidelines, and standards? Percy and Landrum theorize domestic space debris policy could "require spacecraft manufacturers and operators to comply with industry standards,"[53] but domestic policy is not binding law.

Harrington states "the international nature of major space insurers and near-universal need for their products uniquely positions this group to act as a form of quasi-governance that can contractually enforce (or at least incentivize) best practices that effectively function as regulation for the industry."[54] Echoing the sentiment in ESA's commentary regarding the space

[50] Percy and Landrum, 30.
[51] Percy and Landrum, 30.
[52] Dodge, 15.
[53] Percy and Landrum, 30.
[54] Percy and Landrum, 30.

sustainability rating and the potential for incentivizing actors to implement best STM practices by insurance discounts and other "perks" for a high rating, Harrington states "[b]est practices can be implemented first as ways to obtain premium discounts and subsequently as requirements, spreading across the industry as insurers struggle to remain competitive with their peers and cooperative with their clients."[55] Chris Kunstadter believes in a different approach – one that would add a surcharge to a space company's insurance policy if it does *not* implement best STM practices.[56]

Kunstadter states, "[r]isk transfer is one of the ways in which enterprises manage risk, along with avoidance, reduction, and retention," and "[i]nsurers take those risks… But a significant insurance loss due to a collision in orbit will have an immediate, dramatic, and chilling effect on the space insurance market, and thus on the whole space industry."[57] Further, "ambiguous legal regimes threaten the viability of a robust commercial human spaceflight market."[58] He further explains, "[s]pace insurance policies are typically 'all-risks'— they provide coverage for all losses except those that are specifically excluded," i.e. war, terrorism, and cybersecurity-related incidents.[59] Thus, "collisions with debris and micrometeoroids are generally covered," and despite the fact that "some insurance companies have curtailed their exposures or even withdrawn from insuring satellites in LEO," others are "increasingly including the risk of collision in orbit in their underwriting assessments."[60] So, Kunstadter echoes Harrington and explains "[a]s demand for insurance in LEO increases with increasing

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[55] Harrington, 15.
[56] Interview with Chris Kunstadter, February 21, 2022.
[57] Chris Kunstadter, "What Keeps Space Insurers Up at Night?" [hereinafter *Space Insurers*] *The Air & Space Lawyer* 34, no. 3 (2022): 11.
[58] Space Insurers, 11.
[59] Space Insurers, 11.
[60] Space Insurers, 11.

commercial use, a lack of insurance coverage would have a stifling effect on the space economy."[61]

According to Alyssa Goessler, "[a]nalogies are often made between the policy spheres of maritime law and space law, given that both pertain to a physical space with no clear regulatory jurisdiction, or perhaps overlapping regulatory jurisdictions," proposing "the high seas… most resemble near-earth space."[62] She makes the further analogy by describing a canal as a "human-made waterway channel that boats can pass through," and though "[t]here are no human-made passageways in space… there are "orbital highways"–bands of orbit that several… space objects pass through."[63] Using the case of the Ever Given ship that became stuck in the Suez Canal in 2021, Goessler states "[w]e must observe the environment and align our practices with ecological conditions at hand… [j]ust as the salvage crews and Suez Port Authority aligned their work with the environmental conditions at hand." Further, "[w]e must boost efforts to measure and quantify the space environment in order to craft sustainable traffic management mechanisms."[64] Reiterating Jah's point that the comprehensive gathering of good data regarding the space environment and tracking its objects, Goessler states we could use that space environment data to "aid in orbital salvage practices," and this author will emphasize the fact that this data can be used far beyond orbital salvage practices and are, in fact, crucial to all space activity.[65]

Goessler further acknowledges that "[n]o cross-domain analogy will be perfect, but identifying conceptual similarities may better equip us to handle novel circumstances in space,"

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[61] Space Insurers, 11.

[62] Alyssa Goessler, "#SpaceWatchGL Opinion: A Maritime Crisis's Contributions to the Field of Space Traffic Management," *SpaceWatch.Global*, August, 2021, https://spacewatch.global/2021/08/spacewatchgl-opinion-a-maritime-crisiss-contributions-to-the-field-of-space-traffic-management/.

[63] Goessler, "#SpaceWatchGL Opinion, August, 2021.

[64] Goessler, "#SpaceWatchGL Opinion, August, 2021.

[65] Goessler, "#SpaceWatchGL Opinion, August, 2021.

but examining and analyzing these similarities between the maritime and space environments "will enable us to judiciously prepare for and avoid collisions on orbit," a similar theory proposed in the NSS position paper discussed below.[66]

Dr. Jah has stated he "think[s] people are hoping that government basically comes to some common sense to help create and establish a marketplace for industries to engage in" activities that facilitate space sustainability.[67] To that end, "he believes that spacefaring nations have to agree that near-Earth space is an ecosystem like land, air and the ocean" – it falls under the tragedy of the commons and will need to be protected.[68] Then, Jah continues, one could potentially

> assign a bounty for objects and talk about nonconsensual debris removal… Maybe there is a penalty to the sovereign owner of their dead asset that's taking up capacity of an orbit. This could definitely create a marketplace where space-object-removal technologies can thrive.[69]

In concert with the NSS position paper, the foundation for the comparison between the space and maritime environments can begin to be laid.

As echoed by Goessler, the NSS recognizes calls for actions to keep our space environment sustainable and "proposes mechanisms… to overcome barriers to creating a safe space environment via active debris remediation and salvage, including ways to overcome daunting liability and compensation impediments."[70] The NSS realizes ADR and space salvage activity "is very difficult under the current international legal space regime and orbital conditions," and further theorizes these regimes and "orbital conditions" disincentivize actors

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[66] Goessler, "#SpaceWatchGL Opinion, August, 2021.

[67] Leonard David, "Space Junk Removal Is Not Going Smoothly," *Scientific American*, April 14, 2021, https://www.scientificamerican.com/article/space-junk-removal-is-not-going-smoothly/.

[68] David, "Space Junk Removal Is Not Going Smoothly," April 14, 2021.

[69] David, "Space Junk Removal Is Not Going Smoothly," April 14, 2021 .

[70] NSS, 2.

from engaging in ADR and space salvage endeavors. The OST and Liability Conventions, particularly, complicate liability assessment, as again, determination of ownership of a spacecraft is extremely difficult, especially when the spacecraft are "unclaimed and neither the spacecraft owner nor operator nor the launching State can be determined."[71]

Even if a State's liability for its spacecraft could be determined (as a reminder, the burden of proof for determination of whose craft inflicted the damage is on the harmed party) via a multilateral liability apportionment agreement through invoking Art. V of the Liability Convention, "there would remain the issue of funding the compensation for any party harmed."[72] To explore a solution to this problem, the NSS asks whether any lessons can be "gleaned [from] liability and compensation regimes for salvage or the removal of pollution and debris in the maritime context."[73]

Essentially, "[s]hipowners insure against loss of or damage to their ships with Hull Underwriters. However, they look to the P & I Clubs for insurance against their liabilities to others."[74] Thornton might consider a P&I club an analogue to a group captive.[75] Liu and Faure posit "risk-sharing agreements play an important role in providing… compensation" after an incident, "but can equally, via the mutual monitoring inherent in risk pooling contribute to efficient prevention."[76] Thus, "[r]isk sharing may be especially attractive in case of new technologies… where operators themselves may be in the best position to assess the risk and hence to impose preventive measures via mutual monitoring."[77] However, Liu and Faure argue

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[71] NSS, 2.
[72] NSS, 2.
[73] NSS, 2.
[74] R. C. Springall, "P & I Insurance and Oil Pollution," *Journal of Energy & Natural Resources Law* 6, no. 1 (1988): 28.
[75] (Charles Thornton, pers. comm., 3/18/2022)
[76] Liu and Faure, 257.
[77] Liu and Faure, 257.

"a relative homogeneity of the risks involved is crucial for the successful functioning of risk sharing pools," and "[t]oo great heterogeneity may prevent the emergence of a risk-sharing pool or lead to cross-subsidization and hence create suboptimal deterrent incentives."[78] Kunstadter also believes homogeneity is virtually required for a potential space P&I club to function for essentially the same reasons.[79] How homogeneity enters the equation as a factor is examined, but at least some P&I clubs to provide cover to marine craft from small (the size of a yacht) to extremely large (a vessel the size of Ever Given, for example).

Risk-sharing agreements "[resemble] insurance in pooling risks," but a major difference is "under an insurance policy risks are shifted to a third party (the insurance company); whereas in a risk sharing scheme, the operators are both insured and insurer; there is hence no involvement of a third party."[80] If a risk-pooling system is ideally functioning,

> the average premium/contribution should be aligned with the risk profile of most members in a particular pool. However, if the risk different insured possess varies significantly, the good risks whose expected damage is less than the premium/contribution will leave the pool. Only the members with a higher risk have strong incentives to stay.[81]

Thus, it is important to 1) "[create] the right preventive incentives for insurance and risk-sharing pools," and 2) to implement the monitoring function "either by insurers or other parties in the risk pool is also crucial to ensure the deterrent effect," or act as incident prevention (whether a party is taking excessive risks or even acting in a reckless or negligent manner).[82] For example, one serious problem in marine pollution is "the deplorable practice adopted by certain irresponsible Masters of deliberately discharging oil into the seas, usually as tank washings,"

[78] Liu and Faure, 257.
[79] (Chris Kunstadter, pers. comm., 2/21/2022)
[80] Liu and Faure, 260.
[81] Liu and Faure, 260.
[82] Liu and Faure, 260.

which affects a P&I club in the form of fines for which it provides cover.[83] Clark offers this as evidence that "[t]he ability of the P & I Clubs to respond to this new and increasing risk is proof of [clubs'] vitality and the flexibility of the insurance market to provide the necessary cover."[84] All said, "[i]t is in the interests of all other members' claims to be as low as possible, and thus a mutual interest of risk minimization is created.[85]

At the time of Liu and Faure's writing, the P&I club pooling agreement made US$3.1 billion available to cover … potential liability," with a limitation of $1 billion for oil pollution.[86] In an application for club membership, according to Liu and Faure, P&I clubs "are more interested in the 'condition of the vessel as a potential source of liabilities; for example, its ability to carry cargo or passengers or crew carefully,'" and "[b]ased on the surveys, the clubs decide whether to reject or accept the vessels with a 'Defects Warranty' whereby any claim arising out of defects noted during the survey would be excluded from the cover… ."[87] Essentially, clubs "try to tailor the premiums to the risks the vessels are exposed to."[88] As additional background, a P&I Club

> provides more services than a pure insurer and operates as a mixture of an insurance company, a law firm and a loss adjuster. Besides offering an insurance coverage, a P&I Club can also provide a worldwide network of correspondents and representatives to give on-the-spot assistance to the shipowner when required, give Letters of Undertaking to offer a security when members' vessels are arrested and assist in claims handling and settlement.[89]

[83] Clark, 209.
[84] Clark, 209.
[85] Liu and Faure, 261.
[86] Liu and Faure, 260.
[87] Liu and Faure, 265.
[88] Liu and Faure, 265.
[89] Jing Liu and Michael Faure, "Risk-sharing agreements to cover environmental damage: theory and practice," *International Environmental Agreements: Politics, Law and Economics* 18 (2018): 266.

Thus, it is of note that P&I clubs provide many more services in a membership through its dues, including some legal services and instant access to an expert. As a significant example, a

> P & I Solicitor on the spot shortly after an incident occurs is to assist the [shipowner] and to ascertain whether any prosecution is likely to eventuate from the incident. If so, the solicitor needs to ascertain whether any defence is open to the master or owners. If there is, it may be possible to persuade the relevant port authority of that fact and either a prosecution is not brought or it is discontinued. In cases where it is not possible to persuade the port authority that the facts do give rise to a defence, then obviously a prosecution follows."[90]

It is important to note a P&I club has limits to its coverage, as "not all the areas of risk for which the P&I clubs provide cover can actually be regarded as insured risks," and those limits "depend upon the extent of discretionary provisions in the club rules and will vary from club to club."[91] But Liu and Faure argue P&I clubs "can provide an alternative when commercial insurance fails to emerge due to the lack of information or associated high costs," and Springall believes "P & I Clubs, with their support for the concept of a sharing of liability for oil pollution damage between tanker owners and cargo interests, will continue to have a dominant involvement in both the introduction and implementation of voluntary oil pollution liability and compensation schemes."[92,93]

In relevance to the space industry, Harrington touches on the fact that some space insurance companies offer third party space insurance policies, and some of those include separate items for "service interruption, loss of revenue, broadcast events; and 'captive cover' (an insurance company created by an entity or group to provide insurance for itself) to assist

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[90] Springall, 31.

[91] Mark Tilley, "Protection and Indemnity Club Rules and Direct Actions by Third Parties," *Journal of Maritime Law and Commerce* 17, no. 3 (1986): 443.

[92] Springall, 40.

[93] Liu and Faure, 269.

those companies which self-insure their space risks."[94] However, Harrington states these third party policies are "likely… to be extremely expensive and difficult to procure. Thus, the lack of standard coverage in the marketplace that can be endorsed to address the needs of particular entrepreneurial endeavors hinders development of such endeavors. The refinement and standardization of satellite-oriented insurance offerings would also contribute to increased insurance capacity at lower premium, allowing additional entrants to the satellite market. Such standards are particularly relevant for those developing countries wishing to develop space capabilities."[95] Importantly, it is this third-party liability space insurance that "provides coverage to [parties] not involved in the space activity or [insurance] contract, and is a particularly important developing area… ."[96]

Analysis and Discussion

Risk in Space Activity

According to Jim Wetherbee, "[a]voiding tragedy, while performing noble missions at peak effectiveness, is the holy grail of organizations trying to operate in hazardous environments."[97] He explains further, "[f]or long-term viability of a company, a profitability motive is always desired," but if that company is to ultimately succeed, it will also need to continuously monitor the system to "[detect] decremental changes" and "prevent drift toward the next accident."[98] Wetherbee states, "[g]ood executives [use the proper leadership skills to] emphasize working [together in a high-quality and safe way] to accomplish goals, contribute to society, and increase the long-term value of the organization," all while confronting hazards.[99]

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[94] Harrington, 6.
[95] Harrington, 6.
[96] Harrington, 6.
[97] Jim Wetherbee, *Controlling Risk in a Dangerous World* (New York: Morgan James Publishing, 2017), 5.
[98] Wetherbee, 4.
[99] Wetherbee, 20.

Wetherbee explains there is a zone between "catastrophe or bankruptcy," and can be summarized as follows:

> What's the goal of your organization? The goal is to accomplish as much as possible using high-quality processes – with no accidents. How do you do that? You follow the standards and practices of operating excellence. What are the standards? They are the entire collection of written policies, rules, and procedures for operating. What are the practices? They are the established processes, techniques, methods, decisions you make, and actions you take to operate well. Why does this work? Here's the beauty and elegance of this concept. People with experience in operations developed the standards and practices using knowledge of previous accidents and financial problems in your industry. So the standards and practices inherently describe how to operate within the boundaries of catastrophe and bankruptcy. They also include the current constraints of operations, maintenance, engineering, regulations, the condition of the equipment, and readiness of the people. The standards and practices represent the collective wisdom of your organization on how best to accomplish operating tasks, activities, jobs, and roles, in service of the mission."[100]

Realizing a company needs to maintain profitability to remain competitive and "enhance their ability to contribute to society into the future," Wetherbee also states the company must "prevent accidents to survive." But "[m]any managers seem to believe" safety and profitability compete – "Safety requires investments in time and money, which decrease the bottom line of profits in the short term."[101] If a company disregards safety measures in the interest of short-term profit and results, "accidents will follow, which will destroy any short-term improvement" and could lead to serious harm or damage to property, a mission, or even "kill[ing] people [(if humans are involved in the situation)], if not the whole organization."[102] Thus, "systematic directives developed and implemented by the leaders in the organization to help the workforce conduce their jobs effectively in a safe and productive manner," is required. Wetherbee explains

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[100] Wetherbee, 19.
[101] Wetherbee, 23.
[102] Wetherbee, 23.

these methods may be contained in a "*Safety Management System* in the organization," but this author posits extending the scope of these methods and whether they can also be considered part of policy, even out to a global level.[103]

One example of a safety measure a company in the space industry could put in place is a technology readiness level (TRL). For example, NASA's TRL has nine levels – 1 is the lowest, and 9 is the highest.[104] To be considered "flight qualified," a spacecraft requires a TRL 8, which means it is "in its final configuration," has been "successfully demonstrated through test and analysis," its software has been thoroughly debugged, and user/training documentation is complete.[105] to insure 'flight qualified' hardware."[106] It has been previously stated that the satellite industry is risk-averse by nature, therefore "designers are pressured to incorporate proven (i.e., legacy) hardware on space systems" because risks associated with this legacy hardware are relatively known factors.[107] However, "[a]lthough the use of proven technology helps to mitigate mission risk, it also has the negative effect of limiting satellite performance and stalling industry innovation."[108] Some relatively recent technological innovation and development in the satellite industry and risks pertaining thereto will be examined later in this paper.

In a commercial sense, if a spacecraft does fail, operators' responses can be varied. A "larger [operator] can rely on existing free capacity to cover any potential service shortfall and

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[103] Wetherbee, 25-26.

[104] Irene Tzinis, ed., "Technology Readiness Level," *NASA*, October 28, 2012, https://www.nasa.gov/directorates/heo/scan/engineering/technology/technology_readiness_level.

[105] "Technology Readiness Levels (TRLs)," *NASA*, accessed March 20, 2022, https://esto.nasa.gov/trl/.

[106] Andrew M. Long, Matthew G. Richards, and Daniel E. Hastings, "On-Orbit Servicing: A New Value Proposition for Satellite Design and Operation," *Journal of Spacecraft and Rockets* 44, no. 4 (2007): 964.

[107] Long, Richards, and Hastings, 964.

[108] Long, Richards, and Hastings, 964.

may in extremis relocate satellites" to cover any gaps in its service areas.[109] This author will interpret "larger operator" to include constellations of SmallSats as well as large conventional satellites operated by large companies. However, a smaller operator, such as a small business or educational organization, likely would not have the assets nor means to relocate a large conventional satellite or several smaller satellites, or otherwise "free up capacity" to provide service.[110]

In the case of a commercial endeavor, perhaps through the use of innovative technology, a business may desire to extend a satellite's life or may accept a loss of the satellite (and therefore any potential future revenue generated by it). As an example, several years ago, Intelsat "stated that they would use an insurance payout to reduce debt levels following the loss of [one of its satellites] through launcher failure, as the satellite had… expensive… capability which had not found a customer and so a cheaper replacement would be ordered."[111] Again, a small business might not be able to "order a cheaper replacement," but if its spacecraft was lost during launch, it would be covered by some sort of launch insurance, thus the business would be able to "use an insurance payout." However, if the loss of a satellite occurred on orbit and remained there as a defunct craft, and especially if it were to cause issues like conjunction risks, what actions would a small operator have and how might it protect itself with regard to potential third-party liability? How are operators, especially smaller operators, assessing and planning to manage risks such as these? These questions are explored in greater detail below.

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[109] Andrew Robert Graham and Jennifer Kingston, "Assessment of the commercial viability of selected options for on-orbit servicing (OOS)," *Acta Astronautica* 117 (2015): 39.

[110] Graham and Kingston, 39.

[111] Graham and Kingston, 39.

Turning back to the concept of operating risk in the space environment, Dr. Jah states "You're basically trying to mitigate Murphy's law."[112] He further explains there are always risks and "there's always something that comes up that's not necessarily nominal," but if an entity "do[es] a good job with [its] dress rehearsals, then [it] can identify where problems could arise and plans for how to take care of them in short order."[113] Jah States "[o]ne of the things I learned at JPL is: Excellence is not something that happens when you walk out the door for the first time. It happens because you do things over and over and over again," which echoes Wetherbee's emphasis on the importance of implementation of safety measures and control.[114]

If an accident were to occur, an entity may develop and implement "corrective actions… to help the organization prevent future accidents."[115] These "corrective actions" could "include constraints in the form of new rules and procedures for operators to follow," and they "may be successful, for a while, in preventing similar potential accidents from occurring under similar conditions from known causes."[116]

However, risks and "operational situations" change constantly; "new rules become out-of-date, confusing, ineffective, erroneous, and ignored."[117] Wetherbee states "[i]nvestigators can determine why the decisions made and actions taken seemed appropriate to the managers and operators who were under the influence of the sociotechnical system [of the organization]," thus corrective actions that "have a greater chance of helping the organization prevent future accidents" can be developed [and implemented] to improve the sociotechnical system so managers and operators in the future will not be influenced in the same way they were in the past

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[112] Ramin Skibba, "NASA Finally Rolls Out Its Massive SLS Rocket, With Much at Stake," *Wired*, March 19, 2022, https://www.wired.com/story/nasa-finally-rolls-out-its-massive-sls-rocket-with-much-at-stake/.
[113] Skibba, "NASA Finally Rolls Out Its Massive SLS Rocket, With Much at Stake," March 19, 2022.
[114] Skibba, "NASA Finally Rolls Out Its Massive SLS Rocket, With Much at Stake," March 19, 2022.
[115] Wetherbee, 4.
[116] Wetherbee, 4.
[117] Wetherbee, 5.

before the previous accidents."[118] In other words, these corrective actions could be implemented at the overall organizational level in the form of policies that guide the *management* of the entity, not only the operational work instructions in specific areas (for example, proper procedures for soldering).

A danger to organizational policies is "Allowed Violation of Rules, Policies, and Procedures," as we will see with the example of Swarm Technologies later in this study. At times, after an accident occurs, "investigators… [determine] that some organizational rules, policies, and procedures were violated before the accident." [119] Sometimes workers "reported unofficially that some managers were cognizant of these violations in operations before the accident." [120] And "[i]n some cases… managers [even] condoned violations in an effort to entice greater production or faster results." [121] Often, workers are "willing to take excessive risks to satisfy their managers," and sometimes this willingness to take excessive risks is out of concern for one's job or retaliation, thus reinforcing the idea of "going along with" management's decisions, even when they are dangerous or even in violation of regulations.[122]

Not ignoring the concern surrounding best STM practices, overall, when it comes to on-orbit activity, some industry experts remind us that space is vast and odds of a collision are actually low. A collision occasionally occurs, but in terms of individual entities, the chances of one's particular single spacecraft hitting another spacecraft is, again, low. It can be described in degrees of separation: the distance of 250 miles, the distance between the Earth's surface and LEO, is approximately the distance between Washington, DC and New York City. If one degree

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[118] Wetherbee, 5.
[119] Wetherbee, 14.
[120] Wetherbee, 14.
[121] Wetherbee, 14.
[122] Wetherbee, 14.

of separation is 250 miles, it could be said that an example of a collision would be if a minivan hit another minivan on the road between Washington, DC and NYC. The question arises of what the chances are of that actually occurring.[123]

Companies like SpaceX and Amazon with their communications constellations are primarily seeking the lowest latency possible in delivering their signals, thus they desire to operate on as low an orbit as possible. Of note, this is the particular altitude where “things will get crowded.” However, if a spacecraft operates on an orbit that is “just a little higher,” there will only be a few more milliseconds of latency, and a higher orbit has less drag, so there is even a possibility of a longer lifetime. According to industry experts, a few milliseconds of latency will not be very noticeable, and the benefit of operating on a higher orbit may actually be appealing to an operator due to the possibility of less drag and longer life. Thus, operating on a slightly higher orbit could be viewed as a risk mitigation strategy and a good STM practice, not only for sustaining the space environment, but for business, as well.[124]

Space Traffic Management

The question may arise as to why space traffic management is such a concern, especially orbital debris. Why do we continue to discuss it, and why might we need so many laws, policies, guidelines, best practices, and regulations that pertain to it? Here, an overarching background and big picture background using current space traffic statistics is provided. From 1957 through December 31, 2021, there have been approximately 5,682 launches of objects into Earth’s orbit.[125,126] As our technology progresses, and access to space has become less expensive and

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[123] (Charles Thornton, pers. comm., March 18, 2022)
[124] (Charles Thornton, pers. comm., March 18, 2022)
[125] Jonathan McDowell, “Launch List,” accessed April 5, 2018 http://www.planet4589.org/space/lvdb/list2.html.
[126] Ed Kyle, “Space Launch Report: Orbital Launch Summary by Year,” accessed March 6, 2022 https://www.spacelaunchreport.com/logyear.html.

more readily available, the number of space actors is increasing. Thus, logically, the amount of space activity is increasing as well.[127] In 2014, the number of nations and government consortia conducting activity in space reached over 60.[128] As of March 2022, the total was 111.[129] It is said that space is becoming increasingly "congested, contested, and competitive,"[130] and a greater number of players leads to an increase of objects on orbit.

Closely monitoring LEO is crucial due to the amount of very small objects, namely one millimeter or even smaller.[131] As of 2020, there were 400 missions operating between 600 and 1000 km in altitude (approximately 373 and 621 miles), and one aspect of particular concern was, at the time, the "lack of data on millimeter-sized OD above 600 km" in altitude.[132] The concern is "[t]here is far more small debris than large debris," and "mission-ending risk for most operational spacecraft is driven by small, millimeter-sized OD."[133] An example of a collision leading to not only loss of an active commercial satellite and therefore loss of revenue, but the creation of a cloud of debris, occurred between the defunct Russian satellite Cosmos 2251 and Iridium 33 in 2009 (discussed later in this paper).

However, this should not detract from the possibility that incidents can or will not occur on other orbits, such as GEO. According to risk estimates concluded by a collaboration of teams at Analytical Graphics Inc (AGI), SES S.A., and Inmarsat, "the chances of collision in GEO are up to four orders of magnitude higher than some estimates have suggested, and those collisions

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[127] *Statement*, 9.
[128] Hunter, 7.
[129] "Country Totals," *18th Space Control Squadron*, accessed April 25, 2021. https://www.space-track.org/#/boxscore.
[130] Hunter, 6.
[131] J.-C. Liou, "Risk from Orbital Debris," May 13, 2020, 8, https://www.brookings.edu/wp-content/uploads/2020/05/Space-Junk-PPT_J.C.-Liou_5.13.20.pdf.
[132] Liou, 8.
[133] Liou, 8.

can occur at much higher relative velocities than previously thought."[134] Alarmingly, "[t]he researchers predict that the population of active GEO satellites can be expected to suffer one potentially mission-terminating impact every four years on average."[135] It is important to note that "the majority of space commerce is currently conducted" on GEO.[136] Further, it was found that "due to the existence of GEO-crossing debris in eccentric orbits… impacts are energetic enough to cause catastrophic damage to satellites, which are not designed with mechanical robustness in mind."[137] Thus, "'In contrast to low Earth orbits, the GEO satellites are essentially sitting ducks with limited ability to evade the space debris flow.'"[138] Though orbital debris does occur more frequently in GEO than originally thought, for the purposes of this research, the study will be limited to activity on LEO.

We have a lot of traffic in space; some functional, some defunct, and a seemingly incalculable number of "bits and pieces" that we are not able to track at this current time. This debris and especially these nontrackable "bits and pieces" are causing problems and are becoming alarming. The increasing number of objects on orbit concerns us because the more crowded orbit gets, the greater the potential is for spacecraft "fender benders" or worse. As of March 2022, U.S. Space Force's Space Domain Awareness squadron, the 18 SPCS' Space-Track.org website listed 25,666 objects in its public satellite catalog (SATCAT) that were on-orbit at the time of writing.[139] 18 SCPS adds that there is one particular group of satellites considered unfit for public disclosure ("analyst objects"), further explained as objects "about

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[134] Marric Stephens, "Space Debris Threat to Geosynchronous Satellites Has Been Drastically Underestimated," *PhysicsWorld,* December 12, 2017, https://physicsworld.com/a/space-debris-threat-to-geosynchronous-satellites-has-been-drastically-underestimated/.
[135] Stephens, "Space Debris Threat," December 12, 2017.
[136] Stephens, "Space Debris Threat," December 12, 2017.
[137] Stephens, "Space Debris Threat," December 12, 2017.
[138] Stephens, "Space Debris Threat," December 12, 2017.
[139] *18th Space Control Squadron*, accessed March 6, 2022.

which the origin is unknown or the data remains [sic] confidential."[140] These tracked objects are human-made objects 10cm in diameter (about the size of a softball) or larger currently orbiting the Earth.[141,142] Roughly 4,852 of the 25,402 known objects (about 19%) are operational satellites, which means the vast majority (approximately 81%) of the known, tracked objects are non-functional, or debris.[143] Further, it is estimated that between 500,000 and 800,000 objects between 1cm and 10cm in diameter[144], and hundreds of millions of objects smaller than 1cm in diameter[145] reside in orbit. Orbital debris is typically categorized as very small (less than 1 millimeter wide), small (less than 1 centimeter wide), medium (1 to 10 centimeters wide), or large (greater than 10 centimeters wide).[146] Typically, very small debris can be shielded against, but an object that size still "has the potential to damage satellite sub-systems or pierce an astronaut's protective suit."[147] The greatest concern lies with medium-sized debris as it too small to be catalogued and tracked,[148] but "poses a lethal threat to operational satellites."[149]

If orbital debris is left unchecked, our ability to conduct space activity is severely put at risk. Jakhu, et al. explain, "[s]pace debris seriously threatens the sustainability of space utilization since it is considered to be an emerging navigation hazard to functional or operating satellites."[150] Some studies have shown LEO is rapidly approaching the "tipping point" at which our space-based capabilities may begin to decrease.

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[140] Phillip A. Slann, "Space debris and the need for space traffic control," *Space Policy* 30 (2014): 40.
[141] Pease and Jah, 27:00.
[142] *Statement*, 5.
[143] Union of Concerned Scientists, "UCS Satellite Database," updated Jan 1, 2022, accessed March 6, 2022. https://www.ucsusa.org/resources/satellite-database.
[144] Percy and Landrum, 24.
[145] Jakhu, Nyampong, and Sgobba,: 129.
[146] Percy and Landrum, 24.
[147] Slann, 40.
[148] Slann, 40.
[149] Percy and Landrum, 24.
[150] Jakhu, Nyampong, and Sgobba, 130.

The event known as the Kessler syndrome, named for Donald J. Kessler, former NASA scientist who along with Burt Cour-Palais "laid the scientific groundwork" for the study of effects of satellite collisions, spacecraft would collide with one another, creating debris in the process, which would, in turn, strike other craft, to the point where debris "would hit a critical point where it grew at a rate faster than the rate at which debris is removed from orbit through natural decay into the Earth's atmosphere," leading to "collisional cascading" where smaller pieces of debris would collide with larger pieces of debris, "creating... new pieces of small debris which could then collide with other large pieces."[151] A Kessler event would significantly hinder if not prevent access to space, and severely impair capability.

Space/Maritime Analogue

As Goessler states, maritime law and space law can be seen as analogous because of their overlapping or ambiguous jurisdictions, especially the high seas' similarity to LEO.[152] A waterway or canal could be viewed as similar to "orbital highways" on different orbits in outer space, and if a situation were to happen where spacecraft began to become "backed up in traffic," such as the Ever Given ship that became lodged in the Suez Canal in 2021, we could experience a serious disruption of space-based capability, if not the dreaded Kessler Event.[153] Thus, it is crucial that we implement practices that consider the "ecological conditions" of different orbits as the crews working to dislodge the Ever Given worked with their environment – not against it.[154] To do so, "it is important to measure and quantify the space environment," and, in turn we can develop appropriate STM mechanisms that we could not only maintain, but continue to

151 Brian Weeden, "Overview of the legal and policy challenges of orbital debris removal," *Space Policy* 27 (2011): 38.
152 Goessler, "#SpaceWatchGL Opinion, August, 2021.
153 Goessler, "#SpaceWatchGL Opinion.
154 Goessler, "#SpaceWatchGL Opinion.

develop.[155] We could not only use comprehensive gathering and tracking of good space environment data to "aid in orbital salvage practices," but farther into the realm of STM and all space activity, in general, to help reach space environment sustainability goals set forth in laws, policies, and regulations.[156]

The space environment/maritime environment analogue does not perfectly align, but as Goessler and the NSS state, we can still identify and use similar concepts to help us develop solutions for managing space activity and, ideally, preventing collisions or other accidents on orbit.[157] A governing body could step in and implement methods to prevent bad behavior on orbit, perhaps in the form of regulations, and lay a framework to help facilitate space sustainability by creating a marketplace for entities to grow within the field of technological STM solutions. In other words, a government could help set up a structure in which space entities could develop.[158]

But to do so, we as a society must consider the fact that the space environment is, as Jah states, like an ecosystem similar to the ocean, and will need to be protected from suffering the tragedy of the commons any further.[159] This author would like to highlight the fact that Dr. Jah is also involved in the WEF's Space Sustainability Rating initiative, discussed further below in this paper. Jah advocates "space sustainability metrics … a [quantifiable] 'space traffic' footprint,'" similar to a carbon footprint.[160] Indeed, setting quantifiable metrics could help actors develop a system in which entities (perhaps, most likely, in the form of a governing body) issue a penalty for leaving a defunct spacecraft on orbit that might endanger other craft or crews. Such a

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155 Goessler, "#SpaceWatchGL Opinion.
156 Goessler, "#SpaceWatchGL Opinion. .
157 Goessler, "#SpaceWatchGL Opinion.
158 David, "Space Junk Removal Is Not Going Smoothly," April 14, 2021.
159 David, "Space Junk Removal Is Not Going Smoothly," April 14, 2021.
160 David, "Space Junk Removal Is Not Going Smoothly," April 14, 2021.

system might also spark actors to further develop innovative technology in a nascent ADR industry, similar to commercial salvage activity in the maritime environment.[161]

A salvage entity might also theoretically relieve some concerns regarding liability because it would help "clear some of the path" on orbit.[162] It is true, however, that the current legal regime presents challenges to ADR as it actually *disincentivizes* it, particularly the OST and Liability Convention. [163] Ownership of a spacecraft is extremely difficult to determine even if that craft was registered with the UN pursuant to the Registration Convention and other domestic policy and/or regulation, let alone if it were unregistered and/or unclaimed."[164] As discussed, the burden of proof for determination of a craft that inflicts damage on another craft would lie with the harmed party, thus compensation and/or restitution to the harmed party may be unresolved.[165] A key point this author would like to explore is the NSS' theory that

> When aircraft create debris consequent to catastrophic failure over land, it is usually confined to one identifiable terrestrial area. Conversely, ocean vessels sometimes suffer loss of control, are shipwrecked, or contaminate large swaths of the maritime environment with mobile debris: solid objects, such as abandoned vessels, flotsam and jetsam; or liquids, such as oil. Such consequences of catastrophic failure and normal operations also result in the outer space environment, where whole defunct spacecraft and other debris remain uncontrolled in orbit.[166]

This author does not completely agree that the space environment is necessarily overall *more* like the maritime environment than aviation environment, but the above point regarding the location of debris created by spacecraft analogous to debris created by ships or other ocean vessels will be a focus. Namely, as the NSS emphasizes, in stating the fact that "orbital debris *is* pollution."[167]

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[161] David, "Space Junk Removal Is Not Going Smoothly," April 14, 2021.
[162] NSS, 2.
[163] NSS, 2.
[164] NSS, 2.
[165] NSS, 2.
[166] NSS, 3.
[167] NSS, 7.

One downside to using the maritime environment as an analogue for the space environment is the fact that "because of unique liability provisions of the international space treaties… maritime strategies cannot be applied wholesale."[168] For example, the NSS states "the current international regime for compensation for damage caused by oil pollution is based on two conventions: International Convention on Civil Liability for Oil Pollution Damage, 1969 (CLC 69) and International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage, 1971 (Fund 1971), an intergovernmental entity that provides access to liability compensation funds only to CLC 69 State Parties."[169]

The CLC 69 ensures "adequate compensation is available to persons who suffer oil pollution damage resulting from maritime casualties involving oil-carrying ships."[170] It covers "pollution damage resulting from spills of persistent oils suffered in the territory (including the territorial sea) of a State Party to the Convention."[171] Further, CLC 69 "requires ships covered by it to maintain insurance or other financial security in sums equivalent to the owner's total liability for one incident."[172] However, the insurance requirement only applies to ships carrying more than 2,000 tons of oil, but they are required to maintain insurance specifically "in respect of oil pollution damage."[173] Specific financial details of the cost of oil pollution coverage in a conventional insurance policy was not acquired for this study, but if space insurance is used as an analogue, it might be assumed that such an additional line could be as costly as tailored space insurance policies as described by Harrington.

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168 NSS, 3.
169 NSS, 3-4.
170 "International Convention on Civil Liability for Oil Pollution Damage (CLC)," *International Maritime Organization*, accessed April 3, 2022, https://www.imo.org/en/About/Conventions/Pages/International-Convention-on-Civil-Liability-for-Oil-Pollution-Damage-(CLC).aspx.
171 "International Convention on Civil Liability for Oil Pollution Damage (CLC)".
172 "International Convention on Civil Liability for Oil Pollution Damage (CLC)".
173 "International Convention on Civil Liability for Oil Pollution Damage (CLC)".

Fund 1971, as the NSS position paper states, "provide[s] financial compensation for oil pollution damage that occurs in Member States, resulting from spills of persistent oil from tankers."[174] It is funded by "contributions paid by entities that receive certain types of oil by sea transport, and the "contributions are based on the amount of oil received in the relevant calendar year, and cover expected claims, together with the costs of administering the Funds."[175] Of note, and as of this writing, Fund 1971 has "been involved in 150 incidents of varying sizes all over the world. In the great majority of cases, all claims have been settled out of court."[176] Such an IGO could be another possible solution for a space liability pool of funds, but details of founding such an entity warrant further and deeper research.

However, the NSS states

> the main principles and provisions of CLC 69 cannot be used in the space context for two main reasons: First, the general principle provided in CLC 69 is that those causing the pollution should pay the compensation. However, as noted above, often the party causing the orbital debris cannot be determined. And second, Article III of CLC 69 makes the owner of the ship strictly liable even in the absence of any fault.[177]

Here, the CLC 69 conflicts with Art. III of the Liability Convention which states the "launching State is absolutely liable only if damage is done on Earth or to aircraft in flight," but is "liable based on fault if damage occurs in outer space."[178] Further, as a reminder, multiple States can simultaneously bear joint and several liability."[179]

Of note, A.F. Bessemer Clark points out P&I clubs "are, and have always been, staunch supporters of C.L.C. and the Fund Convention," as it "has the inestimable advantage of

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[174] "Funds Overview," *International Oil Pollution Compensation Funds (IOPC Funds)*, accessed April 3, 2022, https://iopcfunds.org/about-us/.

[175] "Funds Overview".

[176] "Funds Overview".

[177] NSS, 4.

[178] NSS, 4.

[179] NSS, 4.

providing one system for the resolution of all disputes, government claims, third party claims and Owners' clean-up."[180] CLC 69 requires a shipowner to "maintain insurance or equivalent security to cover himself against liabilities arising under the respective legislation up to the limits therein set out," and such evidence of "'financial responsibility' must be carried on board each of the Owners vessels caught by the legislation."[181] Importantly, P&I clubs "have agreed to provide the necessary evidence of financial responsibility for each of their members affected by this legislation" by issuing certificates "which the Clubs issue to the appropriate authorities.'"[182] It is not insignificant that certain authorities have accepted certificates issued by P&I clubs as proof of "financial responsibility" because it could be interpreted that insurance is not, in and of itself, the only method to prove said financial responsibility, thus potentially relieving a shipowner of bearing the full burden of carrying a large and costly maritime insurance policy.

Despite the issue with regard to determination of who is at fault for any damages and who, according to some existing maritime convention, *shall* be held liable for damages, the NSS states there are still "other maritime traditions and legal regimes from which we can draw helpful lessons."[183] For example, MARPOL "deals with the prevention of pollution by oil or chemicals, or by harmful substances in packaged form, sewage, and garbage," and "provides various harmful discharge prohibitions," as well as lays down "a mechanism to check the seaworthiness of a ship by providing a framework for the certification of ships with respect to safety and pollution compliance."[184] Notably, there can be some similarities drawn from the provisions of

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[180] A.F. Bessemer Clark, "The Role of the Protection and Indemnity Club in Oil Pollution*," International Business Lawyer* 8, no. 7 and 8 (July/August 1980): 206-207.
[181] Clark, 207.
[182] Clark, 207.
[183] NSS, 4.
[184] NSS, 6.

MARPOL in the limits/prohibition of release of noxious liquids and garbage, which could be seen as an analogue for the release of debris from a spacecraft.

Looking specifically at potential space salvage activity, "the concept of special compensation beyond pure [marine] property salvage for preventing environmental damage is addressed in the "International Convention on Salvage, 1989 (Salvage Convention)," which "considers protection of the environment (even beyond oils spills, for debris) as part of salvage and therefore subject to reward if contamination is *prevented* by the salvor" [185] (emphasis added). This "'liability salvage" is officially termed 'special compensation' by the [Salvage] Convention… ." [186] But "acquiring 'special compensation'… proved to be time-consuming and somewhat limited, [thus] an alternative system for awarding special compensation, known as the Special Compensation Protection and Indemnity Clause (SCOPIC)," and of note, SCOPIC was developed jointly by P&I Clubs, salvors, underwriters, and ship owners.[187] SCOPIC's importance as a set of specific clauses that can be included in a salvage (or even an ADR) agreement is recognized, but these details will not be discussed within the scope of this paper.

Insurance

Insurance can be summed up as "a contract, represented by a policy, in which an individual or entity receives financial protection or reimbursement against losses from an insurance company." [188] Subsequently, the company "pools clients' risks to make payments more affordable for the insured."[189]

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[185] NSS, 5.
[186] NSS, 5.
[187] NSS, 5.
[188] Julia Kagan, "Insurance," *Investopedia*, October 21, 2021, https://www.investopedia.com/terms/i/insurance.asp.
[189] Kagan, "Insurance," October 21, 2021..

Harrington states "[o]ne of the primary concerns with regard to… innovative [space] activities [(such as CubeSats, constellations, and OOS)] is the unavailability of standardized insurance." Individualized tailored policies, or "manuscripted" policies, "tend to be expensive both due to the amount of work that goes into producing them and, more importantly, due to the uncertainty of the risks involved."[190] So, Harrington states, "[a]n understanding of the ways in which law and regulations impact these activities will help insurers produce more efficiently priced insurance, and thus may also help new entrants to the space insurance market take on some of these risks."[191] Thus, the importance of laws, regulations, policies, and guidelines is reiterated, especially Harrington's theory of using an insurance contract as governance, and how each instrument can work together in forming a system to guide the industry toward best STM practices.

For the purposes of this paper, the fact that there are typically three types of insurance is acknowledged: first party, second party, and third party, but third-party liability and damages to parties outside the insurance contract between insurer and insured will be the subject examined within the scope of this paper. Harrington states third-party insurance "is carried specifically to pay for damage and loss caused to others."[192] Further, "[n]o third party liability claims have been made in over two hundred commercial launches licensed in the US since 1989," and other than the Cosmos 954 incident, "the only third-party liability claim made worldwide was in the amount of US$1mil for ground contamination in Kazakhstan as a result of a failed Proton launch in 2007."[193] Thus, even taking Cosmos 954 into account, "this is a low probability area of

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[190] Harrington, 12.
[191] Harrington, 12.
[192] Harrington, 44.
[193] Harrington, 44.

accidents with high potential losses."[194] Of note, the Kazakhstan incident occurred due to a *launch* failure, not a deorbiting spacecraft, and its importance is recognized, it is beyond the scope of this research.

As background, according to Harrington, "in 2018, roughly two-thirds of launched satellites globally carried some form of insurance."[195] Further, "a single rocket crash in 2019 cost space insurers over $411 million dollars."[196] Additionally, "[t]he standard premium cost for launch insurance ranges from 5 to 20 percent of the satellite's value; with the market expected to settle in this phase at around 10 percent."[197] Note, however, this approximation is for *launch* insurance; third party liability insurance is likely to be much higher. Further, Harrington states "[t]his high cost of insurance and relatively low capacity of the market acts as a barrier to entry in the space industry for emerging companies," and especially "[i]n an era when… private companies are encouraged… to participate in space activities," such as in the development of innovative technology to address space sustainability, "it is critically important that the insurance industry be ready and able to provide the necessary coverage to support the space industry."[198]

Harrington states before the CSLA was enacted, the unavailability of space insurance "for the immense liability faced by launch providers," was causing the US commercial space industry to falter.[199] The CSLA "was able to reverse the degradation of the space industry in the United States" by enacting the cross-waiver requirement, but the cross-waivers did not "solve the problem of the limited availability and expense of insurance."[200] Further, though the cross-waivers "rendered the participation in space activities possible without [bearing the whole

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[194] Harrington, 44.
[195] Harrington, 4.
[196] Harrington, 4.
[197] Harrington, 4.
[198] Harrington, 4.
[199] Harrington, 5.
[200] Harrington, 5.

burden] of insurance, it is unquestionable that the availability of reasonably priced, comprehensive insurance would encourage further growth and development."[201] Especially when aligned with existing regulations, policies, and guidelines, as having an insurance policy in place would help companies manage risk and liability, which would seemingly encourage it to undertake innovative endeavors, but to do so in a safe and compliant manner.

Entities manage risk by transferring it away from themselves, and insurers take on that risk.[202] Insurance can be part of a larger picture of how a company handles risk along with risk avoidance and acceptance – in other words, a company can decide whether a risk is worth taking. However, if insurers take on a risk that could have a severe impact, even if the risk of such an impact is low, a high insurance claim payout could be catastrophic for the space insurance industry and the effects could ripple throughout all space activity.[203] In concert with what is arguably a restrictive legal regime with regard to liability, a space insurance industry in "limp-mode" could put a halt to developing space industry.[204]

Especially since conventional insurance policies typically cover losses including collisions with debris and other space objects, other than specific exclusions such as war and cybersecurity incidents, some space insurers believe these risks are too great to accept and are exiting the market. This, too, could mean if too many insurers exit the space insurance market, there would be a negative impact to developing space industry.[205]

Tools exist to address space traffic risks, such as the capability to

> accurately track objects down to 2 centimeters and provide collision warnings in a timely manner is improving with new, globally dispersed radars, inexpensive tracking beacons for satellites, and

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[201] Harrington, 5.
[202] Space Insurers, 11.
[203] Space Insurers, 11.
[204] Space Insurers, 11.
[205] Space Insurers, 10.

> data sharing. Small, reliable propulsion systems allow satellite operators to perform collision-avoidance maneuvers and post-mission disposal. Active debris removal (ADR), life extension, and other forms of on-orbit servicing (OOS) are revolutionizing satellite end-of-life (EOL) activities."[206]

If we have these capabilities, we have the knowledge base from which to implement the rules and procedures proposed by Wetherbee on a larger scale and use such guidance in forming a framework in which to place laws, regulations, policies, best practices, and insurance (and other types of commercial contracts) together to help create a nascent standardized STM system.

However, some roadblocks would still exist. If we take ADR as an example, Kunstadter states "[t]here is currently no requirement to remove objects from orbit, and there is no legal foundation for an entity from a country that is not the State of registry to remove an object from orbit," or to be forced to do so.[207] Further, "[a] State could remove its own object (bearing responsibility and liability) or could allow another State's entity to do so, but if the "client object" colluded with the "servicing vehicle," then "under the Liability Convention, the launching States of both the original object and the retrieval object could bear joint and several liability."[208] Though some industry experts believe the risk of that happening may be low, the situation could still lead to a tangled web of complex legal and regulatory intricacy.

However, Kunstadter continues, "while there is little incentive for States to create additional hazard and take on additional liability by performing [ADR], governments have a responsibility to lead efforts" toward it.[209] He states "[a] recent study demonstrated that while the greatest debris-generating potential is from spent Russian rocket bodies in LEO, the most

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[206] Space Insurers, 10.
[207] Space Insurers, 10-11.
[208] Space Insurers, 10-11.
[209] Space Insurers, 11.

likely collisions among these objects are with U.S. and Chinese debris objects."[210] Kunstadter recommends "[c]ollaboration on an ADR demonstration by the responsible space agencies—NASA, Roscosmos, and the [CNSA]" to "kick-start the ADR industry and build confidence that viable, affordable solutions exist."[211] While international collaboration is certainly welcome and even specifically advised in some of the policies and guidelines, in this current political climate, NASA's collaboration with the two other subject parties is virtually impossible.[212] However, also as previously discussed, we have now seen the successful demonstration of ADR performed by China, so we can hope commercially viable ADR solutions will come to fruition.

Historically, space insurance policies "have protected devices against loss, failure or damage from launch through their orbiting life…" and "[o]perators could add liability coverage in case one satellite damages another or re-enters the atmosphere in a way that causes damage or injury on the ground."[213] But the "surging collision risks have left the handful of insurers that offer satellite coverage pulling back or exiting the market, executives and analysts said," though certainly, according to Kunstadter, not all space insurers are pulling coverage. However, the number of space insurers who are leaving is not insignificant. According to Richard Parker, co-founder of Assure Space (a unit of AmTrust Financial), "'[t]his is a real issue for insurance,' as

[210] Space Insurers, 11.
[211] Space Insurers, 11.
[212] At the time of writing, the Russian Federation has invaded Ukraine and Russia has made threats against States that are currently aiding Ukraine with its defense effort. This includes the fact that some international space cooperation has been slowed due to sactions against Russia, even to the point where Dmitry Rogozin, Director General of Roscosmos, has threated to pull Russia from the International Space Station program if the sanctions are not lifted. For further information, see Space.com, "Russia threatens to leave International Space Station program (again)," https://www.space.com/russia-threatens-leave-international-space-station-program-rogozin.
[213] Carolyn Cohn, " Launching into space? Not so fast. Insurers balk at new coverage," *Reuters*, September 1, 2021, https://www.reuters.com/lifestyle/science/launching-into-space-not-so-fast-insurers-balk-new-coverage-2021-09-01/.

the company stopped providing spacecraft insurance in LEO in 2020, and "the few policies it has sold since then exclude collision damage."[214]

But "[s]pace coverage has been a lucrative niche for insurers, which took in $475 million in gross premiums to cover satellites, rockets and unmanned space flights" in 2020, and paid "$425 million in losses, according to Seradata."[215] Peter Elson, CEO of insurance broker Gallagher Aerospace, states "[s]pace premiums are 10-20 times aviation premiums."[216] Despite the fact that LEO is the focus of industry experts' concern for most risk, "LEO satellites are much smaller than GEO satellites," and need "$500,000 to $1 million worth of coverage, far below the $200 million to $300 million for those in the GEO, industry experts said."[217]

According to Denis Bousquet, in 2021, "'About half of new satellite launches [had] insurance,'" and "[i]ndustry sources expect more policies to exclude collision coverage and fewer satellites to have insurance at all."[218] But also as of 2021, "Only 11 spacecraft have suffered a partial or total failure due to suspected debris strikes over the past decade, according to Seradata, making insurer worries largely theoretical for now," but "Assure Space's Parker said he is confident a major collision will occur within the next three years, rendering insurance nearly impossible to obtain."[219] Still, at present, "'[t]here are no signs such a situation is imminent,'" but "'[such a situation] would render entire orbits uninsurable… .'"[220] For now, "[n]ew insurers may enter the market to alleviate supply-demand strains," but "[u]ntil then,

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[214] Cohn, " Launching into space? Not so fast," September 1, 2021.
[215] Cohn, " Launching into space? Not so fast," September 1, 2021.
[216] Cohn, " Launching into space? Not so fast," September 1, 2021.
[217] Cohn, " Launching into space? Not so fast," September 1, 2021.
[218] Cohn, " Launching into space? Not so fast," September 1, 2021.
[219] Cohn, " Launching into space? Not so fast," September 1, 2021..
[220] Cohn, " Launching into space? Not so fast," September 1, 2021..

industry experts said companies, universities and government agencies will likely bear more financial responsibility."[221]

Regarding risk, echoing the theory of industry experts in the Overview of Risk section of this paper, the risk of damage to a *second* party on orbit is low. For example, if one spacecraft were conducting an OOS mission for a second spacecraft, and the OOS spacecraft bumped its client's spacecraft too hard and, subsequently, the client's spacecraft became defunct as a result of the impact, the client (second party) would address the claim through the contractual arrangement between the OOS provider and the client. Industry experts state they are unable to picture a scenario where that is a real risk about which entities should worry.[222] But the fact that there is some concern regarding the fact that some space insurers are leaving the market due to increasing risks of operation in LEO emphasizes the importance of the insurance industry's place in the space industry.

According to AXA XL's website, in addition to launch coverage, it offers coverage for:

- Post-separation coverage for spacecraft through initial operations, deployments, orbit raising and testing
- In-orbit coverage for ongoing operations of satellites through their life
- Coverage for transponder users, including loss of revenue and extra expenses
- Specialized coverage for small satellites and unique missions
- Launch and in-orbit liability coverage[223]

AXA XL also specifically calls out the fact that they "also support development of unique missions, payloads and capabilities from new, entrepreneurial space organizations." [224]

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[221] Cohn, " Launching into space? Not so fast," September 1, 2021..
[222] (Charles Thornton, pers. comm., 3/18/2022)
[223] "Space Insurance," *AXA XL*, accessed April 3, 2022, https://axaxl.com/insurance/products/space-insurance.
[224] "Space Insurance," *AXA XL*.

Thus, despite the fact that some insurers seem to be pulling their lines of coverage for space activities, especially in LEO, at least one of the major space insurers remains in the arena. Not only does this provide on-orbit coverage, but specifically states it carries specialized coverage for small satellites and "unique missions" (perhaps similar to those discussed in the ODMSP guidelines, such as ADR and OOS). Additionally, there are likely other types of specific types of space insurance in the works.[225] It is a step in the opposite direction from the exiting space insurers, so it can be interpreted that there is still a niche for space insurance and its continued role in space activity is actually growing, not shrinking.

Some of AXA XL's pertinent exclusions to its space policies are as follows:

- War, invasion, hostile or warlike action in time of peace or war, including action in hindering, combating, or defending against an actual, impending, or expected attack

- Any anti-satellite device, or device employing atomic or nuclear fission and/or fusion, or device employing laser or directed energy beams.

- Confiscation, nationalization, seizure, restraint, detention, appropriation, requisition for title or use by or under the order of any government or governmental authority or agent (whether secret or otherwise and/or whether civil, military, or de facto) or public or local authority or agency.

- Nuclear reaction, nuclear radiation, or radioactive contamination of any nature, whether such loss or damage be direct or indirect, except for radiation naturally occurring in the space environment.

It should also be noted that a typical general policy also excludes:

- Loss of revenue, incidental damages, consequential loss, or extra expenses, other than expressly covered under this insurance.

- Third party liability.[226]

[225] (Chris Kunstadter, pers. comm., 2/21/2022)
[226] "Space Insurance," *AXA XL*.

It is important to highlight the fact that a *typical* policy appears not to include coverage for launch and on-orbit liability coverage, consequential damages (such as loss of revenue), but such coverage *is* available. Additionally, revisiting Kunstadter's comment stating "collisions with debris and micrometeoroids are generally covered," it is also important to note this is for *first* party coverage, so it would cover that satellite owner/operator in the event its own satellite if it were to collide with another space object. [227,228]

P&I Clubs

To examine the sub-question of whether liability apportionment and risk-pooling are benefits to members of a P&I club, some background is examined herein. In the maritime industry, P&I "insurance" provides cover to shipowners and charterers against third-party liabilities encountered in their commercial operations. Responsibility for damage to cargo, for pollution, for the death, injury or illness of passengers or crew and for damage to docks and other installations are examples of typical exposures."[229] Essentially, hull and machinery insurance policies will cover damage to an owner/operator's own ship, but P&I coverage would provide supplemental coverage for third-party liability.[230]

Running in parallel with a ship's hull and machinery cover, traditional P&I such as that offered by the American Club distinguishes itself from ordinary forms of marine insurance by being based on the not-for-profit principle of mutuality where "Members of the Club are both the insurers and the assureds."[231] A P&I club could be seen as similar to a group captive or risk-sharing agreement.[232] These types of groups might be attractive to small operators as the clubs

[227] "Space Insurance," *AXA XL*.
[228] Space Insurers, 11.
[229] "About the Club" [hereinafter *About the Club*], *The American Club*, accessed March 13, 2022, https://www.american-club.com/page/about-the-club.
[230] Springall, 28.
[231] About the Club, 2022.
[232] (Charles Thornton, pers. comm., 3/18/2022)

or captives would allow small operators to buy into something larger – they could have an economy of scale. The group captive could have risks pooled at a lower cost to a small operator compared to if that small operator bought insurance itself. For example, rather than buying a $100 thousand policy, perhaps the small operator could purchase coverage from a group captive for $10 thousand.[233]

P&I clubs, group captives, and/or risk-sharing agreements could aid in payment of a claim after an occurrence, but could also facilitate tracking and monitoring of shipping traffic because it would be in all members' interests to keep premiums, calls, and/or risks low within these types of groups or agreements.[234] As Liu and Faure posit, risk-sharing could be appealing to actors who are developing innovative technology where risks may be best identified and assessed by the actors themselves.[235] This "mutual monitoring" might also be seen in space traffic tracking and monitoring between different entities, such as Privateer and Leo Labs, and information could be shared among all these actors. Mutual tracking and monitoring have the potential to prevent malfeasance, as well, because members would theoretically always be watching for occurrences, thus could deter negative intentional acts, such as deliberately dumping garbage or oil into the sea. [236] Thus, based on the above, yes, it can be concluded that liability apportionment and risk-pooling are assets of a P&I club from which members can benefit.

However, a potential downside to P&I clubs, group captives, and/or risk-sharing agreements might be the fact that they may require some type of standard or homogeneity of

[233] (Charles Thornton, pers. comm., 3/18/2022)
[234] Liu and Faure, 257.
[235] Liu and Faure, 257.
[236] Clark, 209.

members to be successful.[237] Otherwise, allocation of risk may be too varied which could actually create disincentives for membership or parties to an agreement.[238] However, of note, some P&I clubs cover a wide spectrum of marine craft from a yacht to an extremely large cargo carrier, so it could be argued a space P&I club could offer a similar broad spectrum of membership. It is also important to note that risks and calls or premiums should somehow scale to meet the needs of each type of craft without disincentivizing other members to participate in a club.[239] Details of maritime P&I club calls with respect to various types of craft are not available due to their proprietary nature, but further study is recommended, if data are made available.

It could also be stated that when a shipowner/operator applies for membership, a P&I club is more concerned with the potential for the craft to suffer an occurrence (or inflict one upon another craft).[240] If this is the case, if a P&I club deems it necessary, it could accept that particular member with a "defects warranty;" in other words, an incident that occurs due to a defect under this warranty would not be covered by the club and would be considered an exclusion."[241] In essence, the P&I club could be seen as "tailoring" a membership to a member's specific needs and situation, which could fill in a gap in which tailored conventional space insurance policies could be too costly to a small or nascent spacecraft owner/operator, as Harrington states.[242,243] A P&I club also makes some legal services available to members as well

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[237] Liu and Faure, 257.
[238] Liu and Faure, 257.
[239] Liu and Faure, 260.
[240] Liu and Faure, 260.
[241] Liu and Faure, 260.
[242] Liu and Faure, 260.
[243] Harrington, 12.

as adjusters to examine damage after an incident, and could provide immediate assistance in handling a claim regarding a vessel, which is an added benefit of P&I club membership.[244]

But though a P&I club states coverage for many incidents is unlimited, it is important to note this does not mean all risks are always covered all the time. As Liu and Faure explain, some risks, especially those arising out of the above-referenced "defects warranty" are excluded, and some other details of a club's membership may set forth bylaws that give the club discretion as to what it covers"[245] These "defects warranties" have the potential to increase the cost of membership calls and could restrict coverage a member would be looking to procure, such as pollution. However, the case remains that P&I clubs can still "provide an alternative when commercial insurance fails to emerge due to the lack of information or associated high costs," as discussed above, and could still have a positive impact on the number of accidents, amount of pollution, and malfeasance (due to self-monitoring and risk-pooling) in the maritime environment, which could work as a parallel in the space environment.[246,247]

In a brief look at the realm of space activity, some space insurance companies provide third-party coverage, but as discussed above, it could be expensive and difficult to procure, thus prohibiting further development of the space industry, and perhaps even hindering what could be innovative technology to help manage space traffic.[248] It is the developing area of third-party liability insurance and issues such as those discussed above with regard to certain space insurance policy exclusions; potential barriers to expensive "manuscripted" policies that *do* carry third-party coverage; developing countries or newspace startups that may desire (if not need)

[244] Liu and Faure, 266.
[245] Tilley, 443.
[246] Springall, 40.
[247] Liu and Faure, 269.
[248] Harrington, 6.

access to the space infrastructure, namely those working with SmallSats or limited STM-related technological capability and/or resources that serve as the reasons to explore other methods of allocating risk and/or liability between space actors. In other words, the NSS argues "P&I space clubs could likewise provide indemnification for risks, which traditional space insurers will not handle."[249] Thus, it can be argued that pooled risks for which a P&I-club could provide indemnification and/or coverage would benefit spacecraft owner/operators similarly to a maritime actor. A potential space P&I club is discussed in further detail below.

In examining maritime P&I clubs from a financial perspective, the question of whether the benefits of being a P&I club member outweigh the cost can be examined. According to The American Club's 2020 annual statement, the "[g]ross Members' claims paid in FY2020 amounted to $73,649,000, with $59,000 in recoveries from the international P&I group reinsurance, $12,586,000 in recoveries from the international P&I club pool, and $18,559,000 in recoveries from other reinsurers, for a total of $59,051,000 for net claims paid."[250] For the Club's FY2020 renewal, there were "no standardized, or general, increase applied to expiring entries;" instead, The American Club implemented "more Member-specific approach… given the varying risk profiles of different cohorts of The American Club's membership, the majority of which enjoyed sustainable levels of rating and conditions of insurance."[251] If we continue to use the 244-gt tug boat example and $5.33/gt average annual call value, an approximate cost of an annual P&I call would be $1,300.52 for the subject 95-foot tug. Thus, despite actual financial details not being readily available, it can be argued that in the maritime industry, the benefits of

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[249] NSS, 5.

[250] "2020 Annual Report" [hereinafter *American Club Financial Statement*], *The American Club*, accessed April 3, 2022, https://www.american-club.com/files/files/2020_Annual_Report.pdf.

[251] American Club Financial Statement

P&I club membership are likely worth the cost if the cost is such a significant fraction of a maritime insurance policy.

The American Club breaks down further details of tonnage by vessel type. Its FY2020 member tonnage is as follows: "8% tonnage general cargo/container/passenger/RoRo [("roll-on/roll-off," or ships that carry wheeled cargo)], 22% tankers, 25% tugs/barges/small craft, and 45% bulk carriers."[252] We can see The American Club provides coverage to a very broad spectrum of marine craft, both in size and what they carry.

The Shipowners' Club based in London states it "offers a special welcome to shipowners and charterers of all kinds from every part of the world… from the broadest spectrum of the shipping industry," and "[i]t is not dominated by, or restricted to, any particular industry sector or interests [253] Further, the Shipowners' Club insures "over 34,000 small and specialist vessels across the globe," including craft similar for which The American Club provides cover, but additionally specifically calls out "dive, fishing, harbour, offshore, passenger/tour boat… and yacht" as types of vessels, thus highlighting the details of the broad range of craft that can acquire P&I cover.[254] The Shipowners' Club has "over 6,500 Members operating over 32,000 vessels at a total of 23,579,295 GT, delivered through a network of nearly 700 brokers.[255]

Though potential lack of homogeneity has been discussed as a potential downside to P&I club membership, it could also be argued that the coverage available for a broad spectrum of vessel types is actually a *benefit* of P&I club membership in that the more members covered, the more self-monitoring and risk-pooling occurs, which could, in turn, lead to better behavior on the

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[252] American Club Financial Statement

[253] "A Profile," *The American Club*, accessed April 3, 2022, https://www.american-club.com/files/files/The_American_Club_a_Profile.pdf.

[254] "About Us," *The Shipowners' Club*, accessed April 3, 2022, https://www.shipownersclub.com/about-us/.

[255] "Celebrating 160 Years," *The Shipowners' Club*, accessed April 3, 2022, https://www.shipownersclub.com/160-years/#2015.

seas. Additionally, if a P&I club call is, in fact, significantly less expensive than a traditional insurance policy, P&I club membership could be appealing to more shipowners, widening the view of self-monitoring. This combined with the additional benefits of legal assistance and emergency help if needed, the argument that P&I club membership benefits outweigh the cost is reinforced. With the above information, we can begin to form a simulation of what a potential space P&I club might look like.

Potential Space P&I Club

To examine the sub-question of whether liability apportionment and risk-pooling are benefits to members of a potential space P&I club, as in the case of the maritime industry, some background regarding potential incident coverage is examined herein.

Coverage

According to The American Club's website, outside traditional hull and machinery coverage provided under a conventional maritime insurance policy, some of the main risks is covers are liabilities, expenses, and costs for the following:

- Collision
- Damage to docks, buoys and other fixed and floating objects
- Wreck removal
- Pollution
- Fines and penalties
- Vessel Diversion Expenses[256]

Some of the liabilities that may not be covered by a P&I club are as follows:

- Ad valorem bill of lading

[256] "Protection and Indemnity (P&I) Insurance," *The American Club*, accessed April 3, 2022, https://www.american-club.com/page/protection-indemnity-insurance.

- Deviation
- Delivery of cargo to a port other than the port specified in the bill of lading
- Failure to arrive or late arrival at a port of loading
- Delivery of cargo without production of bill of lading
- Ante-dated or post-dated bill of lading
- Clean bills of lading in case of damaged cargo
- Deck cargo carried on terms of an under-deck bill of lading
- Arrest or detention of an entered ship[257]

Though not all of the above coverages and exclusions do not perfectly parallel a space analogue, some similarities can be drawn such as collision, wreck removal, and pollution. Except for oil pollution, for which there are limitations of liability set, the above P&I exclusions may not relate directly to space activity, and further research is warranted regarding specific potential space liabilities for which a space P&I club may not provide cover. Specific examples of potential incidents pertaining to spacecraft are discussed below, and, subsequently, how a potential space P&I club membership could provide benefit to its members in response to those incidents.

For further background, as discussed above, Kunstadter believes for P&I clubs to function, there needs to be some sort of homogeneity. It could be very difficult for a P&I club to determine who might be "eligible" to be a member due to widely differing sizes, functions, and orbits of various spacecraft.[258] Thornton does not agree necessarily with the fact that homogeneity needs to be a requirement for a P&I club membership – the main concerns are at the poles where things get "backed up," and he believes there could be some apportionment

[257] "Protection & Indemnity Clubs," *Cult of Sea*, accessed March 21, 2022, https://cultofsea.com/maritime-law/piclubs/.

[258] (Chris Kunstadter, pers. comm., 2/21/2022)

between larger and smaller operators.[259] As exhibited in the list of types of vessels covered by The American Club and The Shipowners' Club, we can see if there is some sort of homogeneity, it is not made clear through publicly available information at this time. Thus, a parallel is drawn and a space P&I club will be assumed to cover a similar broad spectrum of craft.

Space Traffic and Potential Problems and Threats

Incidents on the Earth's Surface

In January 1978, a Russian satellite, Cosmos 954, crashed in Canada leaving a wide swath of radioactive waste in its wake. In 1978, Soviet satellite Cosmos 954 crashed in Canadian territory, and spread radioactive debris over a large area.[260] The incident was the "first instance in the history of space exploration where a claim was made by one sovereign state against another on account of damage caused by a falling space object," and to date, has been the only incident of this nature.[261]

The cleanup effort cost Canada "nearly fourteen million dollars, of which only $6,041,174.70 was claimed," that being costs "over and above what it would have had to pay for personnel and equipment used in the operation in any event."[262] In 1979, Canada made its formal legal claim against the Soviet Union, and subsequently, "a three million dollar settlement which did not expressly acknowledge [the USSR's] legal liability was concluded in Moscow in 1981. An examination of potential third party liability coverage under a space P&I club is examined in the space pollution section of this paper.

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[259] (Charles Thornton, pers. comm., 3/18/2022)

[260] Jakhu, Nyampong, and Sgobba, 130.

[261] Bryan Schwartz and Mark L. Berlin, "After the Fall: An Analysis of Canadian Legal Claims for Damage Caused by Cosmos 954," *McGill Law Journal* 27, no. 4 (1982), 677.

[262] Schwartz and Berlin, 678.

Using Cosmos 954 as a very rough analogue, the effect of P&I's coverage is examined pertaining to liability, cost, and insurance coverage (if any is available) of an incident in which a deorbiting spacecraft, similar to the derelict Chinese rocket body that landed in the Indian Ocean last year, spread pollution over a swath of land, if such an incident were to happen today. For the purposes of this study, it will be assumed that the pollution spread will *not* be radioactive in nature, as further details regarding how a P&I club would handle radioactive waste warrant further research. Instead, this study uses MARPOL's Annex II pertaining to noxious liquids as an analogue for the nature of the pollution spread, and assumes there is a potential for release of noxious liquid, even if a small amount, in residual fuel within a rocket body. It will also be assumed that a commercial spacecraft registered to the US would land somewhere in the US so as not to trigger the insurance provisions in the CSLA.

Thornton states if a company owns a spacecraft and lets it fall into reentry, that company would be subject to third party liability.[263] Thornton believes an aviation liability policy would cover damage caused on land in the US by a US spacecraft, but, of course, it would be subject to the limitations of that particular policy.[264] As Harrington states, third party coverage can be costly and complicated, and as stated above, a typical conventional space insurance policy does not cover third-party liability. In this instance, the US spacecraft owner/operator and the harmed party or parties would work to settle or go to court.

In terms of how a space P&I club would handle the situation, Thornton believes this would be tough – if the incident is truly an accident, if a spacecraft malfunctions and lands randomly, that could be covered with liability insurance. If an owner/operator had the ability to control reentry but did not, that is intentional malfeasance, and it would fall under a

[263] (Charles Thornton, pers. comm., 3/18/2022)
[264] (Charles Thornton, pers. comm., 3/18/2022)

willful/intentional acts exclusion of a policy, and may lead to potential criminal charges. But if it was truly an accident, Thornton believes a third-party policy could cover it, but the question arises of how the accident happened. Similarly, if one were to get into a car accident, and the accident could have been avoided, the auto insurance policy would cover that, so how these mechanisms could work similarly is a question for further study."[265]

A question also arises of the extent of damage that could be caused to the Earth's surface and how that damage be assessed. Thornton believes damage would be assessed in the same way the EPA measures risk and assesses damage by looking for pollutants and contaminants but would otherwise be a relatively simple debris cleanup.[266] For example, if the deorbiting craft were to hit a building, the building would need to be rebuilt, and third-party liability insurance would cover that. If the craft caused damage to a farm, the farmer would need to be paid for those crops, and third-party liability insurance would cover that.

According to Ray Williamson, the then-executive director of the Secure World Foundation, in a 2011 interview, "the stated… reason for destroying [the USA-193 satellite] with a missile was that the satellite had large amounts of what was, by that time, solid hydrazine, and "[i]f that fell in a populated area, or even in an unpopulated area, it would be dangerous to people because it's highly toxic."[267] Thus, it could be argued that MARPOL Annex II is a good analogue for potential noxious pollution. MARPOL is discussed in further detail below.

Thornton is not exactly sure of the mechanism of how third-party insurance would cover this "contamination," but as Harrington states, this third-party insurance could be costly and

[265] (Charles Thornton, pers. comm., 3/18/2022)
[266] (Charles Thornton, pers. comm., 3/18/2022)
[267] Denise Chow,"Q&A: Falling satellites and space junk," *NBC News*, September 22, 2011, https://www.nbcnews.com/id/wbna44634212.

complicated, thus not accessible to many space actors.[268] Even then, would the insurance actually cover the accident, or would there be an exclusion embedded into the policy?

Space P&I club cover could be invoked here, as according to The American Club, pollution is one of the liabilities that would be covered as part of membership. If the spacecraft that causes damage is a large conventional satellite belonging to a large and established company, that company might have a third-party liability policy in place which would cover liability from pollution and/or contamination. However, if the spacecraft that causes damage is a small satellite belonging to a small business or startup, and that small business was cognizant of the fact that it should incorporate technology to adhere to STM policies and guidelines and incorporated a propulsion system on-board to deorbit it accordingly, and that propulsion system carried some type of noxious substance, and that spacecraft were to tumble out of orbit and leave a toxic substance on land, what is the likelihood that small business could carry a traditional third-party space insurance policy that could cover this type of pollution?

In another incident, on April 1, 2018, China's Tiangong-1 space station deorbited and disintegrated over the South Pacific,[269] approximately 860km northeast of Samoa.[270] There were no reports of impact, but other instances of deorbiting space objects crash landing, striking property and even people on Earth have occurred. In May 2021, a tumbling Chinese rocket body reentered Earth's atmosphere and landed in the Indian Ocean near Maldives, but drew "U.S. criticism over lack of transparency."[271] Most of the Earth's surface is covered by water, so the

[268] (Charles Thornton, pers. comm., 3/18/2022)

[269] Mike Wall, "Farewell, Tiangong-1: Chinese Space Station Meets Fiery Doom Over South Pacific," *Space.com*, April 1, 2018, https://www.space.com/40101-china-space-station-tiangong-1-crashes.html.

[270] Jonathan McDowell (@planet4589), "Better map of the Tiangong-1 impact location," Twitter, April 2, 2018, 1:05 p.m., https://twitter.com/planet4589/status/980868849343107072.

[271] Ryan Woo, "Chinese rocket debris lands in Indian Ocean, draws criticism from NASA," May 8, 2021, https://www.reuters.com/lifestyle/science/china-says-remnants-long-march-rocket-landed-indian-ocean-2021-05-09/.

likelihood that the rocket body would land in a populated area was low, with the "likelihood of injuries even lower, according to experts."[272]

However, "uncertainty over the rocket's orbital decay and China's failure to issue stronger reassurances in the run-up to the re-entry fuelled [sic] anxiety."[273] According to Harvard-based astrophysicist Jonathan McDowell, "[s]ince large chunks of the NASA space station Skylab fell from orbit in July 1979 and landed in Australia, most countries have sought to avoid such uncontrolled re-entries through their spacecraft design," which is partly why the incident drew heavy criticism.[274] Again, no harm or damage resulting from this incident was reported, but the chance remains that such an event could cause harm in the future.

Though the risk of debris hitting an actual person is extremely low, in January 1997, Lottie Williams was walking in a park in Tulsa, Oklahoma with a friend when they "saw a huge fireball streaking from the skies;" less than thirty minutes later, Ms. Williams felt something touch her shoulder, and found something that hit the ground behind her. Analysis indicated it was part of a Delta II rocket that was launched in 1996.[275] Fortunately, Ms. Williams was not injured in the incident, but it serves as an example of what could happen as a result of falling debris that survives entering the Earth's atmosphere.

In the examples above, if such incidents were to happen in the future, a potential space P&I club could, indeed, provide a benefit to club members. Based on the fact that incidents involving pollution are covered according to The American Club, coverage could be provided to spacecraft owner/operators in the event of such an incident. It should be noted, however, that the

[272] Woo, "Chinese rocket debris," May 8, 2021.
[273] Woo, "Chinese rocket debris," May 8, 2021.
[274] Woo, "Chinese rocket debris," May 8, 2021.
[275] "Woman hit by space junk, lives to tell the tale," *Fox News*, October 21, 2011, http://www.foxnews.com/tech/2011/09/21/woman-gets-hit-by-space-junk-lives-to-tell-tale.html.

nature of each club member's specific agreement that some limitations or exclusions may apply, and certain types of pollution, such as radiation, should be researched further. But especially if previously referenced legal assistance and emergency help are part of P&I club membership, it could be argued that potential space P&I club membership would benefit members in the event of pollution.

Incidents On-orbit

Greater accessibility to outer space is a double-edged sword. On one hand, it allows developing nations, small businesses, and educational entities to conduct research and technological demonstrations, and to potentially provide services such as navigation and communications capability at a much lower cost than current services. However, there has been a "sudden and rapid increase in the launch rate of small satellites," and according to Pardini and Anselmo, "[b]etween the beginning of 2014 and the beginning of 2020… the total mass of the artificial objects in orbit around the Earth has grown by approximately 22%, but the number of operational spacecraft has more than doubled."[276] Further, based on the number of applications filed by satellite operators, more than 100,000 new spacecraft are projected to be launched into orbit by 2030.[277]

As noted in the US ODMSP section of this paper, constellations are a concern because most of their activity occurs in LEO where there is growing presence and the potential for "crowding." Perhaps one of the most well-known satellite constellations in process of being launched is SpaceX's Starlink. As just one example highlighting the level of this concern, in February 2022, NASA and the NSF submitted letters to the FCC in its "proceedings on SpaceX's

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[276] Carmen Pardini and Luciano Anselmo, "Evaluating the impact of space activities in low earth orbit," *Acta Astronautica* 184 (2021): 11.

[277] Pardini and Anselmo, 11.

proposal for its Starlink "Gen 2" system with approximately 30,000 satellites in LEO."[278] Due to the magnitude of the proposed constellation, the number of tracked objects in LEO would increase by "more than a factor of five."[279] This is especially concerning to NASA because of its upcoming crewed missions (of note, debris was a concern of SpaceX's own Inspiration 4 crew as they launched to and reentered from orbit).[280] Specifically, NASA "'recommends SpaceX generate analysis demonstrating the auto-maneuver capability is sufficiently scalable to the entire proposed constellation size, including inter-constellation conjunctions," questioning whether SpaceX's automated collision avoidance system for its current constellation is capable of scaling to the larger constellation.[281]

In December 2021, China filed a "note" with the UN stating it had to move its Tianhe space station twice "to avoid SpaceX Starlink internet satellites," both incidents "occurring when astronauts were aboard the module."[282] The "note" was serious enough in tone to invoke Art. IX of the OST.[283] Of note, well-known astrophysicist, Jonathan McDowell, "confirmed that the close encounters… did indeed take place," and "posted a graph on Twitter showing that Tianhe and a Starlink satellite were separated by just 1.9 miles (3 km) or so on Oct. 21."[284] However, as noted previously, industry experts have stated that even spacecraft that pass each other at a distance of one mile can still be considered a far enough distance to not pose a high risk of collision.

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[278] Jeff Foust, "NASA outlines concerns about Starlink next-generation constellation in FCC letter," February 9, 2022, https://spacenews.com/nasa-outlines-concerns-about-starlink-next-generation-constellation-in-fcc-letter/.

[279] Foust, "NASA outlines concerns," February 9, 2022.

[280] Jared Isaacman, Countdown: Inspiration4 Mission to Space, ep. 5.

[281] Foust, "NASA outlines concerns," February 9, 2022.

[282] Mike Wall, "China's Tianhe space station module dodged SpaceX Starlink satellites twice this year," *Space.com*, December 30, 2021, https://www.space.com/china-tianhe-space-station-maneuvers-spacex-starlink.

[283] Wall, "China's Tianhe space station module," December 30, 2021.

[284] Wall, "China's Tianhe space station module," December 30, 2021.

As previously stated, approximately 81% of the 25,666 known, tracked artificial objects orbiting the Earth are non-functional spacecraft.[285] As a result, the vast majority of spacecraft in orbit is comprised of objects that are not actively providing service, and satellite operators are required to remain diligent in ensuring their craft are able to maneuver around satellites that are no longer in operation. As spacecraft fleets age and become nearer to EOL, commercial telecommunications satellite operators may face potential gaps in service from satellite failure or fuel depletion. For example, defunct satellites in GEO are taking up valuable orbital "slots," as satellites that may otherwise be ready for operation are prohibited from entering a designated GEO position because a non-functional satellite is "taking up its real estate."

Orbital debris can come from several sources. One is "mission-related debris and rocket bodies that remain in orbit together."[286] The Aerospace Corporation defines "mission-related debris" as "all objects dispensed, separated, or released as part of the planned mission," such as "separation bolts, lens caps, momentum flywheels, nuclear reactor cores, clamp bands, auxiliary motors, launch vehicle fairings, and adapter shrouds."[287] These discarded items remain in orbit after serving their purposes to their respective missions.

The largest source of space debris is fragmentation of satellites and rocket bodies.[288,289] Most of this fragmentation occurs as a result of explosions due to residual fuel or other reactive chemicals in engines or tanks, propellant tanks or batteries being heated by the sun, or micrometeoroid strikes.[290,291] Percy and Landrum state "[i]t is estimated that 70% of all

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[285] *Statement*, 5.
[286] Jakhu, Nyampong, and Sgobba, 130.
[287] "Space Debris Basics: What is Orbital Debris?" *The Aerospace Corpration*, accessed April 5, 2018. http://www.aerospace.org/cords/all-about-debris-and-reentry/space-debris-basics/.
[288] Jakhu, Nyampong, and Sgobba, 129.
[289] Percy and Landrum, 24.
[290] Jakhu, Nyampong, and Sgobba, 130.
[291] Percy and Landrum, 24.

fragmentations are caused by explosions."[292] A recent example occurred in August 2017 when Indonesian satellite operator PT Telkom's Telkom-1 satellite experienced an event that appeared to be some sort of "rupture" that resulted in the generation of a cloud of debris . ExoAnalytic, a commercial space situational awareness (SSA) company located in Mission Viejo, California, recorded the event, and CEO Doug Hendrix said, "preliminary data shows Telkom-1 did not collide with another object," indicating the rupture possibly occurred due to an explosion.[293]

Fragmentation can also occur as a result of collisions between spacecraft. In 2009, a collision occurred between one of United States communication company Iridium's satellites (Iridium 33) and a defunct Russian military satellite (Cosmos 2251) in LEO. Like the FY-1C ASAT mission, the collision resulted in a massive debris cloud, and was estimated to have created hundreds of thousands of pieces of small debris, and approximately 3,273 pieces of large debris.[294] While The Aerospace Corporation's Debris Analysis Response Team (DART) found that much of the resulting debris from the Iridium burned up as it entered the Earth's atmosphere, it is estimated that 48% remains in orbit.[295] Percy and Landrum state only 2% of fragmentation events occur due to collisions between "orbiting objects."[296]

We have not yet determined the best way to clean up space debris, but, for now, we can at least act in ways that will not unnecessarily create additional risk of damage in space. Discussing ASAT activity from a policy perspective, the OST holds States responsible for their actions. Article VI of the OST states "[p]arties to the Treaty shall bear international

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[292] Percy and Landrum, 24.

[293] Caleb Henry, "ExoAnalytic video shows Telkom-1 satellite erupting debris," *SpaceNews*, August 30, 2017, http://spacenews.com/exoanalytic-video-shows-telkom-1-satellite-erupting-debris/.

[294] Ted Muelhaupt, "The Collision of Iridium 33 and Cosmos 2251," *The Aerospace Corporation*, December 10, 2015, http://www.aerospace.org/crosslinkmag/fall-2015/the-collision-of-iridium-33-and-cosmos-2251/.

[295] Muelhaupt, "The Collision of Iridium 33 and Cosmos 2251,", December 10, 2015.

[296] Percy and Landrum, 24.

responsibility for national activities in outer space... and for assuring that national activities are carried out in conformity with the provisions set forth in the present Treaty."[297] Article XI prohibits "harmful interference" with other States' peaceful space activity, and requires a State to engage in consultation with other States if there is reason to believe a certain space activity may create such harmful interference.[298]

In 2007, China successfully destroyed an "aging, but functioning Chinese weather satellite, the Feng Yun 1C (FY-1C), in polar orbit at an altitude of approximately 537 miles"[299] in an anti-satellite (ASAT) test mission, creating thousands of pieces of space debris that will remain in orbit for decades.[300] ASAT activity such as China's FY-1C activity had not been performed since the Cold War era by the United States and the Soviet Union.[301] At their time of writing, Percy and Landrum approximated that 28% of fragmentation events in orbit had been deliberate.[302] China's ASAT activity in terms of liability will be discussed later in this paper, but in terms of violating international law, based on Articles VI and IX of the OST, in and of itself, a State firing a missile at its own satellite is not inherently an internationally wrongful act. It could be argued that such an act violates the "peaceful purposes" requirement in Article IV of the OST.[303] However, destroying a State's own defunct satellite in this fashion is not a placement of weapons of mass destruction, nor is it an establishment of any type of military base.[304] It is not an aggressive act toward another State, and, provided the act is in accordance with Article IX and proper measures are taken, ASAT missions directed at one's own satellite are not internationally

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[297] OST Art. VI.
[298] OST, art. IX.
[299] Michael Miniero, "FY-1C and USA-193 ASAT Intercepts: An Assessment of Legal Obligations Under Article IX of the Outer Space Treaty," *Journal of Space Law*, vol. 34 (2008): 341.
[300] Miniero, 342.
[301] Miniero, 350.
[302] Percy and Landrum, 24.
[303] OST, Art. IV.
[304] OST, art. IV.

wrongful acts. But China did not announce its measure before launching its ASAT missile, nor did it initiate consultation for what may have been a harmful space activity as is required in Article IX of the OST,[305] which is interesting to this author due to the fact that, as stated previously, China essentially invoked Art. IX of the OST in its "note" to the UN. Thus, China was in violation of the OST when it conducted its 2007 ASAT activity.

In light of the aforementioned orbital debris problem, we examine several legal questions raised by China's ASAT activity. Can China be held responsible for its ASAT missile launch act? According to Article VI of the OST, and scholarly and legal interpretation, the answer to this question is yes.[306] Should China bear international responsibility for creating a mass cloud of space debris and failing to conduct international consultations before their missile launch? According to the test set forth in Article VI[307] and Article IX[308] of the OST, China should be held responsible for these specific acts. Pursuant to Art. VII of the OST, what reparations to the international community would be possible and/or needed? According to the Articles on Responsibility of States for Internationally Wrongful Acts,[309] reparation is warranted. Article 31 states, "[t]he responsible State is under an obligation to make full reparation for the injury caused by the internationally wrongful act," and that "[i]njury includes any damage, whether material or moral, caused by the internationally wrongful act of a State."[310] Forms of reparation depend on the nature of the damage, if any, to the injured State(s), but, at the very least, the offending State should issue "official apologies," if there is no material damage.[311] Is firing a missile at one's

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[305] OST, Art. IX.
[306] OST, Art. VI.
[307] OST, Art. VI.
[308] OST, Art. IX.
[309] G.A. Res. 56/83, art. 31, U.N. GAOR, 56th Sess., U.N. Doc. A/RES/56/83 (January 28, 2002).
[310] G.A. Res. 56/83, art. 31, U.N. GAOR, 56th Sess., U.N. Doc. A/RES/56/83 (January 28, 2002).
[311] Frans G. von der Dunk, "Liability versus Responsibility in Space Law: Misconception or Misconstruction?" *University of Nebraska Space, Cyber, and Telecommunications Law Program Faculty Publications* (1992): 364.

own satellite an internationally wrongful act? As we see in the example of USA-193, with due diligence and fulfillment of obligations under the OST and international law, the act of ASAT activity against a State's own satellite is not inherently a wrongful act.[312]

As noted above, Article VI of the OST states Parties to the Treaty are responsible for their activity in space.[313] Frans G. von der Dunk explains:

> State responsibility, first, means responsibility for 'internationally wrongful acts' towards another state. The two decisive criteria for state responsibility to arise are therefore that 'a breach of an international obligation of the [responsible] State' in respect of the second state has taken place, which is called 'objective fault', and that that breach 'is attributable to the [responsible] State under international law'."[314]

Further, McDougal, et al. list some important factors for determining State responsibility, such as the "extent and the degree of harm... [t]he purpose of the activity giving rise to pollution," the duration of harmful consequences, and, perhaps most notably, "[t]he kind of advance warning or notice of danger given."[315] Parties to the OST are "hooked" by its Article VI and are bound to bear responsibility for their actions in space; further examination seems to make it clear that there are several other factors or "tests" that each State's ASAT missions "pass," and holding each State responsible is justified.

Advance warning or notice of danger is noted as an important factor in determining responsibility, as it was a key issue in whether China violated Article IX of the OST by not engaging in consultations with other States prior to its FY-1C mission. In response to the question of whether China should be held responsible for failing to conduct international consultations as well as creating a cloud of potentially harmful space debris: yes. Michael

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312 Miniero, 354.

313 OST, Art. VI.

314 von der Dunk, "Liability versus Responsibility in Space Law," 363.

315 Myres Smith McDougal, Harold D. Lasswell, and Ivan A. Vlasic, *Law and Public Order in Space* (New Haven: Yale University Press, 1963), 632.

Miniero parses out Article IX and explains that for a State to be obligated to initiate international consultation, three conditions must be satisfied: 1) State activity in outer space; 2) reason to believe the activity could cause harmful interference; and 3) that the potential harmful interference may interfere with other States' space activity[316]. China's FY-1C mission, according to Miniero, passes this test; thus, should be held responsible for not initiating international consultations.

ASAT Activity Reparations.

Bin Cheng explains a State "may not even take the trouble" of raising the issue of reparations if no material damage has occurred to a State potentially affected by harmful activity,[317] but von der Dunk states, "[u]nlawful action against non-material interests must receive adequate reparation, even if they have not resulted in... material loss for the claiming state."[318] Article 31 of the United Nations' Responsibility of States for internationally wrongful acts states a "responsible State is under an obligation to make full reparation for the injury caused by the internationally wrongful act," and that injury "includes any damage... caused by the internationally wrongful act of a State."[319]

Forms of reparation include restitution (or returning to the state that existed before the harmful activity), compensation if the damage "is not made good by restitution" (or financial reimbursement for damage caused), and satisfaction if the damage "cannot be made good by restitution or compensation" (potentially including "an acknowledgement of the breach, an expression of regret, a formal apology").[320] In other words, the order in which reparations

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[316] Miniero, 334-335.

[317] Bin Cheng, "Article VI of the 1967 Space Treaty Revisited: 'International Responsibility', 'National Activities', and 'The Appropriate State,'" *Journal of Space Law*, vol. 26, no. 1 (1998): 9.

[318] von der Dunk, "Liability versus Responsibility in Space Law," 369.

[319] G.A. Res. 56/83, ¶ 31, U.N. GAOR, 56th Sess., U.N. Doc. A/RES/56/83 (January 28, 2002).

[320] G.A. Res. 56/83, ¶ 31, U.N. GAOR, 56th Sess., U.N. Doc. A/RES/56/83 (January 28, 2002)..

should take place is: 1) "cleaning up" the situation, 2) monetary or financial compensation if another State has been materially harmed, and 3) an acknowledgment or apology if mitigation and financial compensation are overly burdensome.

In 2013, debris from the remnants of FY-1C caused damage to another spacecraft – apparently enough damage to destroy it. The FY-1C debris collided with a Russian nanosat, "Ball Lens In The Space," or BLITS, likely on January 22, 2013.[321] Russia could have brought legal action against China pursuant to the Liability Convention, but Russia "'would have to show that China was negligent in producing the fragment that struck BLITS and that there was no way that the Russian Federation could have avoided the collision.'"[322] The matter could have potentially been dealt with via settlement negotiations, but due to the fact that BLITS was an inexpensive nanosat, China and Russia had good diplomatic relations, and the burden of proof would have been extremely difficult, Russia did not pursue any action.[323] Of note, as of now, the only precedent that exists for claims pursuant to the Liability Convention is in the case of Cosmos 954, which will be discussed in the Land Pollution section of this paper.

On November 15, 2021, Russia conducted ASAT activity against one of its own satellites, Cosmos 1408, that created a debris field in LEO. This activity is said to have created "more than 1,500 pieces of debris large enough to be tracked by the U.S. Air Force, and hundreds of thousands of smaller, untrackable pieces" that, as discussed previously, are extremely problematic and could be devastating to missions and even life-threatening.[324] The debris is said to be creating "surges of close approaches," or "conjunction squalls… in some

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[321] Leonard David, "Legal Action against China Unlikely in Orbital Debris Collision," *SpaceNews*, March 13, 2013, https://spacenews.com/legal-action-against-china-unlikely-in-orbital-debris-collision/.

[322] David, "Legal Action against China Unlikely," March 13, 2013.

[323] David, "Legal Action against China Unlikely," March 13, 2013.

[324] Michelle Hanlon, "A Date That Will Live in Infamy? Let's Make it So," NSS Ad Astra, Q4 2021 Volume 35, pg. 11.

cases tens of thousands in a week, with active satellites in low Earth orbit."[325] These squalls "come from the interaction of the Cosmos 1408 debris with constellations of remote sensing satellites," and due to the nature of their respective orbits, "the debris overlaps the orbits of remote sensing satellites — but going in the opposite direction," and when the debris and remote sensing satellites "sync up, you have the perfect storm: they're in the same orbit plane but counter rotating, crossing each other twice an orbit, again and again."[326]

In a squall in early April, COMSPOC projects that conjunctions involving all active satellites in LEO "will peak at nearly 50,000 per day," including a baseline of "about 15,000 [conjunctions] per day not associated with the ASAT test, along with those involving Planet's satellites and with other companies and organizations, such as Satellogic, Spire and Swarm."[327] (See Charts and Graphs section of this paper for a graphic representation of these conjunctions.) This author notes here Swarm's picosats will be discussed in the Financial Study section of this paper. Interestingly, "because many of those satellites are cubesats, the risk of collisions does not rise as dramatically… the background average daily collision rate level [is] about 0.0005, [and] during the surge in early April it reaches a peak of only a little more than 0.0008."[328] The relatively low rise in risk of collisions because the number of satellites is significant but they are small in size seems to counter what many experts consider a concern, but strikes a similar chord to what some industry experts say about risk of collision overall.

However, this recent Russian ASAT activity created a hazard for astronauts on board the ISS, who "were directed to take shelter in their docked spaceship capsules for two hours after the

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[325] Jeff Foust, "Russian ASAT debris creating "squalls" of close approaches with satellites," *SpaceNews*, February 18, 2022, https://spacenews.com/russian-asat-debris-creating-squalls-of-close-approaches-with-satellites/.
[326] Foust, "Russian ASAT debris," February 18, 2022.
[327] Foust, "Russian ASAT debris," February 18, 2022.
[328] Foust, "Russian ASAT debris," February 18, 2022.

test as a precaution to allow for a quick getaway."[329] Ultimately, it was determined that the astronauts could safely return to the ISS interior, but the debris cloud will linger and continue to cause problems for other spacecraft, as discussed above.[330] U.S. Army General James Dickinson stated "'Russia has demonstrated a deliberate disregard for the security, safety, stability and long-term sustainability of the space domain for all nations," which presages the concern for national security assets in outer space. ASAT tests could present the perception that there is a "simmering arms race in outer space," and potentially "directly upset the delicate balance of non-aggression that exists" there, as such "weapons would also have offensive capabilities, inevitably increasing the security dilemma in outer space and adding fuel to the arms race."[331]

However, not many States have brought up security concerns outright, and most have been more concerned with the generation of debris.[332] The theoretical potential threat of ASAT activity against another State's spacecraft will be discussed later in this paper, but only within the scope of an exclusion to a space insurance policy and potential cover provided by a potential space P&I club. If a State conducted deliberate ASAT activity against another State's satellite, it would be a different scenario. If that activity was deemed an act of war, looking only within the scope of liability and insurance coverage, it would be an exclusion from a conventional space insurance policy. However, it could be covered by a potential space P&I club as it has been stated to be part of a P&I club's coverage to members.

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[329] Idrees Ali and Steve Gorman, "Russian anti-satellite missile test endangers space station crew – NASA," *Reuters*, November 16, 2021, https://www.reuters.com/world/us-military-reports-debris-generating-event-outer-space-2021-11-15/.

[330] Ali and Gorman, "Russian anti-satellite missile test," November 16, 2021.

[331] Jessica West, "What kinetic ASAT testing tells us about space security governance," *Project Ploughshares*, accessed March 20, 2022, https://ploughshares.ca/pl_publications/what-kinetic-asat-testing-tells-us-about-space-security-governance/.

[332] West, "What kinetic ASAT testing tells us," *Project Ploughshares*.

As in the example of incidents on the Earth's surface, in the above examples, a potential space P&I club could provide a benefit to club members. As The American Club coverage includes collisions, wreck removal, and pollution, similar coverage could be provided to spacecraft owner/operators in the event of incidents such as the above. Again, it should be noted that each club member's specific agreement will likely contain some limitations or exclusions may apply. But as discussed above, especially if legal assistance and emergency help are part of P&I club membership, it could be argued that potential space P&I club membership would benefit members in the event of on-orbit incidents.

Space Infrastructure in Daily Life

Prior to discussing law, regulations, policies, and guidelines pertaining to STM, it is important to examine why addressing matters of STM is crucial. What does this all matter to society in general and how we perform seemingly ordinary functions every day? Satellites and other spacecraft provide many benefits, often critical. They facilitate communication, navigation, remote sensing, security and defense, and other services, the importance of which is specifically addressed in the Space Sustainability Rating initiative discussed below, as it calls for raising public awareness that keeping our space environment clean is critical.

Jah explains "given that our Geospace belongs to all humans and that many space actors behave... without full consideration of the impact of their space operations and activities on the whole environment... our Space Commons!" We are beginning to realize our access to space is finite, and if the population of space objects continues to grow, we may run out of our resource (in this case, access to and capability in space). Jah further highlights the fact that in 2016, the Indian Space Research Organisation (ISRO) launched a record-breaking constellation of 104 satellites. Additionally, at the time of Jah's testimony, satellite manufacturing company

OneWeb had received FCC authorization to place over one thousand satellites into LEO with the aim to provide global internet access, which has since become a reality. Jah noted at the time that SpaceX was planning a similar mission and was working to follow suit with approximately 4,000 satellites, which has now become a reality.[333]

Hunter notes space capabilities "play a role in everything from buying gas to national defense."[334] If the number of objects in orbit around the Earth becomes too great, we risk losing those capabilities to damage from collisions, or we may potentially not be able to launch satellites in the future to continue services because there is too much risk of damage from collisions with other craft – space would have simply become too crowded. Hunter notes further that "[d]isruption in access to space-reliant services potentially range from minor inconveniences to catastrophic global economic collapse."[335]

According to the Satellite Industry Association, the global space economy in 2020 was worth $371 billion, of which $271 billion (74%) was directly comprised of areas of the satellite industry, including telecommunications satellite services (television, telephone, aviation, and maritime), remote sensing services (agriculture, meteorology, and national security), and ground equipment (network equipment, television and radio receivers, and navigation units).[336] Financial damage to the global economy in the event of a catastrophic loss of space-based capability is extremely serious, but the specific dollar values of consequential damages and loss

[333] *Statement*, 9.
[334] Hunter, 4.
[335] Hunter, 4.
[336] SIA 2020 Top-Level Global Satellite Industry Findings https://doc-00-7k-apps-viewer.googleusercontent.com/viewer/secure/pdf/lo8b9io9gfcrkv1nre8julsf0378flrr/488vbot4f0vs1igg6c55q6isoukv6occ/1647009150000/lantern/00878071515667122621/ACFrOgC7utf6UQl72_Qe7vNooWGlO3COuTb9ftCoZPpQ6Y0ytejX-kHvCqxSeOY9-XeqQS31E-dZB5QS2kf-3n5hw87OR6xpfjYJwnT-05RvytIu_I-1O01DCStURrk-EK1s433qgliG7DkT-d0q?print=true&nonce=apnpr4uve824m&user=00878071515667122621&hash=elop47acec25g4l2q2k4r0pp88db1p7q

of revenue in each industry that depends on space for its function is not explored in this paper and is recommended for a point of future study. The social effects, however, are briefly discussed here as follows.

A very recent and very significant example of benefits of spacecraft and use of space-related infrastructure is SpaceX's provision of Starlink terminals to Ukraine when its communications had been cut off after its invasion by Russia. Though it is (hopefully) not likely a situation like this will arise in most of our daily lives, it is a dramatic example of how critical communications capability is.

In a series of now-famous tweets between Mykhailo Fedorov, the First Prime Minister of Ukraine, and SpaceX's Elon Musk, a story publicly unfolded regarding Fedorov's request that SpaceX "provide Ukraine with Starlink stations."[337] Musk responded to Fedorov's tweet approximately ten hours later saying help was on the way.[338] The request was made "to help keep the embattled country connected to the outside world as Russia steps up its invasion."[339]

Satellite capability also contributes to the shipping industry by improving navigation and increasing the flow of data to keep seafaring vessels safe and moving efficiently. For example, Spire Global offers Automatic Identification System (AIS) services through its satellite constellation. Spire Global's website explains AIS was developed for parties within the shipping industry to exchange information with each other pertaining to "ship identity, position, time course, and speed," and can act as a traffic management tool.[340] Most importantly, AIS would

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[337] Mykhailo Fedorov Twitter: https://twitter.com/elonmusk/status/1497701484003213317?ref_src=twsrc%5Etfw%7Ctwcamp%5Etweetembed%7Ctwterm%5E1497701484003213317%7Ctwgr%5E%7Ctwcon%5Es1_&ref_url=https%3A%2F%2Fspacenews.com%2Fspacex-heeds-ukraines-starlink-sos%2F

[338] Brian Berger, "SpaceX heeds Ukraine's Starlink SOS," *SpaceNews*, February 28, 2022, https://spacenews.com/spacex-heeds-ukraines-starlink-sos/.

[339] Berger, "SpaceX heeds Ukraine's Starlink SOS," February 28, 2022.

[340] "Introduction to Automatic Identification Systems (AIS)," *Spire Global*, accessed March 27, 2022, https://spire.com/whitepaper/maritime/introduction-to-automatic-identification-systems-ais/.

lead to safer shipping operations as sharing vessel positions could prevent a ship from running aground or colliding with another ship.[341]

Additionally, Spire goes on to explain how AIS can reduce costs for shipping companies and freight forwarders by providing more data on routes that could maximize a vessel's fuel usage, identify trends in the movement of commodities, and weather forecasts that could affect a vessel's estimated time of arrival into port, thereby streamlining the flow of supply chain logistics.[342] Subsequently, there would arguably be less time, labor, and fuel lost in inefficient shipping activity, thereby resulting in cost savings.

According to OHB, a communications satellite company in Germany, financial transaction data is transmitted globally several billion times per hour every day.[343] This includes simple transactions such as using a cell phone to pay a parking meter to making a stock trade worth millions of dollars.[344] Axess, another communications satellite company, with its main offices in Germany, Mexico, Columbia, and Saudi Arabia, states satellite data transmission is used to "complement… the terrestrial network infrastructure," and can be used where connectivity is limited or terrain is too rugged to install terrestrial networks while keeping systems reliability high with greater than 99.6% uptime.[345] Further, and perhaps most

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[341] Introduction to Automatic Identification Systems (AIS)," *Spire Global*.

[342] "How maritime data reduces costs and builds transparency: A closer look at how Maritime data has a direct impact on profitability," *Spire Global*, accessed March 27, 2022, https://insights.spire.com/hubfs/Spire-Maritime_Cost_Saving_EBook_FA_3.pdf?utm_campaign=%5BMaritime%5D%20nurture_ebook&utm_medium=email&_hsmi=202682306&_hsenc=p2ANqtz-_zd9n67oSg6UEWb_4vOiITyGwSIvPggSgmrELdGrltePnuqomjSnsJLzZeQac4vPeglSrZ_hW-Fzd9_bbq519UsyN6kw&utm_content=202682306&utm_source=hs_automation.

[343] "Why mobile banking would be unthinkable without satellites: The role played by satellites in our modern financial system," *OHB*, April 16, 2018, https://www.ohb.de/en/magazine/why-mobile-banking-would-be-unthinkable-without-satellites.

[344] "Why mobile banking would be unthinkable without satellites," *OHB*, April 16, 2018.

[345] "Satellite communication: the technology behind the banking industry," *Axess Networks*, accessed March 27, 2022, https://axessnet.com/en/satellite-communication-the-technology-behind-the-banking-industry/.

importantly, OHB and Axess state financial transactions via satellite are secure due to tracking of users' locations and signals being "used to check the plausibility of [the]transactions."[346,347]

Financial transactions are not the only activity for which we need to be concerned about security. John D. Hill told the HASC subcommittee on strategic forces that Secretary of Defense Lloyd J. Austin III has also testified that the growth of Chinese and Russian counter space capabilities presents the most immediate and serious threats to U.S. allied and partner space activities. Additionally, "Russia and China view space as critical to modern warfare and consider the use of counterspace capabilities as both a means of reducing U.S. military effectiveness and winning future wars," Hill said.[348] Adm. Guiseppe Cavo Dragone, Italy's defense chief of staff, said it "'will be essential to render the protection of satellites more robust'" and "warned of an 'increase in threats' and a 'risk for security' in space."[349] Of note, Cavo Dragone said watching for threats in space is essential as "it would otherwise be difficult to distinguish between 'irresponsible' and 'aggressive' behavior… and to identify actors who provoke incidents in orbit."[350] Further, response to a direct attack should be treated the same as an attack on a State's ship in international waters, and a State should respond accordingly.[351] Especially in light of "de-stabilizing challenges from Russia and… strategic competition with China," this author agrees with the fact that we must continue monitoring closely for potential intentional acts of

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[346] "Why mobile banking would be unthinkable without satellites," *OHB*, April 16, 2018.

[347] "Satellite communication: the technology behind the banking industry," *Axess Networks*.

[348] Terri Moon Cronk, "Space-Based Capabilities Critical to U.S. National Security, DOD Officials Say," *U.S. Department of Defense*, May 24, 2021, https://www.defense.gov/News/News-Stories/Article/Article/2629675/space-based-capabilities-critical-to-us-national-security-dod-officials-say/.

[349] Tom Kington,"Italy's defense chief of staff urges better protection of satellites," *DefenseNews*, March 4, 2022, https://www.defensenews.com/space/2022/03/04/italys-defense-chief-of-staff-urges-better-protection-of-satellites/.

[350] Kington,"Italy's defense chief of staff," *DefenseNews*, March 4, 2022.

[351] Kington,"Italy's defense chief of staff," *DefenseNews*, March 4, 2022.

aggression toward our satellites and other spacecraft, though such an act will hopefully never be realized.[352]

In a constructive area of space activity, students from elementary schools through universities can conduct educational and scholarly research and learn important lessons about outer space. For example, the University of Georgia Small Satellite Research Laboratory (SSRL) is working with NASA and the Air Force Research Laboratory to develop innovative technology using CubeSats. The SSRL was originally developed "as an avenue for undergraduates to design, build, and test space-ready components," which has expanded over the years.[353] Also, in 2016, a CubeSat designed and built by St. Thomas More Cathedral School students in Arlington, Virginia, in partnership with NASA Goddard Space Flight Center, was deployed as a rideshare via Orbital ATK (now Northrop Grumman) Cygnus launch vehicle.[354] The students' STMSat1 would be used to take and transmit photographs of the Earth to the school's ground station as well as other ground stations in the US, and would facilitate hands-on learning related to outer space activity.[355]

A 2011 MIT News Office article states after the 2010 earthquake in Haiti, space entities were tasked with "providing free images of the earthquake's aftermath," pursuant to an international charter "under which satellite operators around the world offer to share satellite data after a natural or man-made disaster."[356] The article goes on to state there are now countries that are beginning to develop their own satellite programs to obtain their own information

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[352] Cronk, "Space-Based Capabilities Critical to U.S. National Security," May 24, 2021.

[353] "Small Satellite Research Laboratory," *University of Georgia*, accessed March 27, 2022, http://SmallSat.uga.edu.

[354] Erin Mahoney, ed., " First CubeSat Built by an Elementary School Deployed into Space," May 16, 2016, https://www.nasa.gov/feature/first-cubesat-built-by-an-elementary-school-deployed-into-space.

[355] Mahoney, ed., " First CubeSat Built by an Elementary School Deployed into Space," May 16, 2016.

[356] Jennifer Chu, "Satellites in the developing world," *MIT News*, August 4, 2011, https://news.mit.edu/2011/developing-satellites-0804.

pertaining to their own States, namely in mapping and forecasting disasters, monitoring crop yields, and tracking diseases such as malaria.[357] Some of the nations that were beginning to develop their programs at the time of the article's publication included Nigeria, Malaysia, Thailand, Turkey, and Algeria.[358]

Laws, Regulations, Policies, and Guidelines

This section will examine existing laws, regulations, policies, and guidelines pertaining to STM, after which the question of whether policy adherence could be described as a benefit stemming from potential space P&I club membership. A question arises about how we can continue space operations on which our global society heavily relies when our space environment is becoming so crowded with traffic. STM solutions are urgently needed. International space treaties, policy, guidelines, and legislation are in place that provide information on best practices to prevent further accumulation of orbital debris, and several stakeholders in government and commercial industry are working to collect and distribute space traffic status and conjunction notifications as well as develop ADR and OOS techniques.

As far as a clean and concise STM regime, however, a system of governance does not yet exist – not domestically here in the US, let alone globally. Many actors are working toward the one goal of ensuring we do not lose our access to space due to a dangerous cluttered orbit but are doing so through their own avenues. One dedicated comprehensive global "hub" for STM matters does not yet exist. The fragmentation of STM efforts could create a problem due to the fact that they could conflict and "get in each other's way" despite aspiring to the same goal of creating a safe and sustainable space environment. But the efforts could also be seen as part of

[357] Chu, "Satellites in the developing world," August 4, 2011.
[358] Chu, "Satellites in the developing world," August 4, 2011.

the archive of best practices on which we can build best practices for risk management and STM.[359]

If we were to proceed with a "one-stop shop" for STM governance, one potential solution may be the drafting of a new international treaty dedicated to addressing STM, ADR, and OOS.[360] However, especially in this current political climate at the time of this writing, it is extremely unlikely that spacefaring States would be willing to sign on to a new treaty, and domestic (national) legislation would be the most efficient solution to address STM matters at present, especially due to their urgent nature.[361]

Another solution might be the creation of a new international organization, also specifically dedicated to addressing STM, OOS, and ADR matters.[362] A space actor could voluntarily transfer the right of jurisdiction and control of its craft to this organization, which could then maintain registration of that craft and provide ADR and OOS to it.[363] The organization would have cross-waivers in place if an incident occurred during said ADR or OOS, and the parties to the agreement could work among themselves to settle a claim.[364]

A third possible solution would be for an international organization to draft standards for STM practices and to help create a sustainable space environment, such as ISO.[365] It would be in a commercial company's best interest to adhere to these standards to earn "good marks" and place itself as high in competition with other companies in the industry[366] Further, such trade

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[359] Dodge, 5.
[360] Jakhu, Nyampong, and Sgobba, 132.
[361] Jason Krause, "The Outer Space Treaty turns 50: can it survive a new space race?" *ABA Journal* 103.4 (2017): 44, accessed December 13, 2017, http://link.galegroup.com/apps/doc/A492536879/EAIM?u=ndacad_58202zund&sid=EAIM&xid=e45fc5c3.
[362] Jakhu, Nyampong, and Sgobba, 132.
[363] Jakhu, Nyampong, and Sgobba, 132.
[364] Jakhu, Nyampong, and Sgobba, 132.
[365] Percy and Landrum, 30.
[366] Percy and Landrum, 30.

organizations have also had positive impact on airlines' behavior, much like a P&I club or conventions such as MARPOL (discussed below) have had positive impact on shipping owner/operators' behavior in the maritime industry.[367] Thus, it could be argued a similar space-related international organization could also have positive impact on spacecraft owner/operators' behavior on-orbit.[368] A similar organization or set of standards has been in the works for over two years, stemming from the World Economic Forum, in the form of the Space Sustainability Rating, which is discussed below.

A fourth potential solution for STM issues is using insurance policies as contracts, thus forming a quasi-system of governance.[369] Essentially, parties to an insurance policy (contract) would be enforced to operate in a certain way pursuant to that contract, which could incentivize good behavior or disincentivize bad behavior.[370] As discussed above, incentivization is a key part of this research regarding how P&I clubs could provide said incentive to commercial spacecraft owner/operators where there may be gaps in traditional insurance. The fact that an insurance contract could, in part, govern how space entities operate in tandem with P&I club coverage that would theoretically fill in third-party liability gaps arguably provides a comprehensive foundation for best STM practices.

Relevant International Treaties and Conventions

Outer Space Treaty

Certain Articles of the OST carry significant importance pertaining to STM. Article VI of the OST holds States responsible for their actions: "[p]arties to the Treaty shall bear international responsibility for national activities in outer space… and for assuring that national

[367] Dodge, 15.
[368] Dodge, 15.
[369] Harrington,15.
[370] Harrington,15.

activities are carried out in conformity with the provisions set forth in the present Treaty."[371] Article VIII states an object on a State's registry shall remain under the jurisdiction and ownership of that State,[372] and Article IX prohibits "harmful interference" with other States' peaceful space activity, and requires a State to engage in consultation with other States if there is reason to believe a certain space activity may create such harmful interference.[373] While "the space community expects a general decline in the number of intentional fragmentation events due to increased pressure to avoid the creation of orbital debris,"[374] compliance with the OST cannot be assumed. For example, in the case of the FY-1C ASAT mission, it could be argued that China was in violation of Art. IX because a) there was reason to believe its ASAT activity, though conducted against its own space object, could potentially create harmful interference to other States' spacecraft, and b) it did not engage in consultations before proceeding with its potentially harmful activity.

In the case of orbital debris, if a State does not comply with the OST, and engages in potentially harmful activity that puts other States' space capabilities as risk, what remedies are available, if any? Frans G. von der Dunk states, "[u]nlawful action against non-material interests must receive adequate reparation, even if they have not resulted in… material loss for the claiming state."[375] Article 31 of the United Nations' Responsibility of States for internationally wrongful acts states a "responsible State is under an obligation to make full reparation for the injury caused by the internationally wrongful act," and that injury "includes any damage… caused by the internationally wrongful act of a State."[376]

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[371] OST, Art. VI.
[372] OST, Art. VIII.
[373] OST, Art. IX.
[374] Percy and Landrum, 24.
[375] von der Dunk, "Liability versus Responsibility in Space Law," 369.
[376] G.A. Res. 56/83, ¶ 31, U.N. GAOR, 56th Sess., U.N. Doc. A/RES/56/83 (January 28, 2002) .

Forms of reparation include restitution (or returning to the state that existed before the harmful activity), compensation if the damage "is not made good by restitution" (or financial reimbursement for damage caused), and satisfaction if the damage "cannot be made good by restitution or compensation" (potentially including "an acknowledgement of the breach, an expression of regret, a formal apology").[377] In other words, the order in which reparations should take place is: 1) "cleaning up" the situation, 2) monetary or financial compensation if another State has been materially harmed, and 3) an acknowledgment or apology if mitigation and financial compensation are overly burdensome.

Art. VII is also key when discussing liability in outer space, especially as we examine the CSLA, as it sets forth international requirements for liability between States. It is important to note Art. VII is tied to Arts. VI and VIII in that a Party to the Treaty that launches a space object, whether that State owns the object or the object is simply launched from a State's territory, is internationally liable for damage to another Party to the Treaty including its "natural or juridical persons by such object or its component parts on the Earth, in air or in outer space… ."[378] In the CSLA section of this paper, how US legislation addresses liability and insurance pertaining to damage to another State/Party to the Treaty will be examined further.

Registration Convention

Art. II of the Convention on Registration of Objects Launched into Outer Space (Registration Convention) requires a State that launches a space object to "register the space object by means of an entry in an appropriate registry which it shall maintain,"[379] and Art. III requires the Secretary-General of the United Nations (UN) to maintain its own registry from the

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[377] G.A. Res. 56/83, ¶ 31, U.N. GAOR, 56th Sess., U.N. Doc. A/RES/56/83 (January 28, 2002).

[378] OST, Art. VII.

[379] Convention on Registration of Objects Launched into Outer Space, art. II, January 14, 1975, 1023 UNTS 15; UKTS No. 70 (1978), Cmnd. 7271; 28 UST 695; TIAS 8480 [hereinafter Registration Convention].

information provided by the launching States.[380] Art. VI states if an unregistered space object causes damage to a spacecraft under the ownership of a State Party,

> other States Parties, including in particular States possessing space monitoring and tracking facilities, shall respond to the greatest extent feasible to a request by that State Party… for assistance under equitable and reasonable conditions in the identification of the object. [381]

Thus, an outside State Party with space object tracking capability must provide information to the damaged State Party (within feasibility and reason) to try and determine who owns the object that caused the damage, and, in turn, who could be responsible and/or liable under the OST and the Liability Convention. As discussed below, determining ownership of the object in question and, in turn, deeming responsibility and/or liability could be an extremely difficult, if not impossible, endeavor.

Liability Convention

In his article "A Sleeping Beauty Awakens," (title abbreviated), Von der Dunk states "The Liability Convention considered the possibility that something might go horribly wrong in space, and further considered the monetary retribution that might result."[382] He describes it further in his work "Liability versus Responsibility in Space Law," noting liability is a very key factor in space activity – so much so that "a special Liability Convention was devoted to develop the provisions of Article VII of the Outer Space Treaty."[383]

Art. III of the Convention on International Liability for Damage Caused by Space Objects (Liability Convention) states "

> [i]n the event of damage being caused elsewhere than on the surface of the Earth to a space object of one launching State or to persons or property on board such a

[380] Registration Convention, Art. III.
[381] Registration Convention, Art. VI.
[382] Frans G. von der Dunk, "A Sleeping Beauty Awakens: the 1968 Rescue Agreement After Forty Years" [hereinafter *Sleeping Beauty*], *Journal of Space Law* 34, no. 2 (2008): 412.
[383] von der Dunk, "A Sleeping Beauty Awakens," 412.

> space object by a space object of another launching State, the latter shall be liable only if the damage is due to its fault or the fault of persons for whom it is responsible [384]

According to Slann, this means that "in order to prove that a party can be deemed liable for a collision between two space objects in outer space, the other would have to conclusively establish that one of the launching states, or persons for whom it is responsible, is at fault."[385] In other words, the burden of proof falls on the party that suffered the harm. It could be very difficult, then, to prove without a doubt that a certain party's spacecraft caused the damage without identifying information, especially if that space object was not registered per requirements of the Registration Convention.

The international space treaties set international laws pertaining to outer space activity, but in terms of liability, ensuring adherence can become confusing and difficult, especially when a State is Party to several (as in the case of the US). Especially when it comes to coming to a final determination of whose space object caused harm, if this determination is not possible, what is a harmed party's action if no one is deemed liable? How are reparations made to them? This question is further explored when looking at space insurance (within the scope of US commercial space activity). First, however, another important international convention pertaining to pollution of the seas is examined as it is deemed relevant to the maritime/outer space environment analogue.

MARPOL

The International Convention for the Prevention of Pollution from Ships, or MARPOL, is "the main international convention covering prevention of pollution of the marine environment

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[384] Convention on International Liability for Damage Caused by Space Objects, March 29, 1972, 961 UNTS 187; UKTS No. 16 (1974), Cmnd. 5551; 24 UST 2389; TIAS 7762 [hereinafter Liability Convention].

[385] Slann, 41.

by ships from operational or accidental causes."[386] MARPOL "consists of six separate Annexes, each set out regulations covering the various sources of ship-generated pollution."[387] We particularly examine Annex II and Annex V herein.

Generally, it is said that MARPOL has led to innovations that have "contributed greatly to a noticeable decrease in the pollution of the world's seas, though it is fair to recognise that a greater effort to impose compliance must be carried out."[388] This is particularly important as it indicates a set of regulations could lead to actual positive impact in the space environment, as well.

Annex II of MARPOL sets forth regulations pertaining to noxious liquid substances, or carriage of chemicals in bulk.[389] Annex II is a good analogue for space activity due to liquid fuel carried by spacecraft. Annex II "sets out a pollution categorization system for noxious and liquid substances" as follows:

- Category X: Noxious Liquid Substances which, if discharged into the sea… present a major hazard to either marine resources or human health (prohibited from being discharged into marine environment);
- Category Y: Noxious Liquid Substances which, if discharged into the sea… present a hazard to… marine resources, human health, or cause harm to amenities or other

[386] "International Convention for the Prevention of Pollution from Ships (MARPOL)," *International Maritime Organization*, accessed March 20, 2022, https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx.

[387] "International Convention for the Prevention of Pollution by Ships - MARPOL 73/78," *United States Coast Guard, U.S. Department of Homeland Security*, accessed March 20, 2022, https://www.dco.uscg.mil/Our-Organization/Assistant-Commandant-for-Prevention-Policy-CG-5P/Inspections-Compliance-CG-5PC-/Commercial-Vessel-Compliance/Domestic-Compliance-Division/MARPOL/.

[388] "MARPOL Annex I – Prevention of Pollution by Oil," *International Maritime Organization*, accessed April 3, 2022, https://www.imo.org/en/OurWork/Environment/Pages/OilPollution-Default.aspx.

[389] "Carriage of chemicals by ship," *International Maritime Organization*, accessed March 20, 2022, https://www.imo.org/en/OurWork/Environment/Pages/ChemicalPollution-Default.aspx.

legitimate uses of the sea (limitation on the quality and quantity of the discharge into the marine environment);

- Category Z: Noxious Liquid Substances which, if discharged into the sea… present a minor hazard to either marine resources or human health (less stringent restrictions on the quality and quantity of the discharge into the marine environment); and
- Other Substances: substances which have been evaluated and found to fall outside Category X, Y or Z because they are considered to present no harm to marine resources, human health, amenities or other legitimate uses of the sea (are not subject to any requirements of MARPOL Annex II.)[390]

There are several other more technical regulations set forth within Annex II, but as they are technical in nature, they are beyond the scope of this paper. Despite this, we could draft a similar categorization of pollutants from spacecraft that, in the event of a spill, have the potential to create hazards on orbit or on the surface of the Earth. This potential categorization is recommended for further research.

MARPOL Annex V addresses matters of garbage, and "generally prohibits the discharge of all garbage into the sea," (except certain provisions related to "food waste, cargo residues, cleaning agents and additives and animal carcasses") (please see Exhibit A for an overview of the MARPOL Annex V discharge provisions).[391] Generally, "cargo residues which contain substances classified as harmful… must not be discharged at sea… ."[392] Further,

> ships of 100 gross tonnage and above… must carry a garbage management plan… which includes written procedures for

[390] "Carriage of chemicals by ship," *International Maritime Organization*, accessed March 20, 2022, https://www.imo.org/en/OurWork/Environment/Pages/ChemicalPollution-Default.aspx.

[391] "Prevention of Pollution by Garbage from Ships," *International Maritime Organization*, accessed April 3, 2022, https://www.imo.org/en/OurWork/Environment/Pages/Garbage-Default.aspx.

[392] "Prevention of Pollution by Garbage from Ships," *International Maritime Organization*.

> minimizing… and disposing of garbage, including the use of the equipment on board.[393]

Similar to Annex II, Annex V could be seen as an analogue for the space environment, even with current rules, regulations, policies, and guidelines that exist today. For example, FCC regulations that require a narrative of how an operator plans to mitigate debris from being released from its spacecraft could arguably be considered a "garbage management plan," of sorts.

Other Relevant International Policies

IADC Guidelines

Internationally, IADC first issued its SDMG in December 2007 and revised them in March 2020.[394] It is important to note the SDMG contains much of the same content as the United States' Orbital Debris Mitigation Standard Practices (ODMSP) and other policies with regard to guidelines and strategies, and much of that content has made its way into US FCC satellite licensing requirements, discussed later in this paper.

The IADC consists of thirteen space agencies:

1) Italian Space Agency (ASI)
2) Centre National d'Etudes Spatiales (CNES)
3) China National Space Administration (CNSA)
4) Canadian Space Agency (CSA)
5) German Aerospace Center (DLR)
6) European Space Agency (ESA)
7) Indian Space Research Organisation (ISRO)
8) Japan Aerospace Exploration Agency (JAXA)
9) Korea Aerospace Research Institute (KARI)
10) National Aeronautics and Space Administration (NASA)
11) State Space Corporation (ROSCOSMOS)
12) State Space Agency of Ukraine (SSAU)
13) United Kingdom Space Agency (UKSA)

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393 "Prevention of Pollution by Garbage from Ships," *International Maritime Organization*.

394 "IADC Space Debris Mitigation Guidelines" [hereinafter *SDMG*], *Inter-Agency Space Debris Coordination Committee*, IADC-02-01, Revision 2, March 2020, 4, https://orbitaldebris.jsc.nasa.gov/library/iadc-space-debris-guidelines-revision-2.pdf. .

The IADC's purpose is to exchange information, facilitate cooperation, review ongoing activities, and identify and recommend mitigation opportunities related to both "human-made and natural" space debris. However, the SDMG specifically focuses on human-made debris."[395] In turn, the IADC provides guidance on debris mitigation strategies and space traffic measures such as limiting debris release throughout normal operations, minimizing potential for on-orbit breakups/destruction (including during and post-mission), and spacecraft disposal at EOL.

It is important to note the SDMG is one set of guidelines that recommends the "25-year" rule for spacecraft in LEO; that the craft should be limited to a lifetime on orbit of 25 years and then be deorbited or shepherded to a "graveyard orbit."[396] Additionally, the SDMG recommends "developing the design and mission profile" of a spacecraft to mitigate and minimize probability of "accidental collision with known objects" during the craft's lifetime, including small debris, and that which would "[prevent] post-mission disposal."[397]

Thus, the SDMG not only aims to prevent spacecraft from causing debris by minimizing the probability of itself breaking apart or causing additional debris by colliding with other objects, but also to prevent the craft from "passively" becoming debris by not having the ability to deorbit itself or park itself in a graveyard orbit. Subsequently, theoretically, the amount of space traffic could be kept at a minimum and the "orbital lanes" could operate more cleanly with less risk of bumping into each other (or, at least, the idea is that an attempt could be made in good faith to do so).

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[395] SDMG, 4.
[396] SDMG, 12.
[397] SDMG, 12.

UN Guidelines for Long-Term Sustainability of Outer Space Activities

In June 2018, the UN COPUOS issued its Guidelines for the Long-term Sustainability of Outer Space Activities.[398] The document does not advise on technical data recommendations pertaining to space traffic but provides a broad set of strategies that are not binding per international law, but very strongly encouraged as they attempt to make very clear our space environment needs to be kept clean for long-term usability. The UN Sustainability Guidelines align with the OST and are "integrally associated" with it, and they also align with the other policies and guidelines discussed in this paper.[399]

At a high level, the purpose of the UN Sustainability Guidelines is to encourage States to create and implement strategies, such as putting regulatory frameworks in place (or revising them appropriately as new STM data are gathered), to "ensure the effective application of relevant, generally accepted international norms, standards and practices for the safe conduct of outer space activities." Further, these States' regulations should not be drafted in such a way that in the future, they could become a barrier to space activity that facilitates space environment sustainability and should be "efficient in terms of limiting the cost for compliance (e.g., in terms of money, time or risk)… ."[400] The examination of implementing guidelines such as these UN Sustainability Guidelines through the lens of a commercial space company and effects on cost, business/risk management, and insurance/liability will be addressed later in this paper.

Guideline A.3 should be particularly noted as it is integrated with Art. VI of the OST. Guideline A.3, itself, is titled "Supervise national space activities."[401] Essentially, this guideline

[398] Comm. on the Peaceful Uses of Outer Space, *Guidelines for the Long-term Sustainability of Outer Space Activities*, U.N. Doc. A/AC.105/2018/CRP.20 (June 27, 2018) [hereinafter "UN Sustainability Guidelines"].
[399] UN Sustainability Guidelines, 2.
[400] UN Sustainability Guidelines, 5.
[401] UN Sustainability Guidelines, 6.

invokes Art. VI in terms of States being responsible for activities of entities within its jurisdiction, thus should ensure these entities conduct space activity that aligns with the UN Sustainability Guidelines overall; that entities implement "technical competencies," procedures, and structures throughout the spacecraft's entire life cycle that account for long-term space sustainability.[402]

The UN Sustainability Guidelines could be broken out into four pillars: pre-launch, gathering and sharing of orbital data, conjunction assessment during all phases of on-orbit life of the spacecraft, and raising public awareness of the importance of space sustainability. With regard to pre-launch requirements, the Guidelines recommend States "[d]evelop practical approaches for pre-launch… assessment" and share that information to encourage further research into long-term space sustainability. A pre-launch assessment of a manufacturer or owner/operator's spacecraft could consist of a review of "design approaches that increase the trackability of space objects" and whether the entity "implement[s] applicable international and national space debris mitigation standards and/or guidelines.[403] Further, the UN Sustainability Guidelines recognizes the importance of small objects in space activity, especially due to their accessibility to developing and "emerging spacefaring" countries, and recommends implementation of the Guidelines in launching and operating "small-size space objects that are difficult to track, in a way that promotes the long-term sustainability of outer space activities."[404]

With regard to space object tracking data, States should "promote techniques and the investigation of new methods to improve such accuracy" and should coordinate both among themselves and internationally to share and disseminate orbital debris data and "space debris

[402] UN Sustainability Guidelines, 6.
[403] UN Sustainability Guidelines , 12.
[404] UN Sustainability Guidelines , 15.

monitoring information" to create a database.[405] In concert with the pre-launch guidelines pertaining to making spacecraft more trackable, this space object database would ideally become as comprehensive as possible.

Presumably, with a comprehensive space object database at hand, the UN Sustainability Guidelines would aid facilitation of "develop[ment] and implement[ation]" of appropriate "approaches to and methods for conjunction assessment during all orbital phases of controlled flight."[406] Although, gain invoking Art. VI of the OST, the Guidelines further advise "States should encourage entities, including spacecraft operators and conjunction assessment service providers under their jurisdiction and/or control to perform conjunction assessments through national mechanisms, when applicable."[407] "National mechanisms" could be interpreted as via regulatory oversight or use of a domestic space object database, but this matter will not be discussed within the scope of this paper.

Additionally, the fact that the UN Sustainability Guidelines recognizes the importance of raising awareness of the "important societal benefits of space activities and of the consequent importance of enhancing the long-term sustainability of outer space activities" places an emphasized note on how critical it is that we protect our space environment.[408] Some of the industries used in everyday life that rely on space infrastructure are examined and how catastrophic a loss of space-based capability could be. Thus, the more the public understands the cruciality of keeping our orbital environment clean, ideally, the more steps we would want to take to protect it.

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[405] UN Sustainability Guidelines , 11.
[406] UN Sustainability Guidelines, 11.
[407] UN Sustainability Guidelines, 11.
[408] UN Sustainability Guidelines, 18.

An overarching point to be taken from the UN Sustainability Guidelines is the fact that it encourages States to "[i]nvestigate and consider new measures to manage the space debris population in the long term," which could include extending operational lifetime of a spacecraft (such as via OOS or Northrop Grumman's Mission Extension Pods), novel techniques to prevent collision with… debris" and other space objects, and "advanced measures" for post-mission disposal" (such as with a dragsail or being shepherded to a graveyard orbit).[409] Further, if a State has greater "technical and other relevant capabilities" at its disposal, the "greater the emphasis that State should place on implementing the guidelines to the extent feasible and practicable."[410] On the other hand, "States without such capabilities are encouraged to take steps to develop their own capacity to implement the guidelines," but are also encouraged to collaborate internationally.[411]

Together, the UN Sustainability Guidelines are comprised of much content that makes up long-existing treaties, policies, and guidelines, but they are certainly not irrelevant. Several of these Guidelines, especially those regarding facilitating how SmallSats and developing entities address space sustainability, make appearances in the US FCC satellite licensing regulatory requirements, thus fulfilling Guideline A.3 and several other UN Sustainability Guidelines.

United States Law, Policy, and Licensing

United States Legislation

The subject of orbital debris is addressed in the United States Code: 51 U.S.C. § 31501 (2017) and in 2015's Commercial Space Launch Competitiveness Act (CSLCA). 51 U.S.C. § 31501 states "[t]he Administrator, in conjunction with the heads of other Federal agencies, shall

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[409] UN Sustainability Guidelines , 20.
[410] UN Sustainability Guidelines , 3.
[411] UN Sustainability Guidelines, 3.

take steps to develop or acquire technologies that will enable the Administration to decrease the risks associated with orbital debris."[412] "The Administration" refers to NASA, and "[t]he Administrator" refers to the Administrator of NASA.[413] This language does not set forth specific law pertaining to orbital debris mitigation or remediation techniques; only that NASA and other agencies are required to take steps to enable NASA to decrease orbital debris risk. Other agencies, such as the Federal Communications Commission (FCC) and Federal Aviation Administration (FAA), are not mentioned in this legislation, which was passed in December 2010.

However, the CSLCA directs NASA, along with the Secretary of Transportation, the Chair of the FCC, the Secretary of Commerce, and the Secretary of Defense to "enter into an arrangement with an independent systems engineering and technical assistance organization to study alternative frameworks for the management of space traffic and orbital activities."[414] To be included in the study were assessments of best practices, current authorities, STM and orbital debris requirements, existing assets and capabilities to conduct STM and SSA, risk associated with SmallSat launches, existing private sector information sharing activities associated with SSA and STM, and recommendations. [415]

In 2016, the FAA Office of Commercial Space Transportation (AST) issued its mandatory report to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives.[416] The findings were as follows: the FAA AST, with additional legislative authority, could provide SSA

[412] Pub. L. No. 111-314, 124 Stat. 3377 (2010).
[413] Pub. L. No. 111–314, 124 Stat. 3329 (2010).
[414] Commercial Space Launch Competitiveness Act of 2015, Pub. L. No. 114-90, 129 Stat. 708 (2015).
[415] Commercial Space Launch Competitiveness Act of 2015, Pub. L. No. 114-90, 129 Stat. 708-709 (2015).
[416] Federal Aviation Administration, *SSA Feasibility Study (CSLCA Section 110 Report)*, August 12, 2016, https://www.faa.gov/about/office_org/headquarters_offices/ast/media/3_section_110_report_summary.pdf.

data and information to commercial, civil, and foreign entities when not inherently military in nature; the information provided for would include, conjunction assessments, collision avoidance support, and emergency close approach notifications; statutory authority would be required to authorize a civil agency to release safety-related SSA data and information to any entity consistent with the national security and public safety interests of the United States; the Department of Defense (DOD) will continue to maintain capabilities, collect data, and maintain a master object catalog as well as conduct any operations necessary to maintain national security; and pursuant to the 2010 National Space Policy, all departments and agencies will share their capabilities, specifically SSA data and expertise as available, to assist each other in the accomplishment of the space safety mission.[417]

If the FAA Report's recommendations are authorized and put in place, they provide solid groundwork in building solutions to the orbital debris issue. Currently, there are several U.S. entities that are stakeholders in STM, including the DOD, National Oceanic and Atmospheric Administration (NOAA), NASA, the FCC, and the FAA.[418] The development of one "store-front" as a source for all SSA/STM information would combine the interests of the stakeholders and streamline the process for requesting data, thus making it easier for satellite owner/operators to conduct avoidance maneuvers.

The "store-front" in concert with a more comprehensive debris tracking system, such as Space Fence, would facilitate a better "warning system" for potential conjunctions, and would enable the U.S. to fulfill its obligation to the OST in engaging in consultation regarding avoidance maneuvers if there is potential for the activity to be "harmful."

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[417] Federal Aviation Administration, *SSA Feasibility Study*, August 12, 2016.
[418] Hunter, 8.

Removing current SSA/STM operations away from 18 SCPS would relieve it of the burden and allow it to resume focus on their national defense responsibilities. Additionally, the DOD would maintain authority over national defense-related spacecraft so as not to jeopardize national security. Such domestic framework could, according to Jah, allow the U.S. to "step up as leaders and provide a meaningful solution for others to join and follow" in developing a more comprehensive orbital debris management regime.[419]

Further, regarding ADR and OOS, international legal and political issues remain, but as mentioned above, technological demonstrations of these remediation methods are already occurring. Further research into domestic policy specifically pertaining to and licensing of commercial ADR and OOS activity is recommended.

CSLA

In 1984, Congress enacted the CSLA "to promote economic growth and entrepreneurial activity through use of the space environment for peaceful purposes."[420] The CSLA contains requirements pertaining to liability, insurance, and cross-waivers between entities party to launch/reentry activity. Specifically, an entity that has been granted a license to conduct launch/reentry activity shall

> obtain liability insurance or demonstrate financial responsibility in amounts to compensate for the maximum probable loss from claims by—
> (A) a third party for death, bodily injury, or property damage or loss resulting from an activity carried out under the license; and
> (B) the United States Government against a person for damage or loss to Government property resulting from an activity carried out under the license.[421]

Further, currently, "a licensee or transferee is not required to obtain insurance or demonstrate financial responsibility of more than" $500,000,000 in the event of a claim from "a

[419] *Statement*, 3.
[420] 51 USC, Commercial Space Launch Activities, 2010, § 50901.
[421] 51 USC, Commercial Space Launch Activities, 2010, § 50914 (a)(1).

third party for death, bodily injury, or property damage or loss resulting from an activity carried out under the license," and $100,000,000 in the event of a claim from "the United States Government against a person for damage or loss to Government property resulting from an activity carried out under the license."[422] Reciprocal waivers of claim, or "cross-waivers," are required between "applicable parties involved in launch services or reentry services under which each party to the waiver" essentially indemnifies the other for "personal injury to, death of, or property damage or loss sustained by it or its own employees resulting from an activity carried out under the applicable license."[423]

Further, the U.S. Government shall pay a successful claim "of a third party… resulting from an activity carried out under the license issued or transferred under this chapter for death, bodily injury, or property damage or loss" provided that the claim is either "(A) more than the [required] amount of insurance or demonstration of financial responsibility," or "(B) not more than $1,500,000,000… above that insurance or financial responsibility amount," plus any additional amounts that account for inflation."[424]

If the third party that sustained damage is a US-based spacecraft and the inflicting party is also in the US, the parties would seek remedy in the US court system. This factor comes into play in the discussion of third-party liability insurance discussed in the Space Insurance section of this paper.

United States National Space Policy

The National Space Policy of the United States of America of 2010 (US Space Policy) provides guidelines on minimizing space debris, including: leading continued development and

[422] 51 USC § 50914 CSLA (a)(1).
[423] 51 USC § 50914 CSLA (a)(5).
[424] 51 USC § 50915 CSLA (a).

adoption of international and industry standards to minimize debris; using SSA information to identify space activity that is "contrary to responsible use and the long-term sustainability of the space environment;" continuing to follow the US Government Orbital Debris Mitigation Standards; pursuing development of technology to "mitigate and remove on-orbit debris, reduce hazards, and increase understanding of the current and future debris environment," as well as work to foster development of space collision warning measures.[425] In concert with the FAA's recommendations in its above-referenced report, these guidelines provide solid groundwork for a domestic orbital debris solution. It should be noted that policy is not law, however, so further research into methods for holding parties accountable for actions contrary to the preservation of the space environment is recommended.

SPD3

While SPD3 lays a strong framework, as of the time of this writing, we have (arguably) only just begun to pave a solid path toward a solution for managing space traffic – domestically and globally. SPD3 sets forth nine goals to create "the conditions for a safe, stable, and operationally sustainable space environment," and direct the U.S. to continue to serve as a leader in those endeavors. The nine goals are as follows:

1) Advance SSA and STM Science and Technology ("S&T");
2) Mitigate the effect of orbital debris on space activities;
3) Encourage and facilitate U.S. commercial leadership in S&T, SSA, and STM;
4) Provide U.S. Government-supported basic SSA data and basic STM services to the public;
5) Improve SSA data interoperability and enable greater SSA data sharing;
6) Develop STM standards and best practices;
7) Prevent unintentional radio frequency ("RF") interference;
8) Improve the U.S. domestic space object registry; and
9) Develop policies and regulations for future U.S. orbital operations.[426]

[425] National Space Policy of the United States of America. (2010, June 28). Retrieved from https://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf.

[426] *SPD3*, 5.

For ease of reference, each of the above goals may be categorized into one or more of the above-referenced key areas of STM (mitigation of orbital debris and best practices to prevent it, advancement of SSA, greater sharing of SSA data, monitoring and tracking of space objects, and prevention of conjunctions and collisions). Additionally, SPD3 points to U.S. commercial industry to help advance STM and SSA S&T, and charges the U.S. to continue its leadership in these areas by developing and integrating policies, regulations, guidelines, and best practices, and by providing examples to set the standard in global engagement with regard to STM.

The SPD3 Guidelines flow from the SPD3 Goals, and just as each Goal can be categorized, each SPD3 Guideline can fall into a similar "bucket" accordingly. The SPD3 Guidelines are outlined as follows:

1) Managing the Integrity of the Space Operating Environment
    a. Improving SSA coverage and accuracy
    b. Establishing an Open Architecture SSA Data Repository
    c. Mitigating Orbital Debris
2) Operating in a Congested Space Environment
    a. Minimum Safety Standards and Best Practices
    b. On-Orbit Collision Avoidance Support Service
3) Strategies for Space Traffic Management in a Global Context
    a. Protocols to Prevent Orbital Conjunctions
    b. Radio Frequency Spectrum and Interference Protection
    c. Global Engagement

United States Orbital Debris Mitigation Standard Practices

In the United States, alongside SPD3, the ODMSP (last updated November 2019) provides exactly that: best *practices* for STM overall, but, as its name makes clear, mainly addressing orbital debris. The revised ODMSP "includes improvements to the original objectives as well as clarification and additional standard practices for certain classes of space operations," namely quantitative and probability limits on "debris released during normal operations… accidental explosions… and successful postmission disposal."[427] The ODMSP also incorporates language for best practices for constellations, "rendezvous and proximity operations, small satellites, [and] satellite servicing," meaning the US Government is prepared, at least within the scope of these guidelines, for OOS and other rendezvous activities to occur.[428] The ODMSP consists of five objectives, a few of which have been incorporated by the aforementioned 2019 revision: 1. control of debris released during normal operations; 2. minimizing debris generated by accidental explosions; 3. selection of safe flight profile and operational configuration; 4. postmission disposal of space structures; and 5. clarification and additional standard practices for certain classes of space operations (including constellations, CubeSats, and OOS).[429]

The ODMSP considers a "constellation consisting of 100 or more operational spacecraft cumulative" a large constellation and should have a "probability of successful postmission disposal at a level greater than 0.9 with a goal of 0.99 or better."[430] The preferred disposal method for constellations is either direct reentry or placing the craft into a graveyard orbit.[431] For small craft (SmallSats, CubeSats, etc.), the ODMSP states they should follow each of the previous four objectives. Each of these classes of spacecraft should be subject to the "25-year rule," or "the limitation of how long a spacecraft may reside in LEO if there is a certain probability it may collide with another large object,"[432] which is currently 25 years. Further,

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[427] "Orbital Debris Mitigation Standard Practices" [hereinafter *ODMSP*], *U.S. Government*, November, 2019, https://orbitaldebris.jsc.nasa.gov/library/usg_orbital_debris_mitigation_standard_practices_november_2019.pdf.
[428] ODMSP.
[429] ODMSP.
[430] ODMSP.
[431] ODMSP.
[432] National Aeronautics and Space Administration, *Process for Limiting Orbital Debris*, NASA-STD 8719.14, December 8, 2011, revised November 5, 2021, https://standards.nasa.gov/standard/nasa/nasa-std-871914.

there are several other technical guidelines set forth in the ODMSP, but as they are technical in nature, they are considered beyond the scope of this paper.

SPD3, ODMSP, IADC SDMG, the UN Sustainability Guidelines, and USSP are intended to work in concert to manage space traffic, mitigate risk of spacecraft conjunctions or collisions, and plant the seed for future STM capabilities including OOS and ADR. As previously mentioned, many of these practices and guidelines have found their way into US regulatory requirements as in the case of the recently-amended FCC satellite licensing application process.

FCC Licensing Requirements for Launch of Spacecraft

The FCC requirements and application information to obtain a license operate a "space station," or satellite, on a frequency in the US are found in the US Code of Federal Regulations. 47 C.F.R. Subpart B sets forth application filing information, fees, and requirements for several types of satellite licensing, including a newer streamlined small non-geostationary (NGSO) satellite ("SmallSat") and craft that travel beyond Earth orbit.[433,434,435] Within the scope of this paper, 47 C.F.R. § 25.114: Applications for space station authorizations is examined. 47 C.F.R. § 25.114 not only sets requirements to submit technical frequency band information, public interest considerations, and broadcast operations information, but includes recently amended paragraph (d)(14) concerning orbital debris mitigation requirements.[436] The rule amendment, "Mitigation of Orbital Debris in the New Space Age," became effective on September 24, 2020, and contains a list of required information to be submitted with an entity's application, including: A narrative describing assessment and limitation of amount of debris released, both planned and

433 47 C.F.R. § 25.114 (2021).
434 47 C.F.R. § 25.122 (2021).
435 47 C.F.R. § 25.123 (2021).
436 47 C.F.R. § 25.114 (2021).

unplanned; probability of becoming a source of or causing debris; the operator's plans to avoid collisions; passivation and depletion of residual fuel at EOL.[437]

Importantly, during the commenting period prior to issuing the rule amendment, a discussion was had whether insurance should be one of the requirements to obtain an FCC license to operate a satellite within the US.[438] The FCC "sought comment on the utility of insurance on its own as a means to incentivize operators to adhere to best practices in space," and, specifically, whether "the ability to obtain lower insurance premiums could provide an economic incentive for operators to adopt debris mitigation strategies that reduce risk."[439] Based on comments received, the FCC determined that insurance, alone, "generally would not necessarily incentivize good behavior in space," and suggests insurance does not, by itself, "provide adequate incentives for debris mitigation," and thus it "decline[d] to adopt an insurance requirement on its own as a way of incentivizing 'good behavior' in space.[440] In her research, Harrington finds "[t]here exists a line of scholars in traditional insurance fields who argue insurance should never be mandatory, on the basis that not everyone accepts the moral assumptions of… responsibility for the well-being of others," which seems to reinforce the FCC's findings and ultimate determination that insurance should not be part of the licensing regulatory requirement.[441]

However, the FCC states they "seek comment in the Further Notice on whether a rule regarding indemnification will help to ensure that liability is considered as operators make

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[437] Mitigation of Orbital Debris in the New Space Age, Fed. Reg. 52,422 (Aug. 25, 2020) (to be codified at 47 C.F.R. pts. 5, 25, and 97).

[438] "Mitigation of Orbital Debris in the New Space Age," *FCC*, August 25, 2020, https://www.federalregister.gov/documents/2020/08/25/2020-13185/mitigation-of-orbital-debris-in-the-new-space-age.

[439] "Mitigation of Orbital Debris in the New Space Age," *FCC*, August 25, 2020.

[440] "Mitigation of Orbital Debris in the New Space Age," *FCC*, August 25, 2020.

[441] Harrington, 36.

decisions concerning satellite design and operation," which leads this author to believe such a rule pertaining to indemnification and liability is, in fact, going to come to fruition, whether specifically incorporating language regarding insurance or not.[442]

Other Policy Initiatives

Space Sustainability Rating

In 2018, the World Economic Forum launched an initiative in which four entities – ESA, Massachusetts Institute of Technology (MIT), University of Texas at Austin, and Bryce Space and Technology – "formed a consortium to design a rating able to encourage behaviours that are more responsible by promoting mission designs and operational concepts that are compatible with a stable evolution of the environment."[443] The "Framework for the Space Sustainability Rating" paper presented at the European Conference on Space Debris in April 2021 states the proposed rating system "does not want to create a new set of guidelines, but rather to recognize positive behaviours such as compliance with mitigation guidelines and efforts that go even beyond those recommendations."[444] The Framework notes in this iteration, it does not address economic aspects of the rating system (among other categories), but that it will be an evolving system as changes in the space environment occur.[445] As an illustration of how the rating system might function, the Framework provides an example set of statements and scores pertaining to the aspect of coordination for collision avoidance. An owner/operator would appropriately respond to the following questionnaire regarding its/their "capabilities to identify, respond to, and mitigate collisions:"

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[442] Mitigation of Orbital Debris in the New Space Age," *FCC*, August 25, 2020.

[443] F. Letizia, S. Lemmens, D. Wood, M. Rathnasabapathy, M. Lifson, R. Steindl, K. Acuff, M. Jah, S. Potter, and N. Khlystov, "Framework for the Space Sustainability Rating," *Proc. 8th European Conference on Space Debris*, April, 2021. Accessed March 12, 2022 [hereinafter, "Framework"]. https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/95/SDC8-paper95.pdf.

[444] Framework.

[445] Framework.

- None (0 points) Not able to coordinate;
- Low (2 points) Able to coordinate in response to emergencies (but not necessarily on a routine basis);
- Medium (3 points) Able to coordinate during set hours per day;
- High (4 points) Has a system for routine conjunction assessment and capability to respond to concerns 24 hours per day via human or computer system capable of supporting near-immediate coordination and reaction for urgent issues.[446]

Additionally, "[t]here will be 'bonus marks' for adding optional elements, such as grappling fixtures, that could be used for the possible future active removal of debris."[447] This rating would be similar to "energy, efficiency, and nutrition labels now common on household items, food products, and consumer goods," and will ideally transparently show how well spacecraft owner/operators are adhering to STM policies, guidelines, and best practices.[448] Overall, the idea is to spark competition between them "[b]y voluntarily joining the new SSR system, spacecraft operators, launch service providers and satellite manufacturers will be able to secure one of four levels of certification that they can advertise widely to demonstrate their mission's commitment to sustainability."[449]

Most pertinent to this research, in theory, the rating system will

> increase transparency – without disclosing any mission-sensitive or proprietary commercial information – and is expected to incentivise good behaviour by other stakeholders in addressing the problem of space debris. A favourable score for a particular rated operator might, for example, result in lower insurance costs or improved funding conditions from financial backers.[450]

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[446] Framework.

[447] ."Space sustainability rating to shine light on debris problem," *The European Space Agency*, June 17, 2021, https://www.esa.int/Safety_Security/Space_Debris/Space_sustainability_rating_to_shine_light_on_debris_problem.

[448] "Space sustainability rating," *The European Space Agency*, June 17, 2021.

[449] "Space sustainability rating," *The European Space Agency*, June 17, 2021.

[450] "Space sustainability rating," *The European Space Agency*, June 17, 2021.

"The SSR aims to influence behaviour by all spaceflight actors, especially commercial entities, and help bring into common usage the sustainable practices that we desperately require," said Holger Krag, Head of ESA's Space Safety Programme.[451] Especially with regard to commercial entities, the rating system could incentivize best STM practices by sparking competition for high sustainability ratings, especially if the aforementioned "bonus points" are awarded for implementation of technology such as ADR capability.[452]

The first sustainability certifications were to have begun to be issued in early 2022 by EPFL Space Center (eSpace), but at time of writing, information that confirms that to be the case could not be located.[453] The rating system was in development for two years prior to the announcement in 2021 that it had made it to its next phase. This rating system could be an excellent method to incentivize best STM practices, and in concert with existing guidelines, may even be one of the methods of creating a form of governance. However, more information is needed regarding its current status and rollout, and timing and schedule. If time is still needed for the rating system's rollout, there may be opportunity for other methods of encouraging entities to implement these best practices.

As stated above, while these guidelines and best practices essentially have the same goals, and several very significant steps have been taken in just the past four years (more so, perhaps, than had been in the prior decade), STM efforts pursuant to policy have not been realized as much as we might like. Finding solutions that will meet each goal is difficult and complex. For example, a State or private organization with greater financial ability and

[451] "Space sustainability rating," *The European Space Agency*, June 17, 2021.

[452] "Space sustainability rating," *The European Space Agency*, June 17, 2021.

[453] Madeleine Hillyer, "New Space Sustainability Rating Addresses Space Debris with Mission Certification System," *World Economic Forum*, June 17, 2021, https://www.weforum.org/press/2021/06/new-space-sustainability-rating-addresses-space-debris-with-mission-certification-system.

resources to address STM issues, even if the entity were not acting dubiously, might be seen as placing its own interests ahead of focusing on solving the problem for the greater good. Turning to governance matters, it may be preferable that one entity is responsible for providing standard policies, guidelines, and best practices in the multiple facets of STM to prevent fragmented and arguably, in some cases, ineffective and out-of-date guidelines flowed down from governments, agencies, and organizations. Other than the aforementioned policies and regulations, though, there is another potential solution for governance, at least in the shorter-term while legislative and regulatory requirements begin to gel.

Insurance as Governance

As discussed above, incentivization is a key part of this research regarding how P&I clubs could provide said incentive to commercial spacecraft owner/operators where there may be gaps in traditional insurance. The fact that an insurance contract could, in part, govern how space entities operate in tandem with P&I club coverage that would theoretically fill in third-party liability gaps arguably provides a comprehensive foundation for best STM practices."[454] Harrington states best STM practices could be used as a way to earn conventional space insurance premium discounts or other benefits for a high rating in, say, the SSR.[455] Potentially, these best STM practices could become a requirement as part of an insurance policy which would be enforced by the policy as a contract.[456] The opposite approach could also be used – a fee could be assessed to a spacecraft owner/operator's premium if the owner/operator does not adhere to best STM practices.[457] Both approaches could achieve the same end by using either an

[454] Hillyer, "New Space Sustainability Rating," *World Economic Forum*, June 17, 2021.
[455] Harrington, 15.
[456] Harrington, 15.
[457] (Chris Kunstadter, pers. comm., February 21, 2022)

incentive or disincentive to enforce good behavior in managing space traffic, thus helping ensure sustainability of our space environment.[458]

Revisiting Article IX of the OST, Harrington states pursuant to Article IX, States should "act with 'due regard' for the space activities of other States," including "private enterprises," and to avoid harmful interference to those space activities. Further, Harrington states, the "due regard" in avoiding harmful interference includes that pertaining to outer space as well as Earth. Thus, Art. IX "further contributes, albeit weakly, to the liability regime by creating a standard of care owed to other States and a basis for environmental requirements."[459]

Pursuant to the CSLA, the U.S. (among many other States) "require[s] private entities to indemnify [it] and to carry particular levels of third-party liability insurance."[460] Thus, "there is an obvious need for the availability of insurance for space activities."[461] However, Harrington theorizes "[c]urrent insurance availability is not optimal for the encouragement of this industry, and must be further developed in light both of the legal regime and the unique risks inherent to outer space."[462]

In terms of risk, Harrington states "risk society can be viewed as an expansion of choice that comes along with technological advancement… we have sufficient knowledge and understanding to act with a precautionary attitude," as discussed in Wetherbee's comments in the Overview of Risk section of this paper.[463] Thus, Harrington suggests, "[o]ne suggestion is that the most effective way to deal with growing manufactured risks is through the precautionary principle."[464] The precautionary principle is "'when an activity raises threats of harm to human

[458] (Chris Kunstadter, pers. comm., February 21, 2022).
[459] Harrington, 9.
[460] Harrington, 9.
[461] Harrington, 9.
[462] Harrington, 9.
[463] Harrington, 9.
[464] Harrington, 27.

health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically.'"[465] The statement goes on to list four central components of the principle: taking preventive action in the face of uncertainty; shifting the burden of proof to the proponents of an activity; exploring a wide range of alternatives to possibly harmful actions; and increasing public participation in decision making."[466]

Expanding upon the precautionary principle, Harrington states "[i]n an era where threats are beyond appropriate compensation… precaution is achieved through prevention," and those preventive measures should be applied "where an activity could cause harm."[467] Therefore, it "would remain most viable" (and this author goes a step further and states the industry would *continue to grow more* viable) "via constant moving forward of technologies and techniques for managing risks."[468] Some examples of developing technologies include methods described above in the Space Sustainability Rating section and described later in the Technical Capability to Adhere to STM Practices.

These preventive measures, Harrington states, come "with the ability to understand risks and their probability; it requires a certain confidence in the existing knowledge," and this author again refers to existing knowledge within the aforementioned policies, guidelines, and regulations.[469] Harrington theorizes

> if the statistical probability of a collision with an individual insured space object is sufficiently low, it may not be considered worthwhile from an insurance perspective to implement more

[465] David Kriebel, Joel Tickner, Paul Epstein, John Lemons, Richard Levins, Edward L. Loechler, Margaret Quinn, Ruthann Rudel, Ted Schettler, and Michael Stoto, "The Precautionary Principle in Environmental Science" [hereinafter *The Precautionary Principle*], *Environmental Health Perspectives*, 109, no. 9 (2001): 871, accessed March 13, 2022, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1240435/pdf/ehp0109-000871.pdf.
[466] The Precautionary Principle, 871.
[467] Harrington, 27.
[468] Harrington, 38.
[469] Harrington, 29.

> substantial debris mitigation requirements, even if they would be beneficial for the sustainability for the space environment.[470]

For example, as stated in the space sustainability rating framework, "[o]ne can observe how CubeSat missions have low associated risk, but are penalised by the lack of collision avoidance capabilities" (see Figure 2 in the Charts and Graphs addendum to this paper).[471]

It can be surmised that Harrington not only argues insurance can be a form of quasi-governance, but in fact incorporates many of the practices and policies previously discussed in the Relevant International Treaties and other pertinent guidelines. Outside of sometimes being legally mandated, "[i]nsurance… is often required as part of a private contract. When standards of insurance in certain types of contracts deals become near-universal, it is no longer relevant that the insurance is not legally mandated."[472] Thus, the insurance contract, itself, especially one that incorporates the above-referenced policies and guidelines, could, itself, serve as governance.

The above international treaties and conventions; U.S. domestic laws, regulations, and policies; and other initiatives and best practices contain several similar, if not identical, guidelines and intents. In the U.S., the CSLA sets forth legislation under which a U.S. entity that seeks a launch/reentry license must obtain insurance or demonstrate financial ability to pay a potential claim if it inflicts harm on another State's spacecraft (or crew), and the U.S. Government will pay that claim over the required amount of insurance but not more than $1,500,000,000.00. However, as discussed above, the CSLA only applies when a U.S. entity inflicts damage on another State, and only applies to launch/reentry activity. Thus, there are two gaps that could need to be filled with liability solutions for the rapidly growing commercial space industry. Potential space P&I club membership could be one of the solutions to fill these

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[470] Harrington, 39.
[471] Framework.
[472] Framework.

gaps. Using The American Club's covered incidents as an analogue, third-party liability coverage could be provided to a member and the potential space P&I club could pay the third-party claim whether the harmed party were another U.S. entity or a different State.

Further, while the USSP and SPD3 are not binding law, they both set forth STM goals and guidelines to follow when conducting space activity, such as cooperation between government, industry, and academia to develop technology to facilitate STM as well as best STM practices. But similar guidelines have become regulations in the FCC's satellite licensing application process which requires entities seeking an FCC license to show how it will work to mitigate orbital debris. The process sets forth technical specifications commercial entities should strive to meet. Information on what would happen to an entity's license if it becomes non-compliant with the FCC's regulations was not readily available at the time of writing, but should be studied for future research.

However, if a commercial space entity is striving to meet the licensing requirements (and other existing laws, policies, and guidelines), and the costs of its spacecraft increase due to implementation of STM technology, presumably, that spacecraft's value could increase, which, in turn, could potentially increase the premium cost of a conventional insurance policy. This policy may not include third-party liability coverage. As costs to entity increase, third-party liability coverage from a conventional space insurer may seem too costly. Based on this example, a potential space P&I club membership could help this entity acquire third-party liability coverage (plus the additional benefits of a P&I club) at a significantly lower cost for a call. The potential space P&I club member could receive the benefit of P&I coverage, and the club could include the member in its self-monitoring. As previously discussed, the club could facilitate tracking and monitoring as it is in the interests of all members to keep premiums, calls, and/or risks low.[473] Again, risk-sharing (specifically in P&I club membership) could be appealing to actors who are developing innovative technology where risks may be best identified and assessed by the actors themselves.[474]

As Thornton states, a potential space P&I club membership, in and of itself, is not likely to drive adherence to laws, regulations, policies, and guidelines. The club membership could be part of a bigger picture of STM activity that may provide an avenue to help relieve space entities' risk and cost burden of either trying to acquire conventional insurance not within its financial reach or conducting risky behavior and acting in space without coverage. Thus, it can be argued that yes, a potential space P&I club could provide a benefit to members' adherence to existing laws, regulations, policies, and guidelines.

Technological Response to STM Policies and Guidelines

Several companies are already responding to the calls for implementation of STM capabilities, whether out of necessity or as a best practice. In response to NASA's concern regarding Starlink, SpaceX released a statement on its website in February 2022, saying its satellites "have demonstrated reliability of greater than 99%," and "use multiple strategies to prevent debris generation in space," including "design for demise, controlled deorbit to low altitudes," low operating orbit and orbit insertion (below 600 km), "[an] on-board collision avoidance system," and reducing the chance of impact with small debris and risk of explosion."[475] The satellites are also "propulsively deorbited within weeks of their end-of-mission-life." Many of these strategies align with regulation, policy, and guidelines as discussed

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[473] Liu and Faure, 257.
[474] Liu and Faure, 257.
[475] "SPACEX'S APPROACH TO SPACE SUSTAINABILITY AND SAFETY," *SpaceX*, February 22, 2022, https://www.spacex.com/updates/index.html.

above.[476] Additionally, SpaceX states it "holds itself to higher standards than even those proposed by the FCC by de-orbiting its satellites within five to six years, instead of after 25 years — a process SpaceX called 'outdated,'" a sentiment also shared by several industry experts.[477,478,479]

OneWeb, another space company operating a large constellation (and competitor to SpaceX), details several of its initiatives for STM and space sustainability. According to its website,

> Responsible space… is the term OneWeb uses to describe practices that drive sustainability within the space industry, avoiding harming our lower Earth orbit (LEO) environment while developing this new frontier in… connectivity, so that it works for, and benefits, generations to come.[480]

Facets of OneWeb's mission statement pertaining to Responsible Space are threefold: 1) Employing Responsible Design and Operational Practices; 2) Developing the Space Ecosystem; and 3) Supporting Policy Outcomes through Collaboration.[481]

Noteworthy actions coming from OneWeb's Responsible Space initiative are the fact that it is working with 18 SPCS and other companies "to advance the state-of-the-art in SSA," developing "industry best practices that promote space environmental stewardship and sustainable space activities," advocating for "the adoption of sensible, internationally-

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[476] "SPACEX'S APPROACH TO SPACE SUSTAINABILITY," *SpaceX*, February 22, 2022.

[477] Grace Kay, "SpaceX responds to NASA's concerns over Starlink collisions in outer space: 'The reliability of the satellite network is currently higher than 99%,'" *Business Insider*, February 24, 2022, https://www.businessinsider.com/spacex-responds-to-nasa-concerns-starlink-satellite-collisions-in-space-2022-2.

[478] (Chris Kunstadter, pers. comm., February 21, 2022)

[479] (Charles Thornton, pers. comm., March 18, 2022)

[480] "#ResponsibleSpace: OneWeb's commitment to sustainability in space," *OneWeb*, accessed March 20, 2022, https://assets.oneweb.net/s3fs-public/assets/documents/OneWeb-Responsible-Space-Brochure.pdf?VersionId=tHc8CuB1W3JpVHulFaAKyqGiFqp1QcAs.

[481] "#ResponsibleSpace: OneWeb's commitment to sustainability in space," *OneWeb*.

coordinated space environmental policies into national licensing frameworks," and is a part of the Space Sustainability Rating system.[482]

OneWeb's technological part of the initiative regarding its Responsible Design and Operational Practices states it selected its "launch and operational orbits… to avoid the most populated regions of LEO," its "constellation configuration virtually eliminates the possibility of intra-constellation collisions," and it also "goes above and beyond" the FCC licensing requirement and states it will deorbit its satellites "within five years of decommissioning," further reinforcing the belief that the 25-year rule is outdated.[483] This said, OneWeb is very actively working to implement the STM policies, guidelines, and best practices to facilitate long-term space sustainability.

Additionally, OneWeb announced it is "is including a grappling fixture on every one of its satellites to facilitate capture in the event that retrieval should become necessary."[484] The DogTag grappling fixture is universal, so it is ideally versatile and could work with many different types of satellites with varying sizes and masses.[485] The company admits cost is a "formidable challenge" in an ADR endeavor, and it "remains to be seen whether mission architectures and business models can… support [attractive] price points to commercial operators, or whether ADR is destined to be a service only governments can afford."[486] OneWeb states "[t]o be commercially feasible… ADR… has to represent a positive value proposition for its customers, and it is not yet clear what ADR services will cost, nor even who the principal

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[482] "#ResponsibleSpace: OneWeb's commitment to sustainability in space," *OneWeb*.

[483] "#ResponsibleSpace: OneWeb's commitment to sustainability in space," *OneWeb*.

[484] Timothy Maclay, Jonathan Goff, J.P. Sheehan, and Earl Han, "The development of commercially viable ADR services: introduction of a small-satellite grappling interface," *OneWeb*, accessed March 20, 2022, https://assets.oneweb.net/s3fs-public/assets/documents/IOC-Paper_ADR_Final.pdf?VersionId=sCaOpPjSI7bQm5K6K.MddWuv81DKS7o1?VersionId=sCaOpPjSI7bQm5K6K.MddWuv81DKS7o1.

[485] Maclay, Goff, Sheehan, Han, "The development of commercially viable ADR services," *OneWeb*.

[486] Maclay, Goff, Sheehan, Han, "The development of commercially viable ADR services," *OneWeb*.

customers will be."[487] Of note, a cost analysis of a simulation of a potential OOS mission is presented, and while not specifically ADR, the cost came to approximately $395.8 million, which, in this author's prior research, was not a commercially viable STM solution at the time, even for some of the largest commercial communications satellite operators. However, OneWeb is collaborating with "governments and industry on creative ADR mission concepts with an aim to minimize the deorbit cost per satellite," positing one ADR mission may need to retrieve several satellites for the service to be commercially viable for a client.[488] Further, some "proposals for how ADR services may be packaged" include "pay-per-mission" and missions involving insurance coverage, though OneWeb does not provide details on what this insurance coverage would look like.[489] A simulated cost of what an OOS mission using a grappling technique might look like is presented in the Potential Cost section of this paper. OneWeb's financial information will also be discussed in the Cost section of this paper.

In addition to OneWeb's initiatives, there are currently several other technological practices in place to prevent new pieces of space debris from entering orbit or prolonged residences of space debris already in orbit. Some of these include the "25-year rule," the use of graveyard orbits, and passivation.[490] "Graveyard" or "parking" orbits refer to orbits outside the realm of where functional satellites operate, such as an area above geosynchronous orbit. Passivation is a spacecraft end-of-life process that includes "depressurizing all storage tanks to avoid explosion."[491]

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[487] Maclay, Goff, Sheehan, Han, "The development of commercially viable ADR services," *OneWeb*.
[488] Maclay, Goff, Sheehan, Han, "The development of commercially viable ADR services," *OneWeb*.
[489] Maclay, Goff, Sheehan, Han, "The development of commercially viable ADR services," *OneWeb*.
[490] Percy and Landrum, 27.
[491] Percy and Landrum, 23.

ADR has also now been successfully demonstrated on orbit. On January 22, 2022, China conducted a maneuver wherein one of its satellites grappled another of its satellites on GEO, acting as a "space tug" and towed it out of its orbital slot.[492] The mission was classified, but ExoAnalytics, a commercial space monitoring company, provided details of the maneuver, stating Chinese satellite SJ21 "went absent from its orbital slot for several hours" after performing "close proximity operations with the defunct CompassG2 satellite," including docking and pulling CompassG2 out of GEO.[493]

As previously discussed, the size of orbital debris can be broken down into three categories: small, medium, and large. Large objects may be catalogued and tracked, namely by USSTRATCOM, and placed in its catalog of known orbital objects.[494] It is possible for very small objects to be shielded against, but small- and medium-sized debris presents a serious problem because it cannot be tracked nor can spacecraft be shielded from it.[495] Because this size of debris cannot be tracked, "operators cannot perform collision avoidance maneuvers like they can when two large objects are predicted to collide."[496] It is possible for this debris to be lethal to a mission, but even if the spacecraft (or crew) is not lost, functionality may be severely hindered. For example, communications or navigational capabilities may be disrupted.[497]

Additionally, while USSTRATCOM is not the only provider of data regarding the status of orbital debris, it arguably has the most comprehensive database; under 10 US Code § 2274, 18 the DOD is allowed to perform functions such as sending potential conjunction notifications to commercial satellite owner/operators, but as the possibility of collisions increases due to the

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[492] Evan Gough, "A Chinese space tug just grappled a dead satellite," *Phys.org*, February 2, 2022, https://phys.org/news/2022-02-chinese-space-grappled-dead-satellite.html.

[493] Gough, "A Chinese space tug just grappled a dead satellite," February 2, 2022.

[494] *Statement*, 3.

[495] Slann, 40.

[496] Percy and Landrum, 25.

[497] Pease and Jah.

aforementioned increase in space activity, it is becoming increasingly overburdened, which is inhibiting its ability to perform its traditional national defense responsibilities.[498,499]

A major problem in space object tracking and monitoring is the fact that data are not shared communally and/or globally.[500] As discussed, national security, intellectual property, and international regulations are inherently classified and/or confidential and should not be shared, but the more actors conducting tracking and monitoring activity, the more we can manage space traffic and identify and assess risk of a potential problem, such as a collision."[501]

Samoa, close to where Tiangong-1 entered Earth's atmosphere, is approximately 3369 km from the Kwajalein Atoll in the Marshall Islands, where Lockheed Martin constructed its Space Fence, which became operational in March 2020.[502] Space Fence is a ground-based space surveillance phased array radar system, and "is a key contributor to USSF's Space Domain Awareness… which provides information that Space Force needs to make informed decisions and take actions to protect key assets in orbit."[503] The technology improves space traffic monitoring, tracking, conjunction assessment, and collision avoidance.

A critical point highlighted by Jah and Hunter is the fact that USSTRATCOM/JspOC (now 18 SPCS) had already been overburdened by maintaining its database of "resident space objects" (RSOs). Hunter explained at the time, when Space Fence became operational, the number of catalogued items would increase "from the tens-of-thousands to the hundreds-of-thousands range and current processing systems and manpower would be quickly overcome by

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[498] Hunter, 9.

[499] *Statement*, 3.

[500] *Statement*, 7.

[501] Caleb Henry, "Space situational awareness experts urge Russia to join orbital neighborhood watch," *SpaceNews*, March 16, 2018, http://spacenews.com/space-situational-awareness-experts-urge-russia-to-join-orbital-neighborhood-watch/.

[502] "Space Fence" [hereinafter *Space Fence*] *Lockheed Martin*, accessed March 13, 2022, https://www.lockheedmartin.com/en-us/products/space-fence.html.

[503] Space Fence.

the magnitude of data available to be analyzed."[504] More recently, it is reported that Space Fence will be "able to detect targets as small as about four inches in diameter (as opposed to the old 30-inch limit) and will expand the catalog of space debris tracked by the Space Command from about 23,000 objects to 200,000."[505] Currently, Lockheed Martin simply states "the catalog size is expected to increase significantly over time."[506]

Along with Steve Wozniak and Alex Fielding, Jah is one of the founders of Privateer Space, a company that monitors space traffic and orbital debris. Privateer's mission is to create a "data infrastructure that will enable sustainable growth for the new space economy," and enhance how space object data are collected and processed using its "proprietary graph technology."[507] The company has developed one of its first apps, Wayfinder, and has made it publicly available on its website. Wayfinder is "an open-access and near real-time visualization of satellites and debris in Earth orbit."[508] Privateer states it will enable "nations, policymakers, and private ventures to share space responsibly, for the benefit of humankind," through its "open and transparent platform."[509]

Another example of a spacecraft tracking company is LeoLabs, founded in 2016, which offers tracking and monitoring, collision avoidance, launch and early orbit, and space domain awareness data services for $2,500 per month for a 12-month subscription and $4,000 per month for a month-to-month subscription (with a required three-month minimum).[510] LeoLabs states it can track a CubeSat "as small as 0.25u," or 10 x 10 x 2.5 cm.[511] Notably, there is currently a

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[504] Hunter, 6.
[505] Roger Mola, "How Things Work: Space Fence," *Air & Space Magazine*, February, 2016, https://www.airspacemag.com/space/how-things-work-space-fence-180957776/#5V5W08gvTs7t5oaz.99.
[506] Space Fence.
[507] "What We're Doing," *Privateer*, accessed March 27, 2022, https://mission.privateer.com/#mission.
[508] "What We're Doing," *Privateer*.
[509] "What We're Doing," *Privateer*.
[510] "FAQs," *LeoLabs*, accessed March 27, 2022, https://leolabs.space/faqs/.
[511] "FAQs," *LeoLabs*.

constellation of satellites this size on-orbit – Swarm's SpaceBees are 0.25u, so the existing capability to track space objects this small is important. LeoLabs provides conjunction notifications "once per radar pass or multiple times per day," and for well-tracked objects, it "currently generates 20-60 [conjunction data messages] per conjunction event over an eight-day screening period," which will increase in frequency as the company adds more radars to its global network.[512]

Other capability to help address STM matters could be technology implemented into the spacecraft, itself. For example, a drag sail is a passive deorbiting device that is "compact, lightweight, and scalable," and "does not require any propellants or pressurants."[513] In 2016, the Space Flight Laboratory at the University of Toronto Institute for Aerospace Studies successfully conducted a technology demonstration of a drag sail device on the CanX-7 mission.[514] The drag sail was installed on the CanX-7 satellite and was observed to increase the decay rate of the spacecraft "from 0.5 km/year to 20 km/year."[515]

Another type of capability on-board a satellite is propulsion. A propulsion device could be installed on a satellite to adjust its attitude to help it deorbit faster and/or break up in Earth's atmosphere quicker, or theoretically move it to a graveyard orbit. However, it should be noted that most small spacecraft (i.e., CubeSats and SmallSats) do not carry on-board propulsion, making them unable to achieve graveyard orbits for decommissioning."[516] Propulsive devices' use "is still considered risky due to potential failure or malfunction of either the spacecraft… or

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[512] "FAQs," *LeoLabs*.

[513] Brad Cotten, Ian Bennett, and Robert E. Zee, "On-Orbit Results from the CanX-7 Drag Sail Deorbit Mission," *31st Annual AIAA/USU Conference on Small Satellites*, SSC17-X-06, 1, accessed March 27, 2022, https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=3672&context=SmallSat.

[514] Cotten, Bennett, and Zee, "On-Orbit Results from the CanX-7 Drag Sail Deorbit Mission."

[515] Cotten, Bennett, and Zee, "On-Orbit Results from the CanX-7 Drag Sail Deorbit Mission.".

[516] "State-of-the-Art Small Spacecraft Technology," *NASA*, NASA/TP—20210021263, October 2021, 347, https://www.nasa.gov/sites/default/files/atoms/files/soa_2021_1.pdf.

the propulsive capability itself."[517] Additionally, the spacecraft would still need "adequate attitude control capability… [which] requires continuous operation until the reentry takes place, making it inconvenient and costly for a small spacecraft mission."[518] The fact remains, though, that some industry experts state something like a propulsion device is strongly advised to be included as part of a spacecraft to perform in this way to adhere to STM/orbital debris mitigation regulations and policies.[519]

Other technological capabilities include OOS refueling and/or repairing missions, such as SpaceLogistics' MEV, MRV, and MEPs. The Mission Extension Vehicles, or MEV-1 and MEV-2, are active missions performing OOS to satellites running low on fuel in GEO, "taking over [their] attitude and orbit maintenance."[520] The MEVs are equipped with docking stations that are "compatible with nearly 80% of all GEO satellites on orbit today," and are intended to service multiple clients over their lifespans.[521] The Mission Robotic Vehicle, or MRV, will launch in 2024 and is intended to install Mission Extension Pods, or MEPs, but will provide expanded OOS based on its predecessors, the MEVs.[522] The MEPs are sold as products to spacecraft clients as life-extension devices for satellites that are running low on fuel, similar to clients of the MEVs.[523]

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[517] "State-of-the-Art Small Spacecraft Technology," NASA/TP—20210021263, October 2021, 347.
[518] "State-of-the-Art Small Spacecraft Technology," NASA/TP—20210021263, October 2021, 347.
[519] (Chris Kunstadter, pers. comm., February 21, 2022)
[520] "MISSION EXTENSION VEHICLE (MEV)," *Northrop Grumman*, accessed April 3, 2022, https://www.northropgrumman.com/wp-content/uploads/Mission-Extension-Vehicle-MEV-fact-sheet.pdf.
[521] "MISSION EXTENSION VEHICLE (MEV)," *Northrop Grumman*.
[522] "MISSION ROBOTIC VEHICLE (MRV)," *Northrop Grumman,* accessed April 3, 2022, https://www.northropgrumman.com/wp-content/uploads/Mission-Robotic-Vehicle-MRV-fact-sheet.pdf.
[523] "MISSION EXTENSION POD (MEP)," *Northrop Grumman*, accessed April 3, 2022, https://www.northropgrumman.com/wp-content/uploads/Mission-Extension-Pod-MEP-fact-sheet.pdf.

Would P&I Club Benefits Outweigh Cost of Membership?

Such technological endeavors could require a great number of resources and might be extremely costly. How, then, can we facilitate development of innovative technology meant to address STM matters while preventing accidents or, worse, malfeasance? In this section, the question of whether potential space P&I club membership benefits outweigh the costs will be addressed.

Domestic legislation may be put in place to hold "bad actors" accountable for endeavors that "harmfully interfere" with other States' use of the space environment. In the comments provided for the FCC's satellite licensing amendment, NYU suggested "the use of a regulatory fee to deter and mitigate orbital debris," but a fee would require the determination of revenue required "achieve some orbital debris target, e.g., the projected cost for removal, mitigation or better design to minimize debris; and then deciding how to allocate fees across these differing objectives."[524] Further compounding the issue are the facts that "satellite operators are not homogenous and include large global satellite operators as well as smaller regional operators that supply services to distinct geographic regions," which subsequently "affects differently scale[d] economies and… intensity of competition."[525] Essentially, the factors in determining such a fee are too varied. The FCC is also limited under its authority to impose new regulatory fees.[526] Thus, it declined to adopt a fee-based deterrent to prevent orbital debris.

Adherence to licensing regulations is, of course, a requirement in the US. But space activity is costly, and strategies such as OOS and other STM technology implementations are particularly resource intensive. How can small businesses, startups, and educational

[524] Mitigation of Orbital Debris in the New Space Age," *FCC*, August 25, 2020..
[525] Mitigation of Orbital Debris in the New Space Age," *FCC*, August 25, 2020..
[526] Mitigation of Orbital Debris in the New Space Age," *FCC*, August 25, 2020..

organizations continue to have access to space if this level of cost presents a seemingly insurmountable barrier?

In a 2006 article, Kalina K. Galabova and Olivier L. de Weck found that an OOS solution for moving a GEO satellite into a graveyard orbit when it has reached EOL would "make economic sense only for the 10-20 highest-value GEO communications satellites, where six months or more of useful life is wasted because of uncertainty in fuel gauging."[527] While Galabova and Weck's paper focused on towing a GEO satellite into a graveyard orbit, cost of OOS in LEO may be a greater barrier to implementation due to the vast number of small satellites used for academic purposes, small business ventures, etc., that would likely not be able to afford the high cost of servicing.

According to Chris Kunstadter, VP Space at AXA XL, a US satellite owner/operator simply must adhere to licensing regulations, or they will not be able to conduct activity in outer space.[528] As of December 2021, the cost of an FCC license alone to "Construct, Deploy, and Operate" a small satellite is $2,175.[529] To "Construct, Deploy, and Operate" a system of technically identical satellites costs $15,050.[530]

Further, Kunstadter states the US, China, and Russia are the biggest culprits when it comes to objects on orbit, so it can be surmised that the US FCC satellite licensing regulatory requirements would make a significant impact on STM. The potential (positive) impact of these FCC regulations is recognized but quantifying the impact will not be explored within the scope of this paper.

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527 Kalina K. Galabova and Olivier L. de Weck, "Economic case for the retirement of geosynchronous communication satellites via space tugs," *Acta Astronautica* 58, (220060): 495.

528 Interview with Chris Kunstadter, February 21, 2022.

529 Federal Communications Commission, International and Satellite Services Fee Filing Guide, December 15, 2021, https://www.fcc.gov/document/ib-application-fee-filing-guide-1.

530 Federal Communications Commission, Fee Filing Guide, December 15, 2021.

Kunstadter also notes the fact that the barriers to entry for space participants really are not that high. However, reiterating his previous point that an entity must adhere to regulations as a cost of doing business, they must still implement space traffic management practices as set forth in the FCC licensing requirements, which could still potentially be costly and resource-intensive. Three examples of commercial space entities: OneWeb, EnduroSat, and Swarm Technologies are examined, including type of function, estimated cost of spacecraft, and other pertinent financial information. A model OOS mission is also examined as an example of innovative technology to help manage space traffic.

OneWeb, a "global communications network powered by a constellation of 648 low Earth orbit (LEO) satellites" headquartered in London, provides "high-speed, low latency connectivity for governments, businesses, and communities everywhere around the world."[531] In March 2020, OneWeb filed for Chapter 11 Bankruptcy, but it emerged as a joint venture with Airbus Defence and Space, backed by a consortium including the UK Government and Bharti Enterprises, a conglomerate from India, infused with $1 billion.[532,533] Here, OneWeb could serve as an analogue to estimate the potential cost of operating a communications satellite constellation. It is important to do so because one can examine the potential effects of law, regulations, policies, and guidelines on how a business operates.

According to OneWeb's FY2020 Statement (March 2021), it purchased satellites from AOS within its FY2020 (March 25, 2020 – March 31, 2021) for $82.8 million.[534] OneWeb's satellite constellation consists of "mini-fridge-sized satellites each weighing roughly 150

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[531] "Our Story," *OneWeb*, accessed March 19, 2022, https://oneweb.net/about-us/our-story.

[532] Caleb Henry, "OneWeb files for Chapter 11 bankruptcy," *SpaceNews*, March 27, 2020, https://spacenews.com/oneweb-files-for-chapter-11-bankruptcy/.

[533] Jonathan O'Callaghan, "U.K. Government Wins Controversial Bid For Bankrupt Mega Constellation Firm OneWeb," *Forbes*, July 3, 2020, https://www.forbes.com/sites/jonathanocallaghan/2020/07/03/uk-government-wins-controversial-bid-for-bankrupt-mega-constellation-firm-oneweb/.

[534] OneWeb Financial Statement FY2020.

kilograms."[535] As~ of February 2022, OneWeb has 428 satellites on orbit, two-thirds of its complete constellation.[536] The consortium purchase of OneWeb closed in the fourth quarter of 2020, and it had 74 satellites on orbit at the time of closure.[537] There were 72 satellites successfully launched after the transaction, which brings the total number of OneWeb satellites launched to 146. Specific details of the purchase or cost of the satellites are not publicly available, but an estimate is made based on the cost of $82.8 million for 146 satellites under OneWeb's ownership within its FY2020 which would average approximately $561,644.00 per 150-kilogram satellite.

EnduroSat, a European company founded in 2015 commercially offers a CubeSat intended for "lighter" applications.[538] According to its website, its goal is to "provide easy access to space for visionary entrepreneurs, scientists and technologists, helping them drive innovation at the final frontier" with NanoSats enabling "plug & play payload integration and open unique capability to… improve your technology in space."[539] As of second quarter 2016, EnduroSat had 50 customers.[540]

EnduroSat offers several customizable options for CubeSats, computer, and communications capabilities, but for the purposes of this paper, the focus is set on its 1U CubeSat platform. The price for the entire platform with room for up to 0.5u of payload volume, and is aimed for those who want to use it for "science and research, education, and technology

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[535] Caleb Henry, "OneWeb's first six satellites in orbit following Soyuz launch," February 27, 2019, https://spacenews.com/first-six-oneweb-satellites-launch-on-soyuz-rocket/.

[536] "OneWeb Confirms Successful Launch of 34 Satellites, Delivering Ongoing Momentum at the Start of 2022," *OneWeb*, February 10, 2022, https://oneweb.net/resources/oneweb-confirms-successful-launch-34-satellites-delivering-ongoing-momentum-start-2022.

[537] Darrell Etherington, "OneWeb emerges from bankruptcy, aims to begin launching satellites again on December 17," *TechCrunch*, November 20, 2020, https://techcrunch.com/2020/11/20/oneweb-emerges-from-bankruptcy-aims-to-begin-launching-satellites-again-on-december-17/.

[538] "About Us," *EnduroSat*, accessed March 19, 2022, https://www.endurosat.com/about/.

[539] "About Us," *EnduroSat*.

[540] "About Us," *EnduroSat*.

demonstration."[541] There are two options for pricing: an option with "no modifications" for $37,200 and an option with "attitude determination and control subsystem (ADCS)" for $55,200.[542]

EnduroSat states the mission life of this particular CubeSat platform is "2+ years (orbit dependant)," there is "zero volume loss through panel mounted sensors and magnetorquers," and is "available with detumbling and pointing controller."[543] The website did not go into detail on what "no modifications" means, but it could be implied that an "attitude determination and control subsystem" indicates some sort of attitude adjustment capability. To deorbit itself pursuant to regulations and/or policies, a satellite may need to "rely on… techniques such as increasing the drag area by rotating the spacecraft with their Attitude Determination and Control System (ADCS) module if they are in low altitudes."[544]

But even so, "[f]or some spacecraft, their exposed drag area is not enough to meet the 25-year requirement," and still may need to "use deorbit devices such as drag sails (passive systems) or even hire external deorbit services (active systems) to deorbit."[545] The question arises as to the difference between "no modifications" and if this implies there is no control on this particular CubeSat, but that warrants further examination. Even if an owner/operator chose to purchase a CubeSat that had attitude adjustment capability, it still may not function in a way that would allow it to deorbit pursuant to regulations and/or policies.

As further background, EnduroSat also offers satellite shared services to deliver small payloads to space and lists fees of 100 thousand Euros for a "one-off fee" that includes

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[541] "1U CubeSat Platform," *EnduroSat*, accessed March 19, 2022, https://www.endurosat.com/cubesat-store/cubesat-platforms/1u-cubesat-platform/#modifications.

[542] 1U CubeSat Platform," *EnduroSat*.

[543] 1U CubeSat Platform," *EnduroSat*.

[544] State-of-the-Art Small Spacecraft Technology," *NASA*, NASA/TP—20210021263, October 2021, 347, https://www.nasa.gov/sites/default/files/atoms/files/soa_2021_1.pdf.

[545] State-of-the-Art Small Spacecraft Technology," NASA/TP—20210021263, October 2021, 347.

"operations design, payload integration, functional testing and verification, launch acceptance campaign, registration and documentation, [and] launch and early mission operations."[546] Additionally, it offers a yearly in-orbit service for 50 thousand Euros that includes "flexible monthly data downlink, flexible on-demand data processing, dedicated high-accuracy pointing sessions, [and] in-orbit software and operations updates."[547]

A third example of a small satellite business is Swarm Technologies, founded in 2016, and located in Palo Alto, California. Swarm is known for its picosat, SpaceBee, and focuses on a "low-bandwidth service offering that is ideal for IoT applications."[548] For reference, a picosatellite is a satellite that has a mass of between 0.1 and 1kg.[549] Swarm offers a communications service for an annual subscription price of $60 per year, and is intended to be used for applications such as "soil monitors in the middle of corn fields, or buoys in the middle of the ocean," as the SpaceBees' signals "don't need low latency or high bandwidth… so the requirements for a satellite that serves them are much lower than for consumer broadband."[550,551]

Now, unfortunately, Swarm is perhaps notoriously known for being assessed a $900,000 fine from the FCC for launching four of its satellites without permission.[552] In January 2018, the FCC dismissed Swarm's experimental satellite licensing application due to concerns over the

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546 "Shared Satellite Service," *EnduroSat*, accessed March 19, 2022, https://www.endurosat.com/services/shared-satellite-service/#msform.

547 "Shared Satellite Service," *EnduroSat*.

548 "Swarm Data Plan," *Swarm Technologies*, accessed March 20, 2022, https://swarm.space/swarm-data-plan/.

549 Tomas E. Gergely and Andrew Clegg, "Nano and Picosatellites," *National Science Foundation*, accessed March 19, 2022, https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiBofSdytP2AhXgJzQIHSZ_Dm4QFnoECAkQAw&url=https%3A%2F%2Fwww.itu.int%2Fmd%2Fdologin_md.asp%3Flang%3Den%26id%3DR12-ITUR.MANTA-C-0014!!PDF-E&usg=AOvVaw350WlRkgTEhaoem9424rJW.

550 Swarm Data Plan," *Swarm Technologies*.

551 Devin Coldewey, "Swarm gets green light from FCC for its 150-satellite constellation, TechCrunch, October 17, 2019, https://techcrunch.com/2019/10/17/swarm-gets-green-light-from-fcc-for-its-150-satellite-constellation/.

552 Marina Koren, "The Mystery of the 'SpaceBees' Just Got Even Weirder," *The Atlantic*, May 17, 2018, https://www.theatlantic.com/technology/archive/2018/05/rogue-satellites-launch-fcc/555482/.

SpaceBees' size and the fact that they may be "too small to be reliably tracked once in orbit," and "might be a danger to other satellites."[553,554] Swarm's SpaceBees are 1/4u, and are 11 x 11 x 2.8cm in size.[555]

It is important to note Swarm settled matters with the FCC and was granted a license, with conditions, for a Non-Voice, Non-Geostationary Lower Earth Orbit Satellite System in the Mobile-Satellite Services (NVNG MSS) system on October 17, 2019.[556] The condition was that Swarm "is subject to modification to bring it into conformance with any rules or policies adopted by the Commission in this rulemaking" (meaning the Mitigation of Orbital Debris in the New Space Age amendment to the FCC satellite licensing application requirements).[557] Additionally, SpaceX had filed a comment "suggesting that Swarm had not adequately considered its orbital debris footprint, neglecting in particular to include its satellites' antennas in various calculations," and "the satellites might be a risk to the International Space Station."[558] However, the FCC found Swarm's response to these comments satisfactory and "that Swarm has taken the appropriate steps to address SpaceX's concerns."[559]

Of note, Thornton ponders whether $900 thousand is enough in being fined for a violation of FCC regulations. With regard to liability, another domestic company would have an action against Swarm if a SpaceBee did, in fact, inflict damage on its property.[560] If the harmed spacecraft was large and performed a critical function, the nature of the accident could be

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[553] Caleb Henry, "FCC fines Swarm $900,000 for unauthorized SmallSat launch," *SpaceNews*, December 20, 2018, https://spacenews.com/fcc-fines-swarm-900000-for-unauthorized-SmallSat-launch/.

[554] Coldewey, "Swarm gets green light," October 17, 2019.

[555] "Our Technology," *Swarm*, accessed March 19, 2022, https://swarm.space/our-technology/.

[556] "Swarm Technologies licensed for NVNG MSS system," *FCC*, October 17, 2019, https://www.fcc.gov/document/swarm-technologies-licensed-nvng-mss-system.

[557] "FCC FACT SHEET*: Mitigation of Orbital Debris in the New Space Age Report and Order and Further Notice of Proposed Rulemaking, IB Docket No. 18-313, April 2, 2020, 29.

[558] Coldewey, "Swarm gets green light," October 17, 2019.

[559] Coldewey, "Swarm gets green light," October 17, 2019.

[560] (Charles Thornton, pers. comm., March 18, 2022)

paralleled to an old Chevrolet Beretta running into a Lamborghini. Per Thornton, it would be a matter of asymmetry.[561]

In addition to debris removal, on-orbit servicing (OOS) has been discussed as a possible way to either bring defunct satellites back to life, or "shepherd" a non-operating satellite to a "graveyard" orbit. An OOS mission may entail a number of various types of servicing: inspection/scouting, repair, and refueling.[562,563] A NASA study explains that such potential prevention of debris would help prevent collisions between craft and, specific to GEO, would clear failed satellites enabling reuse of their orbital slots.[564] OOS studies and technological demonstrations, specifically pertaining to GEO, have been performed, and it has since been being worked as a potential STM solution.

OOS has been tested on various platforms such as the Hubble Space Telescope (HST), the International Space Station (ISS), and experimental missions such as NASA's Robotic Refueling Mission (RRM), Argon, RAVEN, and Restore-L. [565,566,567] Subsequently, different versions of HST repair tools were created for robotic use in LEO and GEO (GEO being an orbit where it is not feasible for humans to perform repair missions).[568] Further, the possibility of OOS by commercial providers is beginning to pick up speed. In 2018, Orbital ATK (now

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[561] (Charles Thornton, pers. comm., March 18, 2022).

[562] Graham and Kingston, 41-42.

[563] Clemens Kaiser, Fredrik Sjoberg, Juan Manuel Delcura, and Baard Eilertsen, "SMART-OLEV – An orbital life extension vehicle for servicing commercial spacecrafts in GEO," *Acta Astronautica* 63 (2008): 401.

[564] National Aeronautics and Space Administration, *On-Orbit Satellite Servicing Study Project Report*, NP-2010-08-162-GSFC, October, 2010, https://sspd.gsfc.nasa.gov/images/nasa_satellite%20servicing_project_report_0511.pdf.

[565] "RRM: Robotic Refueling Mission," *National Aeronautics and Space Administration*, accessed April 7, 2018, https://sspd.gsfc.nasa.gov/robotic_refueling_mission.html.

[566] "Relative Navigation System," *National Aeronautics and Space Administration*, accessed April 7, 2018, https://sspd.gsfc.nasa.gov/Relative_Navigation_System.html.

[567] "Restore-L Robotic Servicing Mission," *National Aeronautics and Space Administration*, accessed April 7, 2018, https://sspd.gsfc.nasa.gov/restore-l.html.

[568] National Aeronautics and Space Administration. (2017). Satellite Servicing Project Division. Restore-L Robotic servicing mission. Retrieved from https://sspd.gsfc.nasa.gov/restore-l.html (hereinafter "Restore-L")

Northrop Grumman) partnered with Intelsat to launch its commercial OOS Mission Extension Vehicle-1 (MEV-1), and the Defense Advanced Research Projects Agency (DARPA) partnered with Space Systems Loral (SSL) (now SSL, a part of Maxar Technologies) to develop its Robotic Servicing of Geosynchronous Satellites (RSGS) program.[569,570] In February 2020, Northrop Grumman's MEV-1 successfully docked with Intelsat 901, and most recently, MEV-2 successfully docked with a second Intelsat satellite, IS-10-02, in April 2021.[571]

In 2017, then Orbital ATK sued DARPA over the SSL partnership and RSGS, stating the mission violates National Space Policy by putting forth government efforts toward working on a mission when a similar mission is being developed by a commercial company and SSL subsequently sued Orbital ATK over a data breach, stating an Orbital ATK employee "accessed documents related to a project called Dragonfly on a server at the NASA Langley Research Center in Virginia."[572,573] The legal action taken by both companies may indicate a possibility that competition in the nascent OOS industry could be strong.

Whereas NASA's reasoning behind the need for OOS may be extending the lives of expensive "one-off" scientific missions why would commercial companies such as Northrop Grumman and SSL consider OOS?[574] What would they have to gain? One possibility is the fact

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569 "SpaceLogistics Services," *Orbital ATK*, accessed April 7, 2018, https://www.orbitalatk.com/space-systems/human-space-advanced-systems/mission-extension-services/default.aspx.

570 "DARPA Selects SSL as Commercial Partner for Revolutionary Goal of Servicing Satellites in GEO," *Defense Advanced Research Projects Agency*, accessed April 7, 2018, https://www.darpa.mil/news-events/2017-02-09.

571 "Northrop Grumman and Intelsat Make History with Docking of Second Mission Extension Vehicle to Extend Life of Satellite," *Northrop Grumman*, accessed March 13, 2022, https://news.northropgrumman.com/news/releases/northrop-grumman-and-intelsat-make-history-with-docking-of-second-mission-extension-vehicle-to-extend-life-of-satellite.

572 Phillip Swarts and Caleb Henry, "Orbital ATK sues DARPA to stop SSL from winning satellite-servicing contract," *SpaceNews*, February 8, 2017 http://spacenews.com/orbital-atk-sues-darpa-to-stop-ssl-from-winning-satellite-servicing-contract/.

573 Jeff Foust, "SSL sues Orbital ATK over confidential data breach," *SpaceNews*, March 23, 2017, http://spacenews.com/ssl-sues-orbital-atk-over-confidential-data-breach/

574 Alex Ellery, Joerg Kreisel, and Bernd Sommer, "The case for robotic on-orbit servicing of spacecraft: Spacecraft reliability is a myth," *Acta Astronautica* 63, (2008): 633.

that aging commercial satellite fleets are becoming defunct would leave commercial operators to build replacements. According to Hastings, Putbrese, and La Tour, "trends in geosynchronous spacecraft manufacturing have been towards larger, more expensive, longer-lasting spacecraft."[575] However, some of this may be offset by decreasing costs of launch services as companies like SpaceX progress in the development of reusable components of launch vehicles.[576] Commercial operators, then, may explore OOS as a potentially more cost-effective way to maximize revenue and extend the lives of their fleets.

According to an informational presentation on NASA's Restore-L mission, the components of a potential OOS satellite may be broken down into two parts: the servicing payload and the spacecraft bus.[577] NASA's RRM and Restore-L webpages discuss servicing payload components and a toolkit that would be used on the mission that could perform a number of functions, such as cutting wires, unscrewing caps, opening and closing valves, transferring fluid, practicing steps leading up to a coolant (or propellant) replenishment, and providing inspection capabilities.[578,579] Indicated by the contract between DARPA and SSL and other literature, another major component of an OOS mission is a set of robotic arms used to grapple a target satellite.[580] The fourth major component of an OOS mission is the cost of launch.

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[575] Daniel E. Hastings, Benjamin L. Putbrese, and Paul A. La Tour, "When will on-orbit servicing be part of the space enterprise?," *Acta Astronautica*, 127 (2016): 655.

[576] Peter B. de Selding, "SpaceX's reusable Falcon 9: What are the real cost savings for customers?," *SpaceNews*, April 25, 2016, http://spacenews.com/spacexs-reusable-falcon-9-what-are-the-real-cost-savings-for-customers/.

[577] Ron Ticker, "Restore-L mission information: Package for NASA solicitation #NNH15HEOMD001, spacecraft bus concepts to support the asteroid redirect robotic mission and in space robotic servicing," *NASA*, accessed April 3, 2022, https://www.nasa.gov/sites/default/files/atoms/files/restore-l-info_nnh15heomd001_r7.pdf.

[578] "RRM: Robotic Refueling Mission," *National Aeronautics and Space Administration*.

[579] "Satellite Servicing Projects Division. Relative Navigation System" [hereinafter *Relative Navigation System*], *National Aeronautics and Space Administration,* accessed April 2, 2022,https://sspd.gsfc.nasa.gov/Relative_Navigation_System.html.

[580] Flores-Abad, Ma, Khanh, and Ulrich, 1.

In December 2016, NASA announced that it had awarded a contract to SSL for the development of a "spacecraft bus, critical hardware and services for the development, deployment and operations of the Restore-L mission."[581] The total maximum contract value is $127 million, which is the figure used as an example as the cost of a spacecraft bus in a typical OOS mission. Accounting for inflation at the time of this writing, the figure is adjusted to $152 million in CY2022.

In July 2016, SSL announced it had been awarded a contract by DARPA to develop robotic arms for the RSGS mission.[582] The contract is valued at $20.7 million, and is the figure used as an example for the cost of robotic arms in the OOS mission cost simulation. Accounting for inflation, the figure is adjusted to $24.8 million in CY2022.

The servicing payload, or toolkit, contains not only mission servicing tools such as wire cutters and a multifunction tool, but a navigation system, avionics, and a propellant transfer system.[583] Information regarding the cost of this toolkit is not readily available, but it can be assumed that it would cost at least as much as the spacecraft bus. Thus, a figure of $127 million is used as the baseline and estimate for a minimum cost of the toolkit. Accounting for inflation at the time of this writing, the figure is adjusted to $152 million in CY2022. Because this study's focus is the cost of the satellite and its tools alone, launch cost will not be figured into the equation, as it is beyond the scope of this paper. However, further analysis including launch cost is recommended.

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[581] Gina Anderson and Cynthia M. O'Carroll, "NASA Awards Contract for Refueling Mission Spacecraft," *NASA,* December 5, 2016, https://www.nasa.gov/press-release/nasa-awards-contract-for-refueling-mission-spacecraft.

[582]. "SSL to provide robotic arms to DARPA for satellite servicing," *SSLMDA*, July 21, 2016, https://sslmda.com/html/pressreleases/pr20160721.html.

[583] Ticker, "Restore-L mission information," *National Aeronautics and Space Administration*.

The total of the four elements: the spacecraft bus, robotic arms, and toolkit, is estimated at $328.8 million in CY2022. It is reiterated that the estimate for the toolkit is assumed to be the minimum, so it is likely an actual OOS satellite would cost more. However, for the purpose of this paper, the figure of $328.8 million will be used.

Specific details of space and maritime insurance policy premium costs are not available as they are proprietary, but a rough estimate to provide a framework of an economic case for why a spacecraft owner/operator would obtain P&I coverage is attempted herein. In its FY2020, the "[t]onnage in the Club's mutual P&I class declined by about 9% to approximately 17 million [gross tonnage (gt)] overall.[584] The Net premiums and calls earned by The American Club was $90,628,000. Based purely on the approximate premiums and calls earned and amount of tonnage covered by The American Club, the price of a membership call averages to approximately $5.33/gt.[585] According to the Florida Department of Management Services, hull rates for maritime insurance policies can range from "$1.15 to $4.00 per $100 of the insured value depending on vessel's value, age and use."[586] As a secondary reference, financial management company states "[o]n average, boat insurance costs… around 1–5% of your boat's value if you have a big, powerful or expensive boat," though this is more in reference to personal craft than commercial working vessels.[587] An advertisement for a 95-foot bow tug with a volume of 244 gross tonnage for sale for $1,150,000.00 was located.[588] Assuming a

[584] American Club Financial Statement, 2020.
[585] American Club Financial Statement, 2020.
[586] "Ocean Marine Insurance (Hull, Liability, and Cargo)," *Department of Management Services – State of Florida*, accessed April 2, 2022, https://www.dms.myflorida.com/business_operations/state_purchasing/insurance_contracts/ocean_marine_insurance_hull_liability_and_cargo.
[587] "How Much Will Boat Insurance Cost Me?," *Ramsey Solutions*, January 18, 2022, https://www.ramseysolutions.com/insurance/boat-insurance-cost-guide.
[588] "95ft 2060HP Model Bow Tug – 15599," *Ocean Marine Brokerage Services*, accessed April 2, 2022, https://www.oceanmarine.com/detail.cfm?95ft%2D2060HP%2DModel%2DBow%2DTug%2D%2D%2D15599&product_id=15599&category_current=3&category_current_sub=7.

$1,150,000.00 tug boat was fully insured, if we use the median value of $2.58 per $100 of the insured value, we arrive at an annual premium of $29,670.00. If we use the median value of 2.5% of the boat's value as cost of premium, we arrive at an annual premium of $28,750.00. These values are deemed sound for this author to use 2.5% of a craft's value through $2.58 per $100 of a craft's insured value as an estimated range of the cost of an annual premium.

Combined with the above approximate value of a large OOS mission at $328.8 million, an estimate of that particular craft's annual space insurance policy premium could amount to be $8.22 – $8.48 million. As discussed earlier, Harrington states launch insurance could fall between 5 to 20 percent of a satellite's value, and the market is "expected to settle in this phase at around 10 percent."[589] Again, third party liability insurance is likely to be much higher. Even if using the low end of the spectrum (5%) and estimating a policy premium at $16.4 million, we arrive at a value roughly twice as high as if the figures based on a maritime analogue were used.

For a smaller spacecraft such as one of OneWeb's satellites, using the estimated value of $561,644.00 per satellite, the maritime insurance analogue would result in an estimated annual space insurance policy premium of approximately $14,041.00 – $14,490.00 per year, multiplied by 146 satellites would total approximately $2.05 million – $2.12 million in space insurance premiums alone. Using a 5% figure, an annual policy for OneWeb's 146 satellites would be approximately $4.1 million. For a much smaller single craft, such as an EnduroSat 1U CubeSat valued at $55,200.00, the maritime insurance analogue would result in an annual space insurance policy premium of approximately $1,380.00 – $1,424.00. The 5% figure would amount to approximately $2,760.00 annually.

[589] Harrington, 4.

"'Space premiums are 10-20 times aviation premiums,' said Peter Elson, CEO of insurance broker Gallagher Aerospace."[590] "Insurance for a small aircraft will cost around $1,500 to $2,000 per year, but the amount of coverage and cost will vary significantly by the type of policy, aircraft, flight, and pilot."[591] With the caveat that insurance rates vary greatly, a figure of $2,000.00 per year for a small aircraft and the multiplier of 10 to approximate an estimated space insurance policy premium of $20,000.00 per year is used.

Thus, based on a maritime analogue and approximations from other experts, space insurance rates could vary widely based on many factors. However, even at the lowest end of what is examined here – a potential $1,380.00 policy for a 1U CubeSat – the type of coverage provided by that insurance policy could vary as widely as the rates. Again, third-party liability insurance is likely to be much higher, and it is unknown whether a small spacecraft owner/operator would carry insurance at all, especially due to the fact that (at least, of course, in the U.S.) insurance is not required. Though industry experts state the potential for one specific spacecraft colliding with one other specific spacecraft is low,, a risk still exists for a $55,200.00 satellite to collide with a $328.8 million satellite and cause damage, and, if the small satellite is owned by a small business, could result in a claim that may end in financial ruin for that small business. Additionally, depending on the purpose and function of the $55,200.00 CubeSat, a $1,380.00 annual policy might be a high cost to a business that made a high front-end investment on a CubeSat with little revenue.

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[590] Noor Zainab Hussain and Carolyn Cohn, "Launching into space? Not so fast. Insurers balk at new coverage," *Reuters,* September 1, 2021, https://www.reuters.com/lifestyle/science/launching-into-space-not-so-fast-insurers-balk-new-coverage-2021-09-01/.

[591] "The Real Cost of Aircraft Insurance," *Pilot Institute*, March 16, 2022, https://pilotinstitute.com/aircraft-insurance-cost/.

A P&I club's coverage for pollution is stated to be unlimited (except, again, in the case of oil, where liability is limited to $1 billion or other agreement limitations and/or exclusions apply).[592] According to Stevan M. Spremo, Alan R. Crocker, and Dr. Tina L. Panontin, a small spacecraft ranges from 0.01 kg to 1,000 kg, so for the purposes of this exercise this author will use an example of a "mini spacecraft" which is 100 kg.[593] In a very rough comparison, a tug boat in specifications was located, the displacement of which is 545 tons.[594] Displacement is the measure of a "vessel and its contents" "in tons of 2,240 pounds," so a 545-ton displacement equals 1,220,800 lbs or approximately 553,746 kg.[595] Looking at the fact that this 244-gt, 553,746-kg tug boat's approximate P&I club call would be $1,300.52 per year, the amount per kg for the call would be approximately $0.002. If we were to convert these figures and use them to calculate a potential P&I club call of a 100-kg spacecraft, that spacecraft's potential space P&I club call would be approximately $0.23 per year, which is which is almost comically low and does not soundly support the argument that a direct comparison between maritime P&I club calls and potential space P&I club calls exists .

We could also examine the potential cost of a space P&I club call using a different formula and a smaller spacecraft, for example, a 12u CubeSat with a mass of 6-8kg and an available payload volume of 197 x 197 x 225 mm^3, or 8,732,025 mm^3, which is approximately

[592] "A Profile: Seamless Service for Turbulent Times," *The American Club*, May 2020, 4, https://www.american-club.com/files/files/The_American_Club_a_Profile.pdf.

[593] Stevan M. Spremo, Alan R. Crocker, and Dr. Tina L. Panontin, "Small Spacecraft Overview," accessed March 21, 2022, https://ntrs.nasa.gov/api/citations/20190031730/downloads/20190031730.pdf.

[594] "TUGBOATS FOR SALE," *Sun Machinery Corp.*, accessed April 2, 2022, https://www.sunmachinery.com/tugboats%20for%20sale.html.

[595] "Ship Tonnage Explained - Displacement, Deadweight, Cargo, Gross, Etc.," *Gjenvick-Gjønvik Archives*, accessed April 2, 2022, https://www.gjenvick.com/OceanTravel/ShipTonnage/1932-06-28-ShipTonnageExplained.html.

0.308 ft^3.[596,597] According to the Delaware Business Incorporators' Vessel Gross Tonnage Calculator, "[f]or a boat with a simple sailing hull," the "Gross Tonnage = (.5 x L x B x D) divided by 100," where L = length in feet, B = breadth in feet, and D = depth in feet.[598] Using a metric conversion calculator, 8,732,025 mm^3 is approximately 0.308 ft^3.[599] Using the formula in the Vessel Gross Tonnage Calculator, 0.5 x 0.308 / 100, we arrive at 0.00154 gt. Using the figure of $5.33/gt, a potential P&I call for a 12u CubeSat with a 197 x 197 x 225 mm^3 would be $0.008 per year, which is also almost comically low and does not soundly support the argument that a direct comparison between maritime P&I club calls and potential space P&I club calls exists.

As stated, specific financial details of a maritime P&I club membership are not publicly available, nor are details regarding conventional space insurance policy. But the amount of a call can be adjusted using a different calculation – perhaps accounting for different components of a spacecraft, its purpose, its orbit, and the addition of a sliding scale – the resulting price could still be relatively and significantly low, and the economic case for P&I club membership could be beneficial, especially for small entities with large front-end investment and little to no revenue. As stated earlier, the space environment and maritime environment do not perfectly align as an analogue, but we can still identify and use similar concepts to help us develop solutions for managing space activity.[600] As one industry expert drew a similarity between group captives and P&I clubs, and stated that perhaps group captives could be purchased at a fraction of the cost of a conventional insurance policy, it is possible a potential space P&I club membership could also

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[596] Spremo, Crocker, and Panontin, 2022.

[597] "12U CUBESAT PLATFORM," *Endurosat*, accessed April 2, 2022, https://www.endurosat.com/cubesat-store/cubesat-platforms/12u-cubesat-platform/.

[598] "Vessel Gross Tonnage Calculator," *Delaware Business Incorporators, Inc.*, accessed April 1, 2022, https://www.delawarebusinessincorporators.com/pages/vessel-gross-tonnage-calculator.

[599] "Cubic Millimeters to Cubic Feet," *Metric Conversions*, accessed April 1, 2022, https://www.metric-conversions.org/volume/cubic-millimeters-to-cubic-feet.htm.

[600] Goessler, "#SpaceWatchGL Opinion.

be a relatively low cost when compared to a conventional space insurance policy. However, it is important to reiterate specific financial details of P&I clubs and conventional insurance policies need to be researched further. Thus, whether the benefits of a potential space P&I club membership outweigh its cost cannot be fully concluded in this study.

Conclusion

This study has attempted to answer whether liability apportionment and risk-pooling through a potential space P&I club membership would benefit U.S. spacecraft owner/operators enough for them to implement best STM practices set forth in existing regulations, policies, and guidelines, namely SPD3 and FCC satellite licensing regulations. Because a thorough cost analysis could not be conducted with the information available, the answer is P&I club membership *could* provide enough of a benefit for a U.S. spacecraft owner/operator to implement best STM practices to adhere to existing laws, regulations, policies, and guidelines, but under certain conditions.

As previously discussed, potential space P&I club membership would be best used as a solution to fill gaps in the bigger picture of STM, and could not, itself, act as a driver for an actor to implement best practices. When combined with initiatives such as the SSR, however, an entity may be encouraged to conduct better behavior in space because it could make itself more competitive with “high marks” as well as perhaps sharing some of the risk it might take on when it implements innovative technology for STM purposes. This aligns not only with regulatory requirements, but policies, guidelines, and best practices, as discussed above. A P&I club could alleviate some of a spacecraft owner/operator’s burden of bearing a full conventional insurance policy and would help manage and mitigate risk as Wetherbee states is crucial for an organization to survive.

Again, to answer the question fully, more financial details must be examined to determine whether the benefits of a potential space P&I club membership outweigh the costs. But based on the facts that third-party liability insurance from a conventional insurer is likely to be expensive and complicated (as Harrington states, unless there is some standardization in conventional space insurance or is made more widely available and accessible, it may not be a help to everyone), and group captive coverage (as an analogue for P&I club coverage) could be acquired at a significantly lower cost, it can be argued that the benefits of potential space P&I club membership could outweigh the cost. Also, as discussed, P&I clubs provide more than just liability coverage – they provide expertise to help prevent potential accidents and even legal assistance in the event an accident does occur. There is much more benefit than third-party liability coverage. Regarding a potential space P&I club's place within policy, an opinion could be provided to the FCC in its comment-seeking action about a potential future economic incentive-based amendment to its satellite licensing rule. But specifically calling out a P&I club in regulations, policies, or guidelines may not be necessary. As in the case of maritime P&I clubs providing certificates to prove financial responsibility, a P&I club might act in the same way in the space industry, potentially serving to provide similar certificates to satisfy a regulation pertaining to solvency.

Other "carrot and stick" methods for encouraging actors to conduct good space behavior (or deterring bad space behavior) have been suggested. In the FCC's comment period related to its satellite licensing rule, we saw that "NYU suggest[ed] the use of a regulatory fee to deter and mitigate orbital debris," but the implementation of such a fee would be difficult for many reasons, including determining how to assess the fee and FCC's limits on its ability to impose the fee.[601]

Overall, potential space P&I club membership could, indeed, lead to better behavior in space to gradually clean up orbital debris and manage space traffic in a cleaner manner. Again, it would be best used as part of the bigger STM picture alongside existing regulations and policies. Still, a P&I club membership could provide a significant enough benefit where actors could be more likely to adhere to regulations and policies, which would, in turn, have a positive impact on keeping the space environment sustainable for current and future activities.

Recommendations

There are some lingering questions that warrant further research. Most importantly, a further study of financial details of the costs of P&I club calls is necessary to determine whether potential space P&I club membership does, indeed, outweigh the cost. Without this information, an answer to this research question cannot be fully concluded.

Another subject for further study is how P&I clubs specifically address the broad spectrum of types of craft in its member base and how it accounts for small calls from small craft compared to extremely large cargo ships. One of the downsides of a P&I club, as discussed, is the fact that a lack of homogeneity in membership could actually be a deterrent to joining and/or maintaining a membership because a small craft that pays a small call would receive the benefit of unlimited coverage in some types of accidents, or only high-risk members would choose to stay as they are receiving the claims payments and continue increasing calls for the other members. Additionally, one example U.S.-based space P&I club was examined and there must

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[601] Mitigation of Orbital Debris in the New Space Age," *FCC*, August 25, 2020.

be further research into how one State's P&I club would function in an international group. This study starts with one example and advises further study to dovetail.

Additionally, limitations can always be placed in contracts or insurance policies which would govern (as Harrington states) behavior under the performance of that contract or policy. But looking at maritime P&I clubs in concert with all the factors discussed above, P&I club membership could, in fact, incentivize spacecraft owner/operators to adhere to best STM practices, and can help facilitate progress of space technology development and innovation.

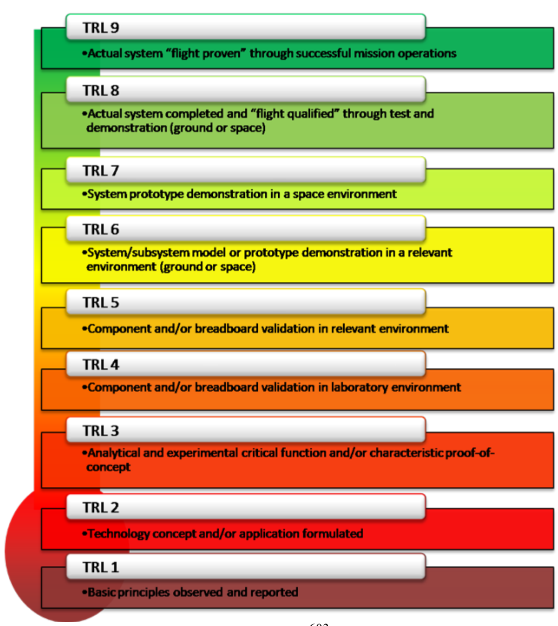
Though some experts have stated an actual risk of one particular entity's spacecraft bumping into another spacecraft is low, the risk still exists, and the impact would be very serious, if not catastrophic. As discussed above, a P&I club membership can fill in some of the gaps left by conventional insurance but can work as part of the bigger picture of STM – as in, membership can ease some spacecraft owner/operators' burden in taking risks to develop new technology that could help manage space traffic in such a way where our space environment and infrastructure remains sustainable, continuing its use and development now and for generations to come.

Charts and Graphs

A simple list of the organizational control methods includes, but is not limited to, the following items:

Organizational Management of Risk

- Safety Management System (rules, policies, and procedures for the entire organization)
- Local Safety Management System and Organizational Practices (for different local areas or entities in the organization)
- Managing Risk (Process Safety)
    1. Identify the Risks (and Hazards)
    2. Assess the Risks
    3. Respond to the Risks (Implement Controls)
    4. Monitor and Review the Risks (and Controls)
- Process Safety Methods
    - Control of Work (Permitting Process, Job Safety Analyses, etc.)
    - Hazard Identification and Evaluation
    - Risk Assessment
    1. Heirarchy of Controls (Hazard and Error Defenses)
        A. System Design (Hard Defenses)
            1. Design Out (some organizations use Elimination or Redesign)
            2. Engineer In (some organizaitons use Substitution or Redesign)
            3. Guard Against (some organizations use Isolation)
            4. Contraints and Affordances (Human Factors design characteristics)
        B. Administrative Rules and Procedures (Soft Defenses)
            5. Warnings
            6. Training
            7. Personal Protective Equipment[602]



Technology Readiness Level (TRL)[603]

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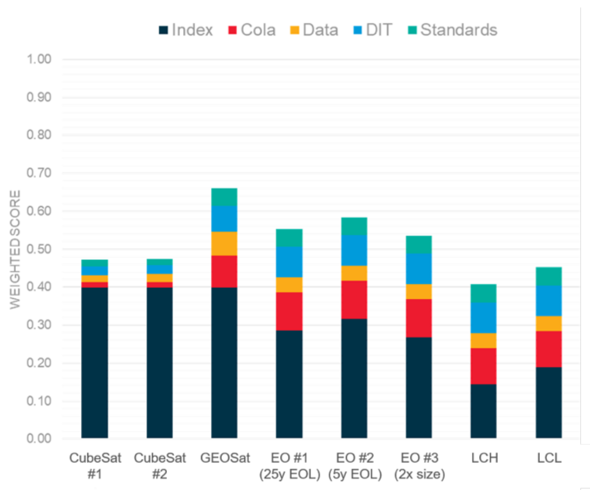
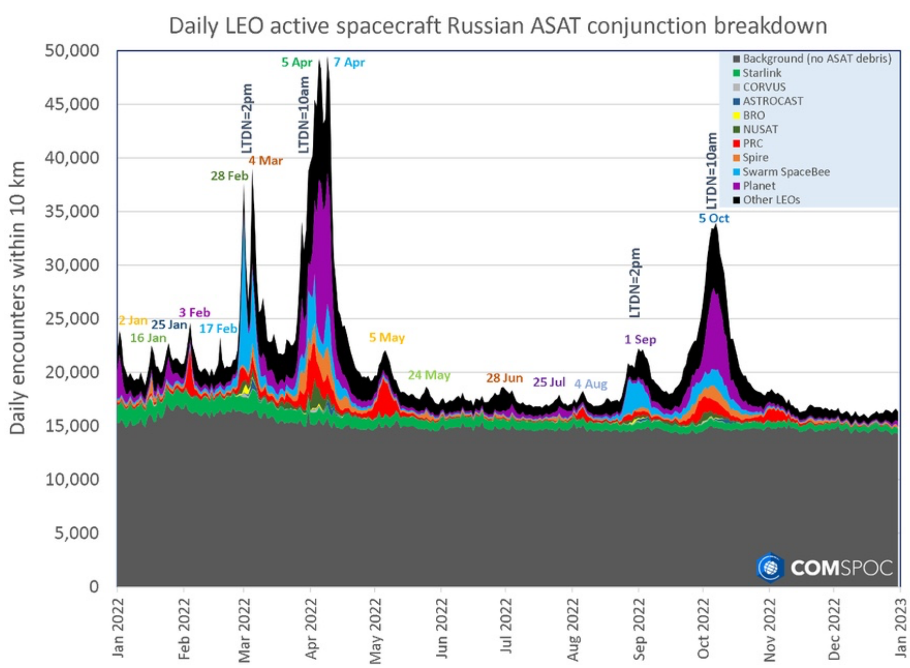
[602] Wetherbee, 25-26.

[603] Irene Tzinis, ed., "Technology Readiness Level," *NASA*, October 28, 2012, https://www.nasa.gov/directorates/heo/scan/engineering/technology/technology_readiness_level.



Space Sustainability Rating Framework Figure 2: "Rating assessment (and module contribution) for a set of representative missions. EO indicates an Earth Observation mission in a Sun-syncrhonous orbit, LCH indicates a Large Constellation in LEO at High altitude, LCL one at Low altitude.[604]



A chart showing the peaks in conjunctions with active satellites in LEO caused by Russian ASAT debris. Credit: COMSPOC[605]

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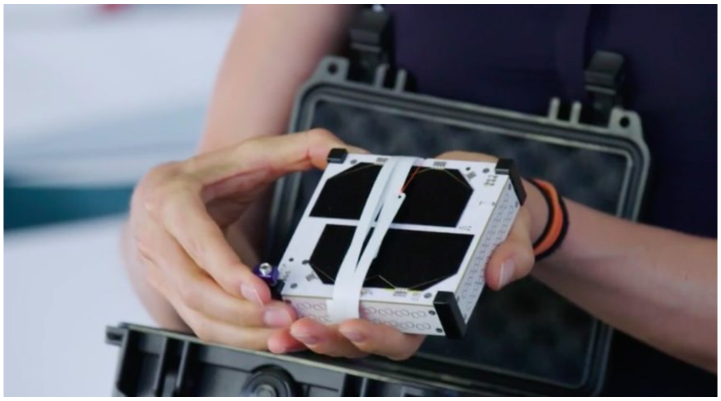
604 Framework

605 Jeff Foust, "Russian ASAT debris creating "squalls" of close approaches with satellites," *SpaceNews*, February 18, 2022, https://spacenews.com/russian-asat-debris-creating-squalls-of-close-approaches-with-satellites/.



One of Swarm Technologies' "SpaceBee" picosatellites. The company wants to operate a constellation of 100 tiny satellites for Internet of Things services. Credit: Swarm Technologies[606]

[606] Henry, *SpaceNews*, December 20, 2018.

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Appendix A
List of Abbreviations

18 SCPS:	18th Space Control Squadron
ADR:	Active Debris Removal
ASAT:	Anti-Satellite
CLC:	International Convention on Civil Liability for Oil Pollution Damage, 1969
COPUOUS:	Committee on the Peaceful Uses of Outer Space
CSLA:	Commercial Space Launch Act
CSpOC:	Combined Space Operations Center
DOD:	United States Department of Defense
FCC:	Federal Communications Commission
GEO:	Geosynchronous Orbit
IADC:	Inter-Agency Space Debris Coordination Committee
INMARSAT:	International Maritime Satellite Organization
INTELSAT:	International Telecommunications Satellite Organization
ITAR:	International Traffic in Arms Regulation
JSpOC:	Joint Space Operations Center
LEO:	Low Earth Orbit
MARPOL:	International Convention for the Prevention of Pollution from Ships
ODMSP:	United States Government Orbital Debris Mitigation Standard Practices
OOS:	On-Orbit Servicing
OST:	Outer Space Treaty
P&I:	Protection and Indemnity
RSO:	Resident Space Object
SPD3:	Space Policy Directive 3
SSA:	Space Situational Awareness

SSR:	Space Sustainability Rating
STM:	Space Traffic Management
USSP:	United States Space Policy
USSTRATCOM:	United States Strategic Command