IAC-14-E3.4.10

ANALYSIS OF UNITED STATES POLICY AND LEGAL IMPEDIMENTS TO ON-ORBIT SATELLITE SERVICING ACTIVITIES

Mr. David Belcher
Space Policy Institute, George Washington University (SPI-GWU), United States, dbelcher898@gwmail.gwu.edu

Mr. Scott Freese
SPI-GWU, Secure World Foundation, United States, sfreese@gwmail.gwu.edu

Ms. Katrina Laygo
SPI-GWU, United States, klaygo@gwu.edu

Mr. Daniel Osborn
SPI-GWU, United States, dosborn@gwu.edu

Communications satellites play a vital role in supporting today's commercial and military information infrastructure backbone. When such satellites fail, they generally require costly launch and replacement with new systems. While many of the current inactive satellites still have working components, they cannot be reused whole or in part. The development of on-orbit satellite servicing (OOS) capabilities may offer many foreseeable benefits, such as an eventual shift to on-orbit satellite assembly, the ability to more quickly upgrade or repair satellites, and a greater return on investment for the U.S. Government and commercial stakeholders through the reuse of the most valuable satellite components. Initiatives such as the Defense Advanced Research Projects Agency's Phoenix Program and ViviSat's Mission Extension Vehicle aim to develop and demonstrate technologies that can enable a shift to Geostationary Orbit OOS mission capabilities. Beyond the business case and technological challenges, several policy impediments exist which may hinder the development of such capabilities. The current lack of domestic and international norms and standards for OOS creates uncertainty in areas including third-party verification, transparency and confidence building measures, and security and proprietary concerns related to imaging of third-party satellites. For OOS technologies to reach their full potential, it is necessary to determine how numerous stakeholders - national governments, agencies, intergovernmental organizations and industry - can communicate and collaborate successfully in order to identify and service assets owned and operated by different organizations and countries. This paper will identify a list of actionable recommendations for actors in the United States' OOS sector. It will articulate clear arguments for how these policy actions can be integrated into servicing mission functions by both the US Government and the broader industry.

I. EXECUTIVE SUMMARY

The development of an on-orbit satellite servicing (OOS) market is currently constrained by uncertainty in six domestic policy areas: *Responsibility and Ownership*, *Insurance, Spectrum and Slotting*, *Imaging, International Assurance, and Operational Regulation.* This paper outlines specific recommendations and a plan of implementation for the U.S. Government to address these impediments.

The primary goal of this paper and its policy recommendations is to reduce uncertainty in U.S. domestic policy in the short term (within the next 5 years) in order to bring satellite servicing activities to an operational level. By meeting this goal, this paper further advances secondary goals of creating an internationally sustainable OOS infrastructure in the medium term (beyond 5 years) and developing advanced OOS activities in the long term (decades from now).

II. SUMMARY OF ISSUES AND RECOMMENDATIONS

II.I Imaging

This issue may be addressed by extending NOAA's land remote sensing regime to the imaging of space objects in order to balance national security with the need for international assurance and monitoring of on-orbit operations. Committee language should be created to clarify NOAA's authority over space imaging.

II.II On-Orbit Operational Regulation

The FAA should be the regulatory authority over OOS operations, which will require a law or an amendment to provide the FAA with authority over OOS operational plans and vehicle inspections. Requiring the publication of plans, capabilities, and telemetry should be a part of the FAA's OOS authority.

II.III Assurance

OOS Policy should require the publication of on-orbit plans and telemetry, and through the creation and following of best practices. This policy will address issues of assurance and the reactions of different countries to servicing missions and concern over (ASAT) potential.

II.IV Best Practices

We recommend the development of Transparency and Confidence Building Measures (TCBMs), including the following initial steps: participation in meetings and conferences, the provision of easily accessible and unencrypted imaging and telemetry data, notices given of areas where imaging will occur, efforts to minimize orbital debris, immediate and accurate reporting of accidents, and a preemptive determination of the responsible entities should be implemented.

II.V Liability, Insurance, Spectrum and Slotting, and Export Control

Minimal, if any, government action is necessary to address these four issues, initially.

Liability: It is recommended that satellite servicers make a positive determination of the responsible entities involved in a servicing operation before beginning operations. Currently, international law makes responsibility and ownership of space objects unclear.

Insurance: Technical demonstrations should be continued in order to gather technical and operational data necessary to adequately assess the risks of OOS activities.

Spectrum and Slotting: On-orbit operations make novel use of spectrum and GEO slots that could raise regulatory concerns. This issue may be sufficiently addressed with the FCC's current system of rules.

Export Control: The current regulatory regime does not appear to preclude the functioning of an OOS market at this time.

III. INTRODUCTION

OOS is generally defined as the repair, maintenance, refueling, or upgrading of a space asset that is currently in its operational orbit[1] and can encompass several different activities, including satellite rescue, repositioning, repair, inspection, deorbiting, debris removal, and debris management.[2] While there are currently no operational programs, initiatives such as the Defense Advanced Research Projects Agency's (DARPA) Phoenix Program and ViviSat's Mission Extension Vehicle aim to develop and demonstrate technologies and methods that can enable an eventual shift from single-use satellites to an OOS-based regime.[3]

Constraints on the formation and growth of an OOS market come from four interrelated areas: economic feasibility, technical capacity, domestic policy, and international law.[4] Each of these areas must be addressed, before a self-sustaining market for OOS can develop. Economic constraints include the cost of establishing a viable market for OOS. Technical constraints consist of the engineering difficulties, novelty, and inherent risk of orbital operations. U.S. domestic policy is currently constrained by inadequate mechanisms to address many OOS issues. Lastly, international concerns are associated with both the current lack of operational OOS experience and the inherently dual-use nature of space hardware, OOS missions can conceivably be utilized for both peaceful and military aims.

These four issue areas are closely interrelated. For example, the uncertainty created by the lack of formal U.S. policies relating to OOS activities makes the business case for OOS services more risky, thereby inhibiting investment. Similarly, increasing technical development decreases the possibility of failure, making the business case less risky, encouraging investment. Internationally, the perception of increased risk from technologies and techniques which may have anti-satellite (ASAT) applications gives rise to international concerns about the intent of OOS operations; transparency in domestic policy can increase assurance by decreasing uncertainty over what OOS operators are doing in space. Of these four areas of economics, technical capacity, domestic policy, and international law, the area most suitable for U.S. action is domestic policy, which will be the focus of this paper.

The primary goal of this paper and its policy recommendations is to reduce uncertainty in U.S. domestic policy in the short term (within the next 5 years) in order to bring satellite servicing activities to an operational level. In addressing this goal, the paper advances the secondary goals of creating an internationally sustainable OOS infrastructure in the medium term (beyond 5 years) and developing advanced OOS activities in the long term (decades from now).

This paper proposes a set of actionable recommendations and a policy implementation plan for the U.S. Government that are realistic in the current political environment. By weighing the costs and benefits of the proposed constellation of policy changes, this paper outlines the minimum actions necessary to address the domestic policy uncertainties in satellite servicing. These changes reduce uncertainty in operations in the short term and set the foundation for realizing long-term, secondary goals.

Reforming domestic policy to enable a robust OOS market is important: Satellites in geostationary orbit (GEO) have vital strategic and economic value. Over two-thirds of these satellites are dedicated to communications, and play a significant role in supporting today's commercial and military information infrastructure. From providing navigation and weather forecasting, to delivering mobile and telemedicine services and TV broadcasting, these assets represent billions of dollars of value to the global economy and are an integral part of the U.S. national security strategy.

Currently, when satellites fail, the only recourse is costly launch and replacement with new systems. Furthermore, many inactive satellites still have valuable and working components that could be reused with proper servicing. One method to recover the value of these satellites is with the development of an On-Orbit Satellite Servicing (OOS) Program, which would salvage and reuse expensive components. The development of OOS capabilities holds great potential benefits for national governments and commercial stakeholders.

The potential benefits of enabling a private servicing market are not limited to extending the life, and thereby increasing the profitability of operational satellites. While current launch technology limits the practical size of satellites that can be launched cost-effectively, a robust OOS market would enable the assembly of larger-scale structures in orbit. OOS technologies could eventually increase the capabilities of programs that are limited by launch vehicle size and mass-lift constraints that would increase the size and utility of space assets, thus allowing more flexible and powerful space hardware.[5]

Fig. 1: Summary of Recommendations to Address the Six Major Impediments

IV. IDENTIFYING POLICY UNCERTAINTIES

IV.I Deriving OOS Policy Impediments and Constructing Enabling Policies

Currently, the field of OOS has no organized body of policies. To understand the policy impediments and construct enabling policies, the well-known engineering technique of the design reference mission (DRM) was repurposed for the policy environment, where it is utilized to analyze systematically the issues, uncertainty, and stakeholders involved in an OOS mission. The analysis begins with a sample mission scenario and three operational phases (including a potential accident) of the mission. From this, six major policy and legal impediments are derived, along with the uncertainty associated with each impediment. Finally, the DRM identifies the stakeholders bearing the primary legal and policy interests for each phase.

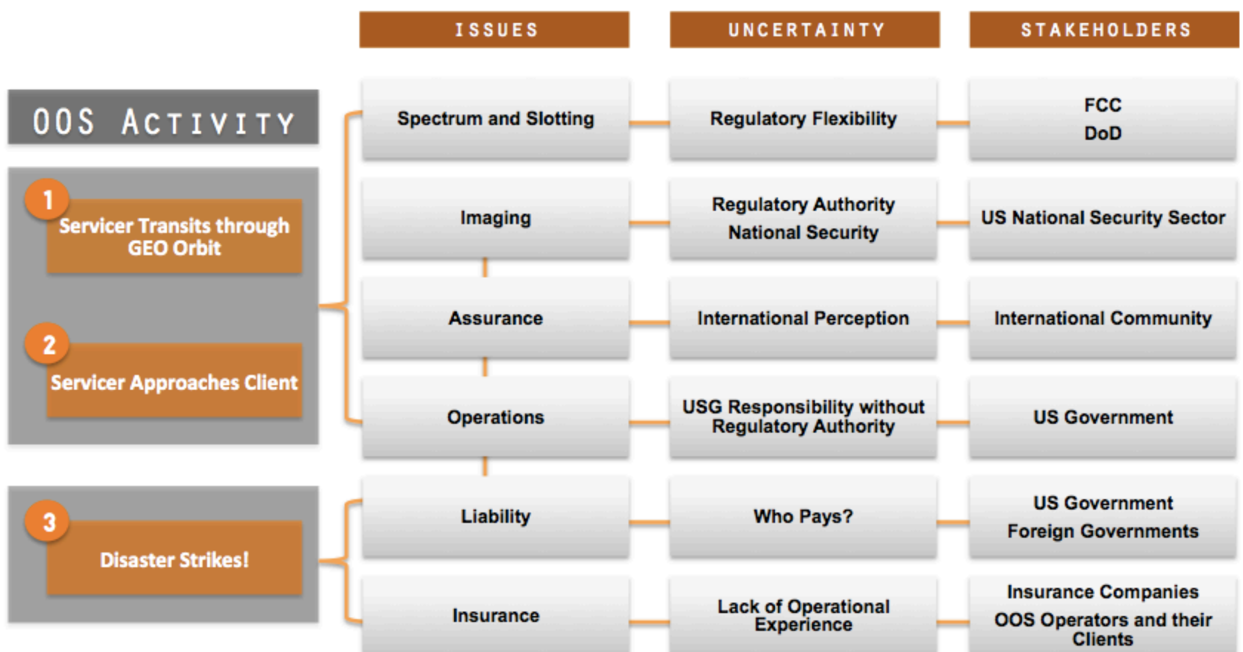

Fig. 2: Policy Design Reference Mission.

V. IMPEDIMENTS AND RECOMMENDATIONS

The policy DRM adduced six primary policy impediments to the formation of an OOS market. This section will describe these impediments and offer solutions to overcoming them.

V.I Liability and Ownership

Because of potential ambiguities in international space laws, OOS operators need a best practice that clearly identifies responsibility (responsibility may be allocated among multiple entities), before entering into any OOS agreements. The United States should publicly adopt and abide by this policy when acting as servicer. As a client, the United States should also insist on this determination. Such determinations will also clarify which entities may be subject to U.S. export control regulations when engaging in OOS activities.

OOS operations require a servicing satellite to dock with another orbital object and potentially alter that object. Such a procedure makes the chance of an accident occurring greater than in traditional satellite operations, where there is no intentional interaction with other space objects.[6] A servicing accident could damage not only the servicer and client, but may create debris that harms an uninvolved third-party satellite.

While states bear international responsibility for national activities in outer space, determining responsibility for space objects is a complex and uncertain process. It requires a careful analysis of the complicated webs of ownership and responsibility, especially with the uncertainty about the definitions of jurisdiction, control, and ownership of space objects. The complexity of this process may limit the number of companies that are willing to participate in the fledgling OOS industry. According to Article VII of the OST,

> Each State Party to the Treaty that launches or procures the launching of an object into outer space, including the moon and other celestial bodies, and each State Party from whose territory or facility an object is launched, is internationally liable for damage to another State Party to the Treaty or to its natural or juridical persons by such object or its component parts on the Earth, in air space or in outer space, including the moon and other celestial bodies.[7]

Moreover, Article VIII of the OST states: "A State Party to the Treaty on whose registry an object launched into outer space is carried shall retain jurisdiction and control over such object…while in outer space or on a celestial body."[8] For example, imagine a scenario in which a publicly traded American-European joint venture builds an OOS satellite, registers it in Brussels, and has it launched from Kazakhstan on a rocket procured in Russia. Which nation or nations would be ultimately responsible if this satellite caused an accident in orbit? The answer is uncertain. This uncertainty could inhibit the growth of a satellite servicing market, both by increasing the business risk to the client, and by increasing general distrust for servicing operations in the international space community. Adopting a preemptive acknowledgement of the responsible parties would significantly reduce this inhibiting uncertainty.

V.II Insurance

Technology demonstrations are necessary to provide data to help accurately identify and assess the potential risks to OOS operators. Because OOS operations are fairly new, they do not have the historical data required by insurance companies to assess adequately the risks of OOS activities. Such insurance would cover not only indemnification against liability for damages to a third party, but also the possibility of damage to the client and servicing satellites.[9]

Operations in space are inherently complex and difficult. Past experience in both the human and unmanned arenas demonstrate that an accident will eventually occur. Without insurance to minimize the risks inherent in space-based enterprises, the costs of most private space activities would be prohibitive.[10] OSS insurance does not exist and will not be able to exist unless two problems are addressed: the lack of technical and operational data about the activity, and an assessment of the actual costs of an eventual accident. These problems will gradually diminish as technical demonstrations allow insurance companies to gather the data that will allow them a more accurate assessment of potential risks.

The involvement of and consultation with insurance companies after a servicing accident may help to limit subsequent increases in the cost of insurance - insurance companies will use data gathered from the accident to better determine the cause and likelihood of similar accidents and to properly set their premiums in response.

Because insurance for launching a rocket is separate from insurance for payloads in orbit, questions of liability would likely be rendered moot. For example, if an accident were to occur in orbit, the potential costs would be lower than for launch accidents, because the risk to human life is lower.[11] Additionally, private insurance can likely cover liability and replacement costs without government involvement.[12] The exception to this general rule is the unlikely possibility of a debris cascade. Such a cascade occurs when debris from an orbital accident causes subsequent collisions involving satellites that were not involved in the original servicing operation.[13] However, there is not yet enough data to accurately predict the exact probability of such a scenario, or its magnitude.[14]

V.III. Spectrum/Slotting

In both the short and medium term, there are no significant domestic or international spectrum/orbital slotting policy issues that would impede OOS operations. On-orbit operations could have the potential to present novel policy concerns due to their transitive location in GEO and their close association in both location and spectrum between the servicer and the client. The Federal Communication Commission's (FCC's) ability to address these requirements was another potential source of uncertainty for the satellite servicing market. However, the FCC's current rules and regulations are robust and adaptable enough to accommodate the unique qualities of OOS operations.

Because orbital spectrum is limited, the FCC has created a licensing regime to maximize the number of orbital satellite systems while minimizing the amount of spectrum interference caused by these systems. Specifically, the FCC has adopted an "Open Skies" policy, which avoids artificially limiting the number of satellite operators and the types of satellite operations, while simultaneously maximizing entry, competition, and innovation in the satellite market.[15] The FCC receives spectrum and orbital slotting allocation from the International Telecommunication

Union, which adds an international dimension to this policy area.

Spectrum allocation/orbital slotting gives rise to three potential impediments to OOS. These impediments include the problems of sharing signal/orbital slotting, the extension of FCC authority to OOS, and the disposition of orbital slotting allocation for itinerant OOS satellites, roaming throughout GEO orbit.

V.III.I Signal/Orbital Slotting Sharing Agreements

Neither spectrum nor slot sharing require significant changes to FCC regulations. Some satellite servicers may plan to use the frequency spectrum of their client in order to avoid frequency interference.[16] Because satellite servicing requires close contact between the servicer and client, orbital slot sharing is a necessity. While the service operator would likely need an FCC license to operate in orbit, conflict between the frequencies of OOS operators and clients can be dealt with contractually between the two parties.

V.III.II Extension of FCC Authority

The FCC's authority would not need to be extended to specifically cover satellite servicing, because OOS satellites, while different in function from current satellites (such as telecommunication or Earth Observation satellites), use spectrum and slotting resources in the same manner as other satellites do; all satellites require spectrum and orbital allocation.[17]

V.III.III Slotting Allocation for Itinerant OOS Satellites

Satellites have transited above and below the GEO belt before; therefore, this practice does not represent a new practice and likely does not require new authorizations or regulations. Satellites, which transit through other orbits in GEO, are covered by a modification to their existing license. This practice covers the operation of OOS satellites in transiting GEO orbits as well.[18] Under current regulations, the operator of the transiting satellite must conduct a Radio Frequency Interference (RFI) impact assessment, to minimize signal interruption to other satellites whose orbit will be crossed.[19] This assessment is usually handled by coordination between the operators of the potentially affected satellites.

V.IV. Imaging

A broad definition of imaging is the acquisition of electromagnetic reflections and/or thermal emissions from an object for the purpose of determining physical characteristics of that object. There are many competing concerns, from proprietary concerns of the client, to national security concerns of the U.S. Government, regarding the images acquired from OOS operations. The best way to address these competing concerns is to regulate private space-based imaging of satellites through the National Oceanic and Atmospheric Administration (NOAA).

NOAA would be able to handle the intersection between the marketplace, international assurance, and national security concerns over the issue of imaging. This intersection is complex and filled with competing interests. The OOS industry needs standards and procedures for making optimal economic decisions, without falling afoul of export control laws; Clarity in how to navigate these concerns minimizes the uncertainty that servicers will face. A servicing vehicle will need to image its target in order to approach, refuel, repair, or perform any other servicing operation that requires rendezvous and interaction with a target satellite. Maximizing the public availability of these images, along with the implementation of a more robust global space situational awareness system, will help to assure other nations that a servicer is following its operational plan. However, the imaging of man-made space objects by commercial entities gives rise to national security concerns regarding the designs and capabilities of U.S. satellites and satellites with U.S. components. The public release of imaged satellites may fall afoul of export control laws in the United States.[20]

NOAA is experienced in regulating the imaging of Earth from space, and has procedures to address all of the above competing concerns, albeit in a slightly different context. Images derived from space-based imaging of the Earth are regulated because they may reveal information that can compromise national security, such as protected facilities or sensitive operations. Images derived from the space-based imaging of space objects will need to be regulated for the same reason: there are protected and sensitive technological components on many satellites, and the U.S. Government has an interest in preventing images of these components from falling into unfriendly hands, for national security reasons. NOAA already has established protocols for protecting proprietary space-based land imaging information and ensuring regulatory compliance with the dissemination of these images: "NOAA has the obligation to keep confidential proprietary information submitted by licensees or potential licensees…NOAA requires licensees to provide a summary of system information that can be made public within 30 days of issuance of the license."[21]

The Department of Commerce, operating through NOAA's Commercial Remote Sensing Regulatory Affairs office, is the only government department with the statutory authority to regulate (through the issuance of licenses) commercial remote sensing platforms.[22]

Licensing/regulation by the Department of Commerce, through NOAA, will ensure that private OOS providers are complying with export control laws and adhering to well established and tested procedures that will not create an undue increase in regulatory burden. Should NOAA require assistance in extending its Earth imaging expertise to space imaging, NASA has experience providing technical advice about space systems.[23, 24]

V.V. On-Orbit Operational Regulation

OOS activities, because they require physical contact with other satellites, have an increased chance of resulting in damaged space hardware than traditional satellite operations. To limit both uncertainty and the concomitant risk, the OOS industry needs a regulatory process that reviews and approves operation plans. The FAA is the logical agency to exercise this regulatory power to due to its past payload regulatory experience, and its activities in the Space Studies group. Minimal requirements of an on-orbit regulatory regime for satellite servicing would increase regulatory certainty for business, liability protection for governments, and transparency of operations for the international community.

Currently, there is little regulation of on-orbit commercial activities by the U.S. Government, beyond the few, broad regulations that exist for space objects in general. This has not been a significant impediment to commercial space activities in the past, but the repeated physical contact between satellites that occurs in OOS activities may make this a more significant issue should OOS activities increase. Under the Liability Convention of 1972, governments are ultimately liable for damages caused from space objects under their jurisdiction.[25]

Regulation of on-orbit satellite servicing activities will help governments ensure the safety and technical capability of OOS payloads, and therefore reduce the likelihood of accidents in space. Such a regime would cover both the servicing payload and the servicing operational plan. To assuage international concerns, the regime should also make the plans, vehicle capability, and telemetry information as public as possible without revealing proprietary or sensitive information. If OOS providers do not face prohibitive costs and will not be subject to losing proprietary information, their desire for governmental regulatory clarity should make their resistance minimal. A sufficiently robust regulatory regime could provide a safe harbor that would provide some shield from liability.[26]

V.VI. Assurance

To address potential international concerns that satellite servicing operations may be used as a cover for clandestine ASAT technology development, OOS operators should seek to be as transparent as possible, while establishing norms of behavior that regularize the OOS practice. For OOS providers with private customers, the proposed on-orbit regulatory regime will require increased transparency – the FAA will make information about payload purpose, a mission plan, and tracking and telemetry data publicly available. By operating in a transparent manner, international entities will be able to verify that servicers are doing what they say they will be doing, when and where they say they will be doing it. Furthermore, future participants in OOS operations will be able to learn the best practices of how to conduct servicing in a responsible manner by reviewing the plans and the data from the operations.

Another source of uncertainty is the fact that space hardware is inherently dual-use. The same technology that allows one satellite to approach another can be easily transferred to ASAT operations.[27] ASAT weapons have traditionally been a contentious issue in international space policy because such weapons constitute a threat not only to the national security assets of many countries, but also because such weapons have the potential to create dangerous orbital debris that can make the orbital environment more dangerous.

It will likely be difficult to have the military release flight plans and data for OOS missions. The military will argue that such data will limit their ability to protect national security. However, a voluntary decision on their part and that of intelligence agencies to release some data can significantly improve efforts to achieve international transparency and trust-building, while giving up no information that is not already discernible. The data that they could release includes a general timeframe of when OOS missions will be conducted on their space assets, a general location of where, and a general description of the OOS mission–type, OOS operations conducted by commercial providers on military and intelligence satellites cannot be held to the same level of transparency as commercial-to-commercial satellite servicing.

However, military and intelligence agencies can still contribute to increasing international confidence and building trust. Orbital launches cannot be kept secret; many amateur observers track the launches and orbital tracks of military and intelligence satellites. Therefore, it is logical to infer that other nations do so as well. Complete secrecy about the location of military and intelligence satellites is difficult if not impossible to maintain, and therefore the release of some very general information regarding military and intelligence OOS operations does not suppose a significant risk to national security.

VI. IMPLEMENTATION

VI.I. Areas where no Immediate Governmental Action is Initially Necessary

Liability, insurance, spectrum and slotting, and export control are all areas where the U.S. Government's regulatory practice currently appears to be sufficient, although some will benefit from the adoption of best practices (as discussed below).

VI.I.I Liability

Space launch has the potential for extensive third-party liability, and without U.S. Government backing, the liability would render private space launch infeasible. But the launch indemnification regime involves technologically complex hardware and is potentially costly, which makes it difficult to maintain, politically; it would be overly optimistic to expect a new, similar indemnification for on-orbit operations to pass, especially without demonstrated need.[28] Fortunately, discussions with private industry and launch insurance providers indicate that at least initially, insurance costs will not be prohibitive.

VI.I.II Insurance

As OOS operations become increasingly routine, should the risks of OOS become prohibitively expensive for the private industry alone, a Congressional response becomes more likely. Insuring against loss from an OOS mission is conceptually no different than insuring against the loss of a satellite from an early mission failure, except for the risk profile. The costs from damage to a single satellite are sufficiently small that despite technical uncertainty, the private insurance industry should be able to finance such risk without governmental aid.[29] As technical demonstrations provide more information about OOS operations, uncertainty will decrease, further refining the insurance industry's understanding of the probabilities of damage for OOS activities.

VI.I.III Spectrum and Slotting

Consultation with various experts indicates that the FCC's current licensing regime for spectrum and slotting is sufficiently flexible that it can administer on-orbit servicing's uniquely variable slotting and frequency allocation requirements without the need for additional rulemaking.[30] Moreover, should the FCC's current rule prove insufficient for OOS, its authority over slotting and servicing is sufficiently robust that further rulemaking will not require additional legislation.

VI.I.IV Export Control

Foreign servicers will have to navigate America's sometimes export control regime before servicing any domestic satellites. The uncertainty in how foreign providers may or may not be allowed to interact with satellites containing American-made components could significantly increase the riskiness of an international OOS venture. While the problems with export control might initially inhibit the creation of an international market for satellite servicing, it may not prove to be a problem once the international demand for OOS activities increases and such activities are proven to be profitable. Over time this will provide a further impetus to clarify how U.S. export control laws relate to OOS activities.

VI.II Imaging

To ensure legal authority and the full confidence of the agency, Congress should clarify their intent for NOAA to regulate all space imaging systems. Clarifying committee report language would give NOAA a stronger legislative basis for extending its jurisdiction to servicing vehicles, but there is a strong case that NOAA already has statutory authority over space imaging systems.

51 U.S. Code § 60121 authorizes the Secretary of Commerce to issue licenses for the operation of private remote sensing space systems. Although this provision falls under the subtitle "Earth Observations," and the chapter "Land Remote Sensing Policy", the text specifies that NOAA's statutory jurisdiction extends to "private remote sensing space systems."[31] This implies that "remote sensing" applies to all other imagery. Nowhere in Subchapter III is "remote sensing" used in the form of "land remote sensing." The Secretary of Commerce thus has the authority to license all remote sensing space systems, including those that are designed for space sensing.

NOAA's own assessment of their regulatory power is slightly more ambiguous, requiring that such systems be capable of imaging the Earth.[32] Despite NOAA's jurisdictional caution, the current regime also covers satellite imaging - any system capable of imaging a satellite must by definition be capable of imaging Earth, even if it never plans to use the capacity. Thus the strict interpretation of NOAA's current rules already includes space systems.

NOAA has not formally defined imaging.[33] While this has not proven to be an impediment to land remote sensing systems, there are some unique aspects to space imaging that may require further clarification. Systems that are meant solely for Guidance, Navigation, and Tracking[34] lack the capacity to image the Earth, but could image third-party satellites.[35] Specifying exactly what functionalities fall under NOAA's regulations could prove complicated, and should be left to NOAA. Fortunately, industry has not found the uncertainty over NOAA's jurisdiction to be an impediment to their satellite servicing efforts.[36] Nevertheless, Congress should request that NOAA clarify this ambiguity, by means of the standard rule-making process. This would not require action by the entire legislature, only a portion of the Committee. Applicable committees include: the House Committee on Science, Space, and Technology, Senate Committee on Commerce, Science, and Transportation, or the House or Senate Appropriations Subcommittee on Commerce, Justice, Science, and Related Agencies.

VI.III Operations

Concerns about liability and international assurance require an open and detailed regulatory regime for on-orbit operations overseen by the FAA. While the FAA inspects every launching vehicle, the FAA's current launch and payload licensing regime is not a complete regulatory scheme: it is concerned only with launch safety and it requires only a safety plan, not a full examination of the payload and operational plan.

This extension of the FAA's authority will require a formal legislative grant - a statute. Rather than a full statute, it may be more politically feasible to attach an amendment to the Commercial Space Launch Act. This amendment would extend the FAA's jurisdiction to the regulation of OOS activities. The amendment could specify that commercial servicers must submit operational plans and telemetry information, as well as allow the inspection of their servicing vehicles to verify the safety and capability of their designs. Due to the complexity of such craft, the law should include a formal recognition of NASA's capacity to act as a potential technical consultant, if and when its expertise is sought.

VI.IV Norms of Behavior/Best Practices

Requiring publication of operational plans, images, and telemetry information, would be very helpful to reassure the international community of the U.S. Government's benign intentions. Other, less formal steps would also bolster international confidence, including requiring a transparent framework of defining principles, publication of specific plans that abide by those principles, and the publishing of data that allows others to verify U.S. adherence to those principles. There are informal policies that would allow the U.S. Government to set the standard for private companies, and later for the international satellite servicing community. Best practices and standards are usually enforced by contract or risk markets - the government can require that a contractor use a standard, and insurance companies can push companies to use a best practice by charging lower rates for projects that use that practice.

As has been the case with international debris mitigation guidelines, the specific suggestions detailed below should be seen as initial steps in an ongoing effort to foster international trust of American and global satellite servicing efforts. The U.S. Government can set an example by publishing the results of best practices for its own satellite servicing missions, as well as requiring that any private companies contracted to service American satellites do the same:

- Avoid the perception of American arrogance or unilateral action in satellite servicing through a strong U.S. Government presence at relevant international **meetings and conferences,** while detailing the United States' current efforts in the area of OOS. To the greatest extent that national security allows; the U.S. Government should also be a ready and willing source of advice and expertise for international governments that seek satellite servicing capacity.
- Make imaging and telemetry **data available in an easily analyzable form** to set a cooperative tone as the market for on-orbit operations develops.
- Operational plans for satellite servicing should **follow international debris mitigation guidelines**,[37] including efforts to minimize orbital debris creation, and the risk of debris creation. Such plans should also take into account the mission's impact on orbital congestion and spectrum interference.
- Give **public notice of areas where OOS servicing vehicles will be imaging** to assure transparency, and encourage other countries to do the same. This will allow the protection of classified or proprietary orbital information.
- When an accident occurs, the servicer and client must be as transparent and cooperative as possible in **accurately reporting details of the accident**. It is important to not set a tone of secrecy that could grow into a nationalist defensive posture as the satellite servicing market grows.

- Without an **initial positive determination of the responsible entities** before an accident, the international community could find the resultant legal tangle contributory to increased skepticism of future satellite servicing activities. An initial positive determination of the responsible entities involved in satellite servicing will help to prevent legal tangles when an accident occurs, thus reducing legal uncertainty, which may be a threat to the formation and efficient functioning of a satellite servicing market.

VII. POLICY DRM REVISITED

Following the first Design Reference Mission (DRM), which identified the six impediments and associated uncertainties and stakeholders, this second DRM illustrates how the recommendations in this paper minimize uncertainties through the actions of the OOS community. Specifically, three federal regulators (FCC, NOAA, and FAA) can minimize potential uncertainties in the areas of spectrum and slotting, imaging, international assurance, and operations during the first two phases of the sample mission scenario. In the third phase, should an accident or disaster occur, uncertainty in the areas of liability and insurance may be minimized through an initial positive determination made by the OOS community (servicer and client) of the responsible entities.

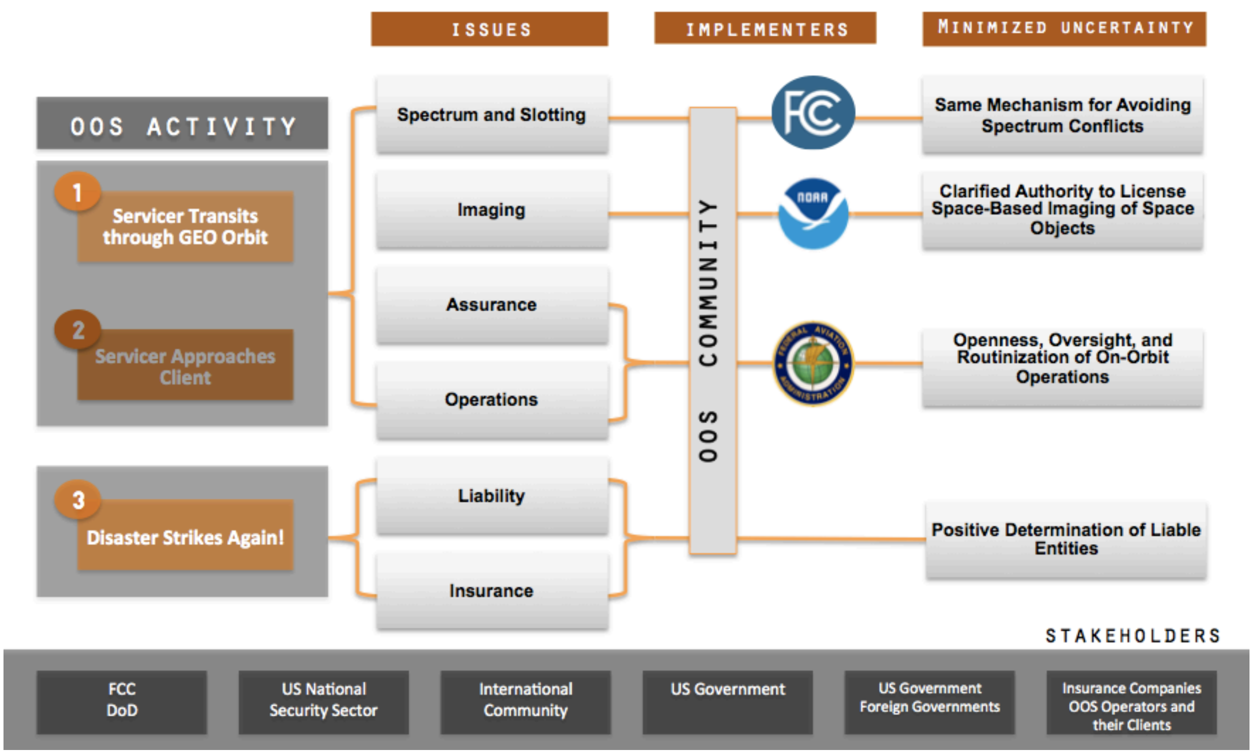

Fig. 3: Revisited Policy Design Reference Mission.

VIII. CONCLUSION AND FUTURE CONSIDERATIONS

VIII.I Conclusion

To allow for the development of a robust private OOS market and infrastructure, the United States Government should take action to reduce policy uncertainty. From the outset, OOS capabilities could save money by extending the lifetime of satellites, and reusing parts from otherwise defunct satellites. These benefits would persist and grow with the maturation of the industry. In the long term, this infrastructure and capability creates the conditions needed to develop the ability for large-scale orbital assembly.

Although the vast majority of space technologies are inherently dual-use, the potential military applications of OOS technologies are more evident than for most other space hardware. The technologies and techniques that allow a servicer to remove and repurpose parts from an inactive satellite can just as easily damage or dismantle an active satellite. An OOS vehicle's ability to approach and contact other satellites raises national security concerns. Though this paper’s primary goal is minimizing legal and policy uncertainty in the development of OOS capabilities, it does not fail to account for international concerns.

These domestic proposals are necessary to allow the development of OOS capabilities in the short and medium terms. The development of a robust and transparent long-term OOS regime begins with engaging in international consultation and collaboration in the development of best practices and norms of behavior. Although domestic policy actions can assist with the initial development of OOS capabilities, operations in space are inherently international in scope, and the long-term sustainability of OOS activities will require a significant degree of international transparency in OOS programs.

VIII.II Considerations for the Future

Beyond the private OOS market, OOS operations will encourage the growth of orbital operational technical capacity. This opens up the possibility of developing manufacturing techniques that would be needed for the capability to eventually assemble satellites in orbit. Unmanned orbital assembly would be a cost-effective way to avoid the mass-constraints of current launch technologies and to allow for the use of larger satellites with greater capabilities than currently exist.[38] Beyond increasing capabilities in areas like communication and weather forecasting, orbital construction opens up functionalities beyond those enabled by current technologies, such as next-generation space exploration.[39] Domestic policies that help foster an OOS market may be a prerequisite for the construction of these advanced technologies.

Encouraging international consultation and collaboration early in the process of developing OOS capabilities is likely to lead to a growing adoption and acceptance of international norms of behavior. While nothing will, or should, prevent the United States from developing and implementing its own system of practices and norms, seeking input from the international community has a greater chance of leading to the sort of changes that a long-term, vibrant OOS environment will require.

The key international treaties for OOS are the OST and Liability Convention, both of which were written and ratified at a time when private, commercial activity in space was extremely limited or non-existent. As space operations become increasingly private and international, these treaties will likely need to be revisited. Considering that treaty-making can be a lengthy and contentious process, the most practical method for space treaty evolution is to allow informal rules to develop organically from long-term international consultations and practice, in conjunction with the growth of actual capabilities.

There are multiple potential scenarios for added maturation of an international OOS market, ranging from unregulated norms and standards, to actual international regulatory agencies. Norms and standards, while not regulated by governments, could take the form of industry self-regulation, by means of an organization like the Space Data Association. International agencies could range in form from an ITU-like body, to the development of an international system for standardizing and codifying rules for safe activity, such as the system suggested by Jakhu and Nyampong based on the International Civil Aviation Organization, the UN agency "responsible for the safe and orderly development of international civil aviation."[40, 41] Regardless of what system develops in the future, clear domestic policy in the United States is required at present, in order to lay the groundwork for the conditions in which that future will develop.

This paper cannot easily suggest policies beyond the short-term recommendations that have been presented. The industry lacks technical demonstrations associated with the development of complex, continuous OOS capabilities. It also lacks the ability to comprehensively assess the needs and concerns of international space actors. To build a solid foundation for OOS activities in the long term, industry and policymakers must first address immediate domestic policy concerns. To help ensure the maturation and success of long-term OOS operations, capabilities must first be successfully achieved in the short and medium terms, and this paper's recommendations reflect that fact.

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[1] *See generally* ‘‘On-orbit satellite servicing study project report’’ (Greenbelt, MD: National Aeronautics and Space Administration, Goddard Space Flight Center, October 2010); Long A.M., Richards M.G., and Hastings D.E., "On-Orbit Servicing: A New Value Proposition for Satellite Design and Operation", Journal of Spacecraft and Rockets, Vol. 44, No. 4 (2007), pp. 964-976; Kreisel J., ‘‘On-orbit servicing: issues and commercial implications’’ (presented at the International Astronautical Congress, Bremen, Germany, September 29, 2003).

[2] Krolikowski, David E. "Commercial On-Orbit Satellite Servicing and Active Debris Removal: Policy Considerations Raised by Industry Plans." (2012) *Available at*: http://swfound.org/media/62009/CommercialOn-OrbitSatelliteServicingandActiveDebrisRemoval_V_5.pdf

[3] *See* Foust, Jeff (2012-06-25). "The space industry grapples with satellite servicing". Space Review. *Available at:* http://www.thespacereview.com/article/2108/1.

[4] Meredith, P.L. Phone Interview. 21 February 2014.

[5] *See, e.g.* Shubber, Kadhim "NASA-backed space spider concept to build giant satellites in orbit" Wired, September 10, 2013. *Available at:* http://www.wired.co.uk/news/archive/2013-09/10/spiderfab-tethers-unlimited

[6] *See* Weeden, B.C., et al. "International Perspectives on On-Orbit Satellite Servicing and Active Debris Removal and Recommendations for a Sustainable Path Forward." Secure World Foundation (2013) p. 4. *Available at:* http://swfound.org/media/119601/IAC-13-E3.4.7-Paper.pdf

[7] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (1967). Article VII.

[8] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (1967). Article VIII.

[9] Meredith, P.L. Phone Interview. 21 February 2014.

[10] Elbert, Bruce R. *The Satellite Communication Applications Handbook* p. 106 Section 3.4.2.1 "Launch Insurance." (Artech House, 2004).

[11] Steptoe, J. Phone Interview. 7 March 2014.

[12] *Id*.

[13] Kessler, D., Cour-Palais, B. (1978). "Collision Frequency of Artificial Satellites: The Creation of a Debris Belt". Journal of Geophysical Research 83: 2637–2646.

[14] *See* "Space junk at tipping point, says report," BBC News. 1 September 2011, *Available at:* http://www.bbc.com/news/world-us-canada-14757926.

[15] FCC, "Connecting the Globe: A Regulator's Guide to Building a Global Information Community. VIII. Regulating Satellite Networks: Principles and Process" *Available at:* http://transition.fcc.gov/connectglobe/sec8.html

[16] Kensinger, K. Phone Interview. 13 March 2014.

[17] *Id*.

[18] *Id*.

[19] *Id*.

[20] *See*, "Export Controls and Research at WPI," Worcester Polytechnic Institute Presentation, pgs. 4-10. *Available at:* http://www.wpi.edu/Images/CMS/OSP/WPI_Export_Control_Slides-web_training.pdf

[21] NOAA, "About the Licensing of Private Remote Sensing Space Systems," *Available at:* http://www.nesdis.noaa.gov/CRSRA/licenseHome.html

[22] "The Land Remote Sensing Policy Act of 1992." 15 USC 82 Sec. 5621.

[23] The possibility may exist that various forms of electromagnetic radiation used in imaging may damage sensitive components on imaged satellites. Improper treatment of each of this issue could render a servicing mission unviable, however NASA has the technical expertise to assess this potential risk and suggest means to mitigate it.

[24] *See*, *e.g.*, NASA Technical Consulting Team (NTCT) for The Sentinel Mission. *Available at:* https://b612foundation.org/our-team/sentinel-review-team/

[25] Convention on International Liability for Damage Caused by Space Objects (1972). *Available at:* http://www.oosa.unvienna.org/oosa/SpaceLaw/liability.html

[26] *See, e.g.* American Home Products Corp. v. Johnson & Johnson, 672 F. Supp. 135 (S.D.N.Y. 1987) (FDA approval of labels fit preclude tort cases).

[27] *See* International Space University. (Summer 2007). "DOCTOR: Developing On-Orbit Servicing Concepts, Technology Options, and Roadmap." *Available at:* http://isulibrary.isunet.edu/opac/doc_num.php?explnum_id=102

[28] Meredith, P.L. Phone Interview. 31 March 2014.

[29] *Id.*

[30] Kensinger, K. Phone Interview. 13 March 2014.

[31] "The Land Remote Sensing Policy Act of 1992." 15 USC 82 Sec. 5621.

[32] 15 CFR Part 960

[33] *See Id*.

[34] *E.g.* star trackers.

[35] Weeden, B.C. et al. Personal Interview. 24 January 2014.

[36] Armor, J. and Weston, C. Personal Interview. 21 February 2014.

[37] Space Debris Mitigation Guidelines of the Committee on Peaceful Uses of Outer Space (2007). *Available at:* http://www.oosa.unvienna.org/pdf/publications/st_space_49E.pdf

[38] *See* FAA, "Commercial Space Transportation 2013 Year in Review" *Available at:* https://www.faa.gov/about/office_org/headquarters_offices/ast/media/FAA_YIR_2013_02-07-2014.pdf

[39] *See, e.g.,*Gralla, Erica L., and de Weck, Oliver L. “Strategies for On-orbit Assembly of Modular Spacecraft." Journal of the British Interplanetary Society V.60 pp. 219-277 (2007) *Available at:* http://strategic.mit.edu/docs/2_20_JBIS_60_6_219_Tugs.pdf

[40] Jakhu, R. “Are the current international space treaties sufficient to regulate space safety, and establish responsibility and liability?” Proceedings of the 2nd IAASS Conference: Space Safety in a Global World. 14-16 May, 2007. Chicago, USA.

[41] Nyampong, Yaw Otu Mankata. (February 2013). Legal and Regulatory Challenges to Active Debris Removal and On-Orbit Satellite Servicing Activities. (pdf) Singapore Conference on On-Orbit Satellite Servicing and Active Debris Removal. Web. February 19, 2014. *Available at:* http://swfound.org/media/101969/Yaw-Legal_Regulatory_Challenges.pdf