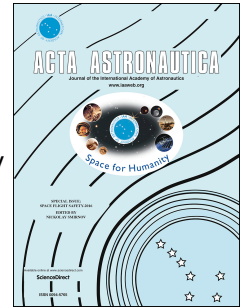


Accepted Manuscript

Promoting international co-operation in the age of global space governance – A study on on-orbit servicing operations

S.W. Chiu



PII: S0094-5765(18)30180-2

DOI: [10.1016/j.actaastro.2018.07.019](https://doi.org/10.1016/j.actaastro.2018.07.019)

Reference: AA 7000

To appear in: *Acta Astronautica*

Received Date: 24 January 2018

Revised Date: 4 July 2018

Accepted Date: 11 July 2018

Please cite this article as: S.W. Chiu, Promoting international co-operation in the age of global space governance – A study on on-orbit servicing operations, *Acta Astronautica* (2018), doi: 10.1016/j.actaastro.2018.07.019.

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

68th International Astronautical Congress (IAC), Adelaide, Australia, 25-29 September 2017.
Copyright ©2017 by _____. Published by the IAF, with permission and released to the IAF to publish in all forms.

IAC-17-D4.2.14

**PROMOTING INTERNATIONAL CO-OPERATION
IN THE AGE OF GLOBAL SPACE GOVERNANCE –
A STUDY ON ON-ORBIT SERVICING OPERATIONS**

_____*

7 September, 2017

* Corresponding Author

Abstract

Outer space exploration has been an area where the international community demonstrated a significant level of co-operation, successfully transcending geographical, national and cultural boundaries. In the age of global governance, international co-operation has never been more important in resolving today's global challenges. One of such challenges is the growing amount of space debris in orbits, which, if unresolved, will not only undermine global information and communications technology (ICT) system, but will also hinder areas of sustainable development where outer space activities contribute to. (e.g. satellite imaging for disaster warning and management, satellite imaging for agricultural purpose) This paper proposes to conceptualize space orbit and radio frequency as an essential global commons, whose governance requires international co-operation. In examining potentials and challenges in moving forward space orbit governance, the paper pays particular focus on ensuring space safety and sustainability through the introduction of on-orbit servicing (OOS) operations. The paper will identify aspects of OOS that warrant further collaborations, specifically, the standardization of docking and rendez-vous practices that could facilitate future space activities. Recognizing the potential of future commercialization of refueling, repairing and debris removal operations in orbits, this paper argues that standardization practices would be the first step towards enhancing international co-operation, as well as in strengthening the existing regime of peaceful use of outer space. Ultimately, it could play a role in addressing one of today's most imminent challenges – ensuring sustainable use of global commons.

Keywords: Global Governance, Space Sustainability, International Co-operation, On-Orbiting Servicing

Acronyms/Abbreviations

CCS	Carbon Capture and Storage	
CPR	Common Pool of Resources	
CTBTO	Preparatory Commission for the	Comprehensive Test Ban Treaty
ECOSOC	United Nations Economic and Social	Council
GEO	Geostationary Orbit	
GPS	Global Positioning System	
IADC	Inter-Agency Debris Co-ordination	Committee
IRNSS	Indian Regional Navigation Satellite	System
ITU	International Telecommunication	Union
LEO	Lower Earth Orbit	
OOS	On-Orbiting Servicing	
PMD	Post-Mission-Disposal	
SDG	Sustainable Development Goals	
TRL	Technology Readiness Levels	
UNOOSA	United Nations Office on Outer Space	Affairs

1. Introduction

Space is gradually and firmly becoming the next arena to face what Hardin would describe as the “tragedy of the commons.” [1]

In multiple international forums, scholars and policy-makers have expressed their concerns over the sustainability of space activities. Immaterial resources in outer space, such as space orbits and radio frequency, are becoming increasingly competitive, contested, and congested.[2]

Many conceive space to signify infinite resources. On the contrary, resources in outer space, most notably orbital slots, require international co-ordination and co-operation in order to ensure sustainable use. While space may be forever expanding and thus infinite, outer space resources such as the moon and orbital regimes are not. As the international community joins hands in addressing global problems such as climate change and environmental conservation, the need to ensure sustainable use of limited outer space resources are often neglected at international forum. In recent years, practitioners and policy-makers in the space sector have become increasingly alarmed of the deteriorating situation of congestion in major orbits. As viable means of active debris removal in space are yet to emerge, on-orbit collision becomes a question of when, not a question of if. [3]

1.1 The Importance of Space Technologies in Society

The introduction of the UN Sustainable Development Goals signals a global consensus in pursuing global prosperity and development through sustainable means. Neither could be achieved without the support of space technologies.

The consequences of orbital disruptions, thus, could be very dire. Satellite technologies play an integral role in navigation, in providing early warning of natural disasters, such as tsunamis and hurricanes, as well as in enabling rural mobile and instantaneous communications and broadcasting across the globe. In addition, multiple industries have become dependent on space data and technologies. Take the example of the imminent commercialization of fully autonomous vehicles, an emerging technology for which satellite navigation systems have become critical in providing real-time navigation. Even before the full dominance of driverless vehicles on the road, many drivers and vehicles nowadays already rely heavily on Global Navigation Satellite Systems (GNSS).

Satellite communication constitutes an integral and essential part of today's global socio-economic activities, not only for developed countries, but also for emerging economies. In India, land-based broadband faces considerable cost and technical challenges in reaching remote areas. Satellite internet coverage has hence proven an effective alternative in connecting the poor in rural areas, driving development in areas with limited infrastructure. [4]

1.2 Technological Development and Growing Pressure on Space Sustainability

There are mounting concerns over worsening congestion and accumulation of space debris in major orbits, including the geostationary orbit (GEO) – where a number of the world's navigation systems are currently located. According to Joseph Gangstad, orbital slots at GEO are described as “prime - and scarce - real estate.” [5] To understand the scale of increasing satellite population in outer space, one needs only to examine the expanding number of navigation constellations installed in the past decade. The US NAVSTAR Global Positioning System (GPS) was the first navigational satellite system in orbit in early 1993. Russia followed by sending its GLONASS system later that year. Within 6 years, the number of constellations has tripled. By 2017, Europe's Galileo, China's BeiDou, Japan's Quasi-Zenith (QZSS) and the Indian regional navigation satellite system (IRNSS) all have multiple satellites in orbit. [6] Given this remarkable rate of growth, continuous negligence of mitigating orbital congestion and space debris could pose significant risk to telecommunications and navigation infrastructures. In worst case scenario, experts have voiced the possibility that a whole orbital regime could be compromised. [7]

As international organizations, governments, industry and civil society all seek to meet the vision of Agenda 2030 and the UN Sustainable Development Goals (SDGs), the international space community has much to contribute to driving socio-economic development and promoting sustainability on the ground. At the same time, while sustainable development is understood as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs,” [8] there is still much for the space community to establish and achieve in order to ensure that outer space activities are conducted in a sustainable manner.

With reference to Hardin and Ostrom's work on global commons, and principles underscored in UN Sustainable Development Goals, this work conceptualizes space resources as valuable global commons that warrant further examination and international attention. Focusing on addressing sustainable use of orbital resources, the paper investigates limits and potentials of international co-operation that could ensure space sustainability in orbits. Drawing from the experiences of standardization practices in other industries, the paper seeks to identify a possible framework of co-operation, along with potential challenges that the international community need to overcome in promoting a sustainable future for space activities and technologies.

2. Theoretical Framework and Literature Review

2.1 Tragedy of the Commons

Hardin's seminal work examining the “tragedy of the commons” in 1968 identifies a scenario where common resources become depleted. As a result, users sharing the same pool of resources face diminishing returns for their activities. He uses the example of overgrazing to illustrate the problem -- herdsman sharing the same meadow (i.e. the commons) have the incentive of adding more animals to his/her herd, enjoying increasing profits that each additional cattle generates. However, each additional animal would add to the problem of overgrazing. Each herdsman enjoys almost all the profits that an additional animal brings, but only a fraction of the cost of overgrazing,

since such cost is shared with other herdsmen. All would hence seek to put more animals on the meadow to maximize profits for his/her own interest. This would ultimately lead to what Hardin describes as the “tragedy of the commons” -- when the ecosystem of the meadow reached its limit and unable to support any further addition of cattle. The condition of the meadow would deteriorate, rendering further additional animals to yield diminishing returns. [9] Hardin argues, “Freedom in a commons brings ruin to all.”[10]

Following Hardin's publication, scholars argued that *only* private property rights could prevent the tragedy of the commons. By delineating clear ownership of land, the herdsmen would then take into account the cost of overgrazing, preventing the tragedy of the commons from occurring. [11]

2.2 Governing the Commons

For a long time, clear property rights were considered the sole means to prevent the tragedy of the commons. It was not until Elinor Ostrom's 1990 study that alternative measures in governing the commons are identified. In studying farming practices in Swiss village, Ostrom found that the villagers managed to share a communal meadow effectively for five centuries. The village avoided overgrazing by establishing rules that prohibit farmers from sending more cows to the meadow than he/she can feed in the winter.[12] Similarly, lobster fishermen in Maine also put in place effective self-regulated mechanisms which prevent overfishing of lobsters in the region. In both scenarios, tragedy of the commons are avoided with self-initiated measures within the groups, without resorting to private ownership, nor top-down rules and regulations imposed by external authorities. The Economic Sciences Prize Committee for Nobel prizes recognizes Ostrom's work as highly original and “challenges conventional notions whereby enforcement should be left to impartial outsiders.” [13]

3. Analyses

3.1.1 Planet Earth as Common Pool of Resources

While the discussion on sustainability has been around for decades, it was only recently that a global consensus emerged in acknowledging that it requires concrete collective actions. The 2030 Agenda for Sustainable Development (also known as the UN Sustainable Development Goals) cements planet earth as the undisputed global commons. Putting particular emphasis on people, planet, prosperity, peace and partnership, the SDGs seek to tackle poverty and hunger, to realize the full potential of human beings, and to promote prosperity through peaceful partnership., all the while taking into account the necessity of protecting our planet. [14]

3.1.2 Space Orbits as Common Pool of Resource

It has taken decades for the international community to agree that the environment and the planet constitute what Ostrom would call a “common pool of resources” (CPR). It is finally agreed that international challenges such as environmental degradation, poverty and resources depletion affect us all. Yet in spite of current international efforts in ensuring sustainable development, sustainable use of outer space resources remains outside mainstream discussions. This could be partly explained by the invisibility and intangibility of immaterial resources in outer space, and the misconception that they are infinite. Unlike public goods which are non-excludable and non-rivalrous, certain outer space resources (i.e. space orbits) exhibit many of the characteristics of CPR. For example, consumption of resources such as orbital slots and frequency spectrum would mean reduced availability for others, including future generations. [15]

Reduced availability is aggravated by a growing number of space debris that increases the probability of orbital collision. In minor instances, collision may not undermine the operations of space objects in orbit. In more severe cases, however, orbital collision could trigger a chain reaction that significantly affects the lifetime and functions of operational satellites. [16] To date, an economically viable way of removing space debris is yet to emerge. A number of demonstration of On-Orbit Servicing (OOS) operations are now in advanced stage of development and testing. Many projects show substantial potential and demonstrate the feasibility of debris removal. 2018 in particular witnesses multiple advances in OOS projects. In April 2018, three types of space-debris removal technologies had been launched for the International Space Station aboard a SpaceX's Dragon capsule. These technologies, part of a EU-funded project called RemoveDEBRIS, include space-debris capture techniques using a harpoon, a net, and a drag sail. [17] Many of these experiments have undergone rigorous trials and research on the ground before the

launch in April. The Harpoon approach, for example, was initially invented by Astrium as early as in 2012. [18] If successfully deployed, it was envisioned that the technique could remove up to 10 objects per year. [19]

The RemoveDEBRIS experiment is by no means the only endeavours in advancing space debris removal or OOS technologies. Orbital ATK has also scheduled to launch its first Mission Extension Vehicle (MEV) in late 2018, with the objective of beginning its mission extension service in 2019. [20]

In addition, the finance sector has also joined major industry actors and governments in taking an interest in space debris removal technologies. Emerging start-ups, such as Astroscale, currently leads technologies to tackle the problem of space debris accumulation. [21] Collectively, these efforts reflect a burgeoning community of actors dedicated to advancing research in tackling the problem of space debris accumulation.

While multiple studies illustrate the potentials of the future use of OOS, it faces a number of challenges before these technologies could reach the state of commercialization that enables space debris removal in a meaningful scale. Technological obstacles aside, non-technical challenges also pose substantial barrier to roll out this first-of-a-kind technology. First, underdevelopment of space law and legal uncertainty surrounding space activities hinder R&D endeavours in this area. Due to concerns over liability, the RemoveDEBRIS Experiment discussed had to carry its own “debris” up to space for testing purpose. This is in spite of the fact that there are considerable amount of existing debris already in orbit. Considering the fact that the cost of launching objects into space remains an extremely costly endeavour, inadequate legal infrastructure poses considerable challenges to the commercialization of OOS technologies and operations.

Second, a lack of standardization for existing satellites means that the majority of today's satellites are not designed to be serviceable, posing questions on technical interoperability and cost-effectiveness in the longer-term horizon as OOS technologies mature.

Although there exists initiatives in tracking trajectories and movement of space debris, as well as multilateral guidelines in de-orbiting satellite at the end of its mission (both will be discussed in later sessions), only OOS has the potential to substantially reduce the number of space debris. In other words, we are still putting more cows to Hardin's meadow. If no major governance mechanism is put in place, major orbits could very soon face the “tragedy of the commons” – a scenario similar to overgrazing that renders any further addition of satellites in orbit to yield diminishing returns.

Considering how much today's society relies on satellite technologies, this risk should not be taken lightly. Depletion of orbital positions could have direct implications on development and sustainability on earth. Imagine a scenario where satellite monitoring, navigation and communication are compromised, not only would it mean interruptions of access to internet, rural mobile communication, and satellite entertainment (i.e. TV), it would also jeopardize food production, detection of earthquake, and undermine relief efforts in areas hit by natural disasters and humanitarian crises. To illustrate the diverse applications of space technologies, consider India's RISESAT – dedicated to facilitate and maximize rice production [22] ; and the satellite network of the International Monitoring System of the Preparatory Commission for the Comprehensive Test-Ban Treat (CTBTO) – the organization tasked with analyzing seismic, hydro-acoustic, radionuclide, and infrasound data transmitted from around the world for detection of nuclear testing, and more importantly, assisting in the detection of earthquake. [23]

3.2 Global Space Governance

To ensure a viable future of space activities, the international community would need to recognize orbits as global commons that require international efforts in co-ordination and co-operation.

There are various approaches to archive global space governance and prevent tragedy of the commons from happening in space. However, privatization and private ownership in this case cannot be the most ideal approach in addressing the problem. Not only would it be difficult to enforce, it may also be controversial as some would interpret privatization of space orbits to contravene principles outlined in the Outer Space Treaty. Ostrom's conceptualization of governance of the commons, on the other hand, could be highly relevant in examining sustainable use of the orbits. It may also foster deeper co-operation among States.

3.2.1 Space Governance without Space Government

First, Ostrom's understanding of self-governance of commons can exist without the interference of an impartial outsider. International Relations scholars have long argued that the international system is one of anarchy – where there is no superior authority exterior to the State in policing violations of established rules, norms and regulations. [24] Compliance to international law is based largely on States' voluntary adhesion. In instances of violations, certain sanction mechanisms are in place. (e.g. the International Court of Justice, and the WTO dispute settlement mechanism) However, punishments such as sanctions are either imposed unilaterally by States, or collectively after careful deliberation at the international level. There is no impartial external entity beyond the State that can impose and enforce punishments on States. All sovereign States are equal. The United Nations system *does not* have an enforcement unit endowed with hierarchically superior authority to police Member States' behaviours.

Numerous cases documented in Ostrom's work have shown that governance of CPR can be self-initiated and can be achieved without the intervention of impartial third party with hierarchically superior authority. In practice, there already exists numerous measures governing the use of orbits to varying degree of success. The following sector will examine the potential and limitation of these multilateral and international measures.

3.3.1 Governance of Geostationary Orbit -- The International Telecommunication Union (ITU)

The geostationary (GEO) orbit is a “tunnel-like ring” stretching to around 161,500 miles in circumference, with each degree constituting 448 miles. [25] To avoid physical collision, the satellites at GEO orbit maintain a certain distance apart from one another. In practices, avoidance of frequency interference and demands for specific positions along the orbital arc also play a part in determining the distance. In past decades, satellite spacing has gradually decreased, shrinking from 9 degrees to 5, and even to 2 degrees over the sought-after arc covering North America. [26]

Recognizing the finite nature of orbital slots and radio frequencies, the ITU has in 1998 asserted that radio frequencies and associated orbits are “*limited natural resources*.” [27] Orbital slots and radio frequency licensing are currently co-ordinated by the ITU. International legal instruments are also in place to register satellites which occupy radio frequency and orbital positions.

While existing governance mechanisms contribute significantly to resolving co-ordination problems, they only managed to mitigate congestion problems and address issues of space sustainability to a much lesser degree. This is due to the fact that the right to occupy radio frequency and orbital slots commence not when the satellite reaches orbit, but as soon as registration is successfully secured with the ITU. Furthermore, the right to use these two resources are granted on a first-come, first-served basis. As a consequence, multiple actors rushed to register for these increasingly scarce slots, resulting in not only mounting physical congestion, but also the emergence of the phenomenon of “paper satellite” - where slots are occupied with no immediate schedule of actual satellite launch. In other cases, it is observed that some satellites appear to be procured with the sole purpose of occupying an orbital position (also known as dummy satellite), while their actual functions are still under development.[28] Heightened congestion is further evident by an ever growing number of disputes filed between States over the use of orbital positions and frequency interference, many of which the ITU was unable to resolve. Ram Jakhu attributes these challenges to the limitations of dispute resolution mechanism of the ITU and inadequate regulations at the national level. [29]

3.3.2 Inter-Agency Space Debris Co-ordination Committee (IADC)

In addition to international legal instruments that are legally binding, governance of CPR in space could also be pursued through voluntary adhesion to international guidelines. The Inter-Agency Space Debris Co-ordination (IADC) Steering Group and Working Group issued the Space Debris Mitigation Guidelines in 2007 to address the sustainable future of outer space activities. According to the guidelines, satellite coming to an end of its service in GEO orbit should be manoeuvred away to a “graveyard” orbit in order to avoid interference with other functioning satellites, and to minimize the danger poses to other operational spacecrafts as a result of collision with space debris. [30]

The international guidelines emerged after examining inputs from numerous space agencies from across the world. It demonstrates that international co-operations are plausible and that States do recognize the need to discuss issues of space sustainability. They share their own national experiences in governance and space legislation.

Nevertheless, the introduction of standard practices for post-mission disposal only emerged in the past decade and is yet to achieve full compliance. In the US, binding national legislation stipulates that satellite needs to ensure sufficient fuel at the end of its lifespan to manoeuvre it to graveyard orbits. Unfortunately, even with binding regulations, only around one third of satellites complied with the regulation. Those failing to manoeuvre to graveyard orbits become space junks and continue to orbit in the congested ring, aggravating the deteriorating situation of space debris in outer space. [31] Data from the European Space Agency shows that only 6% of catalogued space objects in GEO orbit are operational satellites. [32] The number of space debris is likely higher as current technology only tracks and detects debris larger than the size of a softball in lower earth orbit (LEO), and larger than 1 meter in GEO orbit.[33] While many debris at LEO orbit will eventually succumb to gravity and be destroyed while entering earth's atmosphere, those in the GEO orbit will linger on for thousands of years. [34]

4. Ensuring Space Sustainability – On-Orbit Servicing

While the above examples illustrate that international co-operation can organically emerge to govern CPR, these mechanisms currently cannot adequately ensure sustainable future of space activities, and would need to be strengthened.

At the moment, it is observed that compliance to binding regulations and voluntary adhesion to guidelines are comparatively weak. In 2015, less than half of satellites that retired in the GEO orbit complied with the IADC guidelines.[35] Multiple factors contribute to the low rate of compliance, and State's maximization of self interests may not be the sole reason.

First, monitoring non-compliance and violations are expensive and difficult. The technologies that monitoring requires may also not be readily available. Unlike other international regimes, such as the Human Rights regime, where a large number of NGOs with ECOSOC observer status contributes to monitoring compliance, space-related civil society is still under development. Furthermore, in the hope of inspiring voluntary adhesion, the IADC has decided not to use “naming and shaming” as in the Human Rights regime to ensure compliance, refraining from identify those who failed to respect the guidelines.

Second, compliance to existing guidelines is expensive and require technical expertise, particularly for developing countries. Messeri and Richards observe that the satellite industry has moved towards producing customized products that are getting larger and more expensive.[36] Purchase and investment in new satellite also entail higher risk than in other businesses. As such, there is little financial incentive for space actors to invest in extra fuel for post mission manoeuvring.

4 Discussions

4.1 The Necessity of On-Orbit Servicing

Given that orbital resources are global commons, ensuring sustainable use of space resources is paramount. Existing international governance mechanisms are not only weak, they cannot fully halt ongoing production of space debris, nor recycle defunct space objects. They are devised mainly to slow down the pace of debris accumulation and deteriorating congestion in orbits. In other words, there needs to be ways to *reduce* the number of space debris, in addition to slowing down the process of debris creation.

Here, OOS technologies become crucial. There is the prospect of prolonging satellites' lifespan through repairing, refueling, and of alleviating congestion and minimizing the potential of collision through tugging defunct spacecrafts and satellites accurately to graveyard orbits. However, the fact that existing models of satellites are not designed to be serviceable means that there remain considerable obstacles to commercialize or promulgate OOS.

This paper contends that the international community could play a crucial role in facilitating the promulgation of OOS operations, by establishing common standards and ensuring interoperability of future models of satellites and emerging OOS technologies.

4.2 Promoting International Co-operation – Standard-Setting

Although many States and private actors recognize the relevance of OOS technologies in tackling the problems of space debris and orbital congestion, to date there are but limited discussions on the long-term vision of integrating OOS into the space industry. Some of the barriers are technical, some are legal and financial, but an important part is policy-related. If the objective is to ensure space sustainability, OOS needs to be commercialized and an OOS industry needs to emerge, mirroring the gradual expansion of the satellite industry, or the solar panel industry.[37]

But for a commercial OOS industry to emerge, there needs to be sufficient demand for OOS service. Yet, there can be no sufficient demand if satellites' design remain unserviceable, or worse, incompatible with mature OOS technologies. This is what Messeri and Richards understood as the “chicken and the egg” problem.[38] They argue that “without external forces affecting supply and demand (e.g. government-sponsored proof-of-concept missions, tax incentives), market forces themselves may not be adequate to foster an OOS industry.” [39]

Experiences of developing carbon capture and storage (CCS) technologies in the UK similarly echo Messeri and Richards' argument. Government support appears essential in enabling the taking-off of new, “first-of-a-kind” technology aimed mainly at addressing sustainability. After having cancelled its second pledge of support worth £1bn for two CCS demonstration projects, it became extremely unlikely for CCS to be successfully developed and implemented within the UK. Experts in general agree that without CCS, the UK is unlikely to meet its binding carbon reduction target. [40]

The next problem that needs to be resolved is compatibility issue. Intergovernmental engagement is needed for establishing standardization for the commercialization of OOS. Messeri and Richards observe that, “presently, it is unclear who the key institutions are that might have enough industry sway to dictate the direction in which interoperability standards should head.” They also assert that “the most critical barrier to further development of robotic OOS is an overarching organizational issue.”[41]

Standard docking or rendez-vous mechanisms for refueling and repairing can prove to be essential enablers of the commercialization of OOS. However, contrary to Messeri and Richards' contention, these standards should be developed in close consultation with both State and industry actors, instead of being dictated by one, or a few actors. The following paragraphs highlight the rationales behind promoting standardization through international co-operation.

4.2.1 International Standard-Setting as Confidence-Building

Last year, discussions on establishing common standards for future space-based capabilities have finally gained momentum in the US. In late 2016, the US Defense Advanced Research Projects Agency (DARPA) announced a call for proposals to create a Consortium For Execution of Rendezvous and Servicing Operations (CONFERS). This DARPA-led initiative has the objective of building “consensus-based technical standards” for the promotion of “responsible on-orbit commercial servicing operations.”[42] DARPA also asserts its intention to ensure that the Consortium is transferred to industry stakeholders by 2021. [43]

In late 2017, it was announced that the Phase 1 of the consortium has been awarded to a team led by Advanced Technology International (ATI). The team consists also of other US-based entities, including the Secure World Foundation, Space Infrastructure Foundation, and the University of Southern California's Space Engineering Research Center. [44] While such initiative reflects positive developments of multi-sectoral efforts to enable OOS commercialization, it would be ideal if such discussions could stretch beyond national, and/or regional confines, to encompass contributions and inputs from the international community.

There is a case to call for discussions on standardization and interoperability for OOS at the international level, to be led by UN, and engage actors from both spacefaring and non-spacefaring States, as well as the industry, and academia. This is not only to ensure a comprehensive understanding of the issue, but also to strengthen confidence-

building efforts at the international level. Long-term space sustainability requires collective contributions from both States and private actors, from both developed and emerging economies. Due to the potentially dual-use nature of OOS technologies, there have been concerns over the security implications brought by this new technology. [45] And while there are many ongoing international collaborative space projects, the exclusion of certain State from participating in the International Space Station signifies that more efforts are required to consolidate confidence among States. As such, confidence-building regarding the development of OOS operations is necessary.[46]

Finally, an international approach to standardization could also avoid the emergence of rendez-vous and docking standard as strategy to establish market dominance, leading to competing standards that are not interoperable. While competition could be deemed conducive to innovation under certain contexts, the long design lifespan of GEO satellite models and the risk-averse nature of the space industry suggest that competition could hinder commercialization of OOS technology. The following sections examine the characteristics of the space industry in support of the argument for an international approach towards rendez-vous and docking standardization instead of national, regional, or alliance-based initiatives.

4.2.2 Remedying the Risk-Averse Nature of the Market and the Industry's Reliance on Redundancy

The satellite industry is characterized by two main characteristics: it is built on the principle of redundancy and is extremely risk-averse. In the U.S., for example, newly developed spacecrafts would only employ the most tested and proven technologies. Using a scale of 1 to 9 to describe the maturity of technology (i.e. the technology readiness levels TRL), most NASA projects require a TRL of at least 8. [47] This stands in contrast to other commercial technologies, which are able to adopt a lower level of technology readiness. According to a report on emerging technologies and trends from the Australian Government, some consumer electronic devices can mature from TRL 3 to TRL 7 within a few years. [48] The space industry, on the other, has a much slower pace of innovation. It relies on redundancy, instead of innovation, to ensure safety and reliability.

To illustrate, the average time of doubling the speed of computer processor was 18-24 months in 2007. The time required for designing GEO satellites, on the other hand, was about 13 years in 2003. [49] Instead of decreasing design time for many consumer technologies, as in the case of mobile phones and computers, the design timespan for satellites has actually drastically increased since the development of the earliest models, which initially only took less than 2 years. [50]

These examples suggest that standardization initiatives should not be left completely to the market, and that governments' support and co-operation are required. The risk-averse nature of the satellite industry, coupled with the long design time, signal that it would take significant time for the market to adjust to changing trends and market demands. In the event that multiple competing OOS technologies with comparable functions emerged, it could take decades for new models of satellites to adjust and respond to OOS specificity.

Even for many ground-based technologies, competition may not always produce the most ideal result. One example would be the drawbacks of a lack of standardization for mobile phone chargers. Research indicates that each year around 51,000 tons of redundant chargers are produced.[51] The lack of standardization for mobile phone chargers not only incurs costs to phone companies, inconveniences consumers, it also puts undue pressure on natural resources and the environment. According to Dennis Bodson, standardization of mobile phone charger could reduce greenhouse gas emissions by 13.6 million tons annually.[52]

There is also the fear that lock-in effect may hinder technological progress. In examining national attempts at standardization, Amy Rabinowitz and Seongmin Lee found that the Korean government's earlier effort at standardizing mobile phone chargers impaired the pace of technological innovation. [53] However, one should note that the long design life for satellites differs considerably from the mobile phone industry, where major companies release multiple phone models annually. For example, in 2014, Samsung released as many as 56 phone models, followed by HTC at 27, and Motorola at 11. [54] This suggests that the benefits of standardization for the satellite industry may very likely outweigh potential drawbacks caused by lock-in effect. The long design time and the practice for redundancy in the industry mean that it is highly unlikely for the market alone to be able to adjust and adapt to changing standards. Furthermore, without States-supported initiatives, the lack of standardization risks delaying the implementation of measures that can ensure space sustainability.

5. Conclusions & Future Research

With reference to Hardin's and Ostrom's earlier work on governing the commons, this article put forward the argument for conceptualizing immaterial space resources as global commons. Once States recognize the non-excludable, rivalrous nature of space resources, as global commons the international community would need to co-operate and co-ordinate to avoid their depletion, which, if unresolved, would ultimately have severe consequence leading to the "tragedy of the commons."

The article puts forward a case calling for international co-operation in standardization efforts in order to ensure faster development and commercialization of OOS. This call takes into account the risk-averse nature of the satellite industry, and the continuous accumulation of space debris in face of society's growing reliance on satellite technologies. There is considerable tension between promoting the promulgation of OOS, and retaining the status quo business model of building satellites that are not serviceable. The article understands the need of a viable business case to support the argument for change in the industry, and recognizes the need for further research in identifying the costs, consequences, policy hurdles and security implications associated with such initiative. A multi-scenario cost-benefit analysis could greatly complement existing literature and further inform future policy debate. However, such investigation would need to take into account multiple factors, at both national and international level, stretching beyond the scope of this discussion paper.

Inevitably, any future cost-benefit analysis (CBA) would need to address the debate over the designation of discount rate. Similar to other CBA that tackles *intergenerational global challenges*, such as the Stern Review Report on the Economics of Climate Change [55], stakeholders from government, industry and academia may diverge on the choice of discount rate. The priority of preserving longer-term space sustainability may come in tension with more immediate concerns over costs and profits from the industry. A higher discount rate may be preferred by the industry (e.g. closer to market's interest rate), while intergovernmental agencies may opt for a lower discount rate, which put more emphasis over longer-term future.

While a comprehensive CBA exercise that examines the global impacts of an international docking standard for future satellites is yet to emerge, there have already been attempts at estimating the costs and benefits for specific types of OOS operations. In 2016, the TeSeR project funded partly by the European Union analyzed potential economic challenges in commercializing a module that can enable a one-year extension of satellite's life and Post-Mission-Disposal (PMD).[56] For a business case to be created for PMD, Bensoussan's analysis argues that the start-up cost for each PMD module should not exceed the cost of traditional integrated propulsion and additional fuel load, which is estimated to be around \$3-4 million. [57] Bensoussan puts forward the example of Orion 3, a geostationary satellite which costed \$150 million, (plus an additional \$80 million for launching). It has a design lifespan of 15 years, and a potential revenue estimated at around \$43 million per year. Base on these estimates, Bensoussan asserts that a TeSeR module could potentially yield revenues between \$30-50 million by extending one year of the satellite's operations. [58] The Orion 3 case is of particular relevance to the discussion, as the expensive Orion 3 suffered from an ill-fated launch and was placed at the wrong orbit, causing a \$265 million insurance payout.[59] Bensoussan contends that the benefits of incorporating PMD module could potentially outweigh the conservative estimation of \$30 – 50 million, as it would open up the possibilities for the satellites to adapt to changing mission requirements. For example, adoption of PMD could potentially allow for orbit correction. Bensoussan also argues that commercialization of such component could lead to future satellites to have a shorter lifespan, reducing the need for redundancy, thus lowering both construction and deployment cost. [60]

The above example demonstrates that further CBA for emerging OOS is desirable but complex, requiring substantial resources and careful consideration of both immediate and longer-term non-monetary or indirect benefits, including long-term sustainability of space activities, potential scientific breakthroughs, and enhanced defence capability.

Mounting pressure on immaterial resources in outer space stipulates immediate international co-operation in order to ensure a sustainable future for outer space activities. The international community has failed to capitalize on collaborative momentum for realizing the SDGs, and left space sustainability outside of the main scope of Agenda 2030. It may be advisable for the space sector to raise awareness regarding space sustainability, and endeavour to

include considerations for sustainable use of orbits and radio frequency in the next round of development goals after 2030.

Existing space governance mechanisms are guided by the Outer Space Treaty and Liability Treaty. Both were devised in a very different era, under a very different social, economic and political context from now. Sovereign States were the dominant actors in space-fare. In recent years, however, development of space technologies have increasingly witnessed the involvement of private companies. Based on this development, international governance mechanisms should consider viable ways to incorporate inputs from the industry and academia, and promote engagement with society in order to raise awareness.

The Apollo-Soyuz test project illustrates that even in the most testing time, political tension does not necessarily constitute a critical barrier to international co-operation. OOS operations present a valuable opportunity to engage a wide range of actors in the discussions of space sustainability. In consultation with industry, governments could play a critical role in enabling technological innovation in the space sector. Recognizing the importance of space sustainability, international discussions on co-operation and OOS standardization could be the first step in contributing to confidence-building among States, and long-time prosperity through peaceful use of outer space.

6. References

- [1] Garrett Hardin, "The Tragedy of the Commons," in *Science, New Series*, Vol. 162, No. 3859, Dec 1968
- [2] UK Mission to the UN in Vienna, "UN Space Agency highlights growing pressure on space sustainability," 17 July 2015. <<https://www.gov.uk/government/news/un-highlights-growing-pressure-on-space-sustainability>>
- [3] Expert opinion at Panel Discussion on "The evolving space domain and future challenges: Space Situational Awareness – How is the UK monitoring & mitigating space debris, methods and regulatory issues," *UK Space Conference*, Manchester, 31 May 2017.
- [4] N. Satak, N. et al. "Exploring the Potential of Satellite Connectivity for Digital India." *Space India 2.0*, 37, 2017.
- [5] Joseph W. Gangestad, "Orbital Slots for Everyone?" *Center for Space Policy and Strategy Policy Paper*, March 2017, <https://aerospace.org/sites/default/files/2018-05/OrbitalSlots_0.pdf>
- [6] Sarwant Singh, "The Space Industry: Seriously Congested, Contested And Poised For Growth" in *Forbes*, 2 July, 2014
 <<https://www.forbes.com/sites/sarwantsingh/2014/07/02/space-industry-mega-trends-of-growth-for-the-future/#879d4182aef3>>
- [7] Expert opinion at Panel Discussion on "The evolving space domain and future challenges: Space Situational Awareness – How is the UK monitoring & mitigating space debris, methods and regulatory issues," *UK Space Conference*, Manchester, 31 May 2017.
- [8] World Commission on Environment and Development, 1987
- [9] Garrett Hardin, "The Tragedy of the Commons," in *Science, New Series*, Vol. 162, No. 3859, Dec 1968, pp. 1244
- [10] Ibid
- [11] Hardin, 1968
- [12] Ostrom, 1990
- [13] Economic Sciences Prize Committee of the Royal Swedish Academy of Sciences, "Economic Governance," *Scientific Background on the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 2009*, 12 Oct 2009.
 <https://www.nobelprize.org/nobel_prizes/economic-sciences/laureates/2009/advanced-economicsciences2009.pdf>
- [14] United Nations, *Transforming Our World: The 2030 Agenda for Sustainable Development*, A/RES/70/1, 21 Oct 2015.
- [15] Jose Apesteguia and Frank P. Maier-Rigaud, "The Role of Rivalry: Public Goods versus Common-Pool Resources," in *The Journal of Conflict Resolution*, Vol. 50, No. 5, Oct 2006. pp. 646-663
- [16] On-Orbit Servicing working group, *Final report on on-orbit servicing commercial opportunities with security implications*, Space Generation Advisory Council, 2014, p. 54. <<http://sro.sussex.ac.uk/56894/>>

- [17] See Tereza Pultarova, "This Space Junk Removal Experiment Will Harpoon & Net Debris in Orbit," *Space.com*, 6 April, 2018, Accessed 15 June 2018, <<https://www.space.com/40221-space-junk-debris-sweeper-experiment.html>>; and University of Surrey, "REMOVEDEBRIS," *Surrey Space Centre*, <<https://www.surrey.ac.uk/surrey-space-centre/missions/removedebris>>
- [18] Space Safety Magazine, "Astrium Explores Space Debris Harpoon," *Space Safety Magazine*, 11 October, 2012. Accessed 12 June 2018. <<http://www.spacesafetymagazine.com/media-entertainment/atrium-explores-space-debris-harpoon/>>
- [19] Tom Clarke, "A junk harpoon on a mission to clean up space," *Channel 4*, 17 April 2013. Accessed 24 June 2018. <<https://www.channel4.com/news/space-junk-harpoon-system-british-engineers>>
- [20] See Caleb Henry, "Intelsat Announces Five-Year In-Orbit Servicing Agreement with Orbital ATK", *Via Satellite*, 13 April 2018, Accessed 20 May 2018. <<https://www.satellitetoday.com/innovation/2016/04/13/intelsat-announces-five-year-in-orbit-servicing-agreement-with-orbital-atk/>>; Kendall Russell, "Intelsat Bets More on In-Orbit Servicing with Orbital ATK," *Via Satellite*, 4 Jan 2018, Accessed 20 May 2018, <<https://www.satellitetoday.com/innovation/2018/01/04/intelsat-bets-orbit-servicing-orbital-atk/>>
- [21] Dom Galeon and Christianna Reedy, "Startup Gets Funding to Clean Up Our Orbital Space Junk," *Futurism*, 20 July 2017, Accessed 28 July 2018. <<https://futurism.com/startup-gets-funding-to-clean-our-orbital-space-junk/>>
- [22] Ciro Arevalo Yepes, and Mateo Arevalo Botero, "Implementing space technology into sustainable development and resilience theory," in *Oasis*, No. 18, 2014. <<http://www.iafastro.org/wp-content/uploads/2014/04/Report-by-Ciro-Ar%C3%A9valo-Yepes-GRULAC.pdf>>
- [23] CTBTO, *Overview of the Verification Regime*, Accessed 7 Sep 2017. <<https://www.ctbto.org/verification-regime/background/overview-of-the-verification-regime/>>
- [24] See Kenneth Waltz, *Man, the State, and War*, (Columbia University Press, 2001), and Kenneth Waltz, *Theory of International Politics*, (McGraw-Hill Higher Education, 1979)
- [25] Siegfried Wiessner, "The Public Order of the Geostationary Orbit: Blueprints for the Future," in *Yale Journal of International Law*, Vol. 9, 1983, p. 225
- [26] Ram Jakhu, "Legal Issues of Satellite Telecommunications, The Geostationary Orbit, and Space Debris," in *Astropolitics*, 5:2, 2007 p. 179
- [27] Art. 44, "Constitution and Convention of the International Telecommunication Union as amended by the 1998 Plenipotentiary Conference," 1999.
- [28] Jakhu cited the example of Pakistan, noting the statement, "If this slot was not protected by bringing in a satellite and placing it there, this strategic asset and any future opportunity for Pakistan to enter the space would have been lost forever." See Jakhu, p. 188
- [29] See Jakhu, pp. 185-190
- [30] IADC Steering Group and Working Group 4, IADC Space Debris Mitigation Guidelines, Sept 2007, p. 9. <<http://www.iadc-online.org/Documents/IADC-2002-01,%20IADC%20Space%20Debris%20Guidelines,%20Revision%201.pdf>>
- [31] Luke A. Idziak, "Cultural Resources Management in Outer Space: Historic Preservation in the Graveyard Orbits," in *Synesis: A Journal of Science, Technology, Ethics, and Policy*. 2013, pp. 64-65
- [32] European Space Agency, Clean Space, 19 Nov 2017. <http://www.esa.int/Our_Activities/Space_Engineering_Technology/Clean_Space/CleanSat>
- [33] Brian Weeden, "Dealing with Galaxy 15: Zombiesats and on-orbit servicing," in *The Space Review*, 24 May, 2010. <<http://thespacereview.com/article/1634/1>>; and NASA, "Space Debris and Human Spacecraft," 27 September 2013. <https://www.nasa.gov/mission_pages/station/news/orbital_debris.html>
- [34] Jakhu, p. 192
- [35] Peter B. de Selding, "Most geo satellites retired in 2015 violated orbit-debris guidelines," in *Space Intel Report*, 3 Feb 2017. <<https://www.spaceintelreport.com/most-geo-satellites-retired-in-2015-violated-orbitdebris-guidelines/>>

- [36] Daniel E. Hastings, Benjamin L. Putbrese, and Paul A. La Tour, "When will on-orbit servicing be part of the space enterprise?" in *Acta Astronautica*, July 2016.
- [37] For details on the growth of the satellite industry, see Andrew Edgecliffe-Johnson, "Rising demands push industry to new height," in *Financial Times*, 30 Nov 2012.
<<https://www.ft.com/content/be1314f0-3263-11e2-916a-00144feabdc0>>
- [38] Lisa R. Messeri and Matthew G. Richards, "Standards in the space industry: Looking back, looking forward," *Management & Organizational History*, 4:3, 2009. p. 293
- [39] Ibid
- [40] See National Audit Office, "Carbon capture and storage: the second competition for government support," 20 Jan 2017, p.5.<<https://www.nao.org.uk/wp-content/uploads/2017/01/Carbon-Capture-and-Storage-the-second-competition-for-government-support-Summary.pdf>>; and Damian Carrington, "UK cancels pioneering £1bn carbon capture and storage competition," in *The Guardian*, 25 Nov 2015.
<<https://www.theguardian.com/environment/2015/nov/25/uk-cancels-pioneering-1bn-carbon-capture-and-storage-competition>>
- [41] Messeri and Richards, 2009, p. 294
- [42] DARPA Outreach, "DARPA Creating Industry/ Government Group for Safe Operations of Space Robotics," *Defense Advanced Research Projects Agency – DARPA, News and Events*, 29 Nov 2016. Accessed 10 May 2018. <<https://www.darpa.mil/news-events/2016-11-29>>
- [43] Ibid.
- [44] DARPA Outreach, "CONFERS to Establish 'Rules of the Road' for On-Orbit Servicing of Satellites," *Defense Advanced Research Projects Agency – DARPA, News and Events*, 4 Oct, 2017. Accessed 10 May 2018. <<https://www.darpa.mil/news-events/2017-10-04>>
- [45] See Brian Weeden, "Dealing with Galaxy 15: Zombiesats and on-orbit servicing," in *The Space Review*, 24 May 2010, Accessed 30 June 2018,
<<https://goes.gsfc.nasa.gov/text/Zombiesats.pdf>>
- [46] See On-Orbit Servicing working group, *Final report on on-orbit servicing commercial opportunities with security implications*, Space Generation Advisory Council, 2014.
<<http://sro.sussex.ac.uk/56894/>>. For an older discussion on the topic, see Darryl Roberts, "Space and International Politics: Models of Growth and Constraints in Militarization" in *Journal of Peace Research*, Vol. 23, No. 3, 1986
- [47] Andrew M. Long, Matthew G. Richards, and Daniel E. Hastings, "On-Orbit Servicing: A New Value Proposition for Satellite Design and Operations," in *Journal of Spacecraft and Rockets*, Vol. 44, No.4, July-August 2007. p. 964.
- [48] See Ksenia Ivanova and Guy Edward Gallasch, Australian Government, Department of Defence, Science and Technology, *Analysis of Emerging Technologies and Trends for ADF Combat Service Support 2016*, (Land Division, DST Group Edinburgh, Edinburgh, 2016), p. 10
- [49] Long, Richards, and Hastings, pp. 964-965
- [50] Earlier models of satellites were developed under the context of the space race during the Cold War.
- [51] Dennis Bodson, "One-Size-Fits-All Mobile Phone Charger," in *IEEE Vehicular Technology Magazine*, Sept 2011.
- [52] Ibid
- [53] Amy Rabinowitz and Seongmin Lee, "Interoperability Case Study – Mobile Phone Chargers," *Berkman Centre for Internet & Society at Harvard University*, Research Publication No. 2012-16, Sept 2012.
- [54] Ron Amadeo, "Samsung decides 56 smartphones a year is too many, will cut lineup by 30%," in *Ars Technica*, 18 Nov 2014. <<https://arstechnica.com/gadgets/2014/11/samsung-decides-56-smartphones-a-year-is-too-many-will-cut-lineup-by-30/>>
- [55] See HM Treasury, *Stern Review Report on the Economics of Climate Change*, 2006. For discussions on the choice of discount rate for intergenerational CBA, see also Nicholas Stern and Christ Taylor, "Climate Change: Risk, Ethics, and the Stern Review" in *Science*, Vol. 317, 2007
- [56] Ed. Denis Bensoussan, "TeSeR – Technology for Self-Removal of Spacecraft" in *Market Study*, Issue 1., June 2016, Accessed 20 May 2018, European Commission, Research & Innovation, Ref. Ares (2016) 2899621
<<https://ec.europa.eu/research/participants/documents/downloadPublic?documentsIds=>

080166e5af8c2d59&appId=PPGMS>

- [57] Ibid
- [58] Ibid, p. 17
- [59] Ibid, p. 17
- [60] Ibid, p. 18; see also Todd Master, “Consortium Operations (CONFERS)”, *DARPA – Defense Programme Information*, Accessed 10 May, <<https://www.darpa.mil/program/consortium-operations>> for Execution of Rendezvous and Servicing Advanced Research Projects Agency, 2018, [for-execution-of-rendezvous-and-servicing-](https://www.darpa.mil/program/consortium-operations)

- Space technologies are critical to daily socio-economic activities
- Immaterial space resources (e.g. orbital slots) are limited, finite resources
- Space resources are susceptible to depletion if their use is not co-ordinated
- On-Orbit Servicing (OOS) can ensure sustainable use of resources in outer space
- International docking and rendez-vous standards could enable OOS to take-off