ADDRESSING SPACE DEBRIS AS A TRAGEDY OF THE COMMONS

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JUNE 3rd, 2021

ABSTRACT

Along with the growing democratization and commercialization of space, comes the increasing threat of unhandled space debris that could potentially cause harm to present and even end up preventing new projects to be safely and successfully launched into space. For several years, this issue has not been properly addressed by stakeholders of the industry, thus reaching a point in which is not yet clear who will pay and act upon what is needed to mitigate the problem before it becomes irremediable. Such overexploitation of space in the condition of a free-to-access and communal physical resource by its users without any of them acting towards its long-term sustainability and conservation is clearly a market failure, namely a tragedy of the commons. Such phenomenon is not exclusive to space only, having been perceived throughout history in various other domains, for which actions have already been taken and considerable progress has been made towards a desired state of controlled use and a remediation of the negative circumstances it was found to be in. This paper highlights some of the insights obtained from such other domains, and states how the acquired knowledge can be transferred to the stakeholders of the space industry, particularly the ones pertaining to the satellites market, into adopting strategies to follow a more debris-conscious behavior towards a future in which a sustainable use of the space commons can be considered.

KEY WORDS

SATELLITES - SPACE DEBRIS - TRAGEDY OF THE COMMONS - STAKEHOLDERS

ACKNOWLEDGEMENTS

I would like to thank Mrs. Sophie Darmagnac for her kind support, understanding and guidance throughout this challenging academic year. Her direction of the MSc in Aerospace Management gave the development of the program a very human and warm sense of belonging, regardless of the physical distances, the low levels of human interaction and the obvious difficulties of the industry.

To Mr. Victor Dos Santos Paulino for his assistance through not only 1 but 2 research projects. His guidance led me to approach the projects with a more business-oriented mindset, which for my engineering background, clearly helped to pave what will be my way forward into a professional life.

To my colleagues from the master, which turned into friends and ultimately became brothers. They became family while away from my family and helped me to fight back the loneliness that came with these difficult times of living through a pandemic.

Finally, to my parents, my guiding light at every level who with much love and effort helped me to pursue this dream of an international master degree and a total change of approach to my career as a mechanical engineer. Without them, absolutely nothing would have been possible, and my dreams would still only be dreams. Our mutual support and unity has been fundamental through all difficulties that came during the last year.

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THE TRAGEDY OF SPACE:

The jump from space being “the next frontier” towards “the next tragedy” is imminent. The transition of the space age from its traditional era which lasted for a major part of the second half of the last century into the New Space boom, brought along an immense portfolio of new possibilities for technological developments to emerge in order to take advantage of space and at the same time for us to be able to reach it easier, faster, cheaper, and safer. The commercialization of space happened incredibly fast, and it sems that it was so fast that it outpaced the capacity of the governing bodies and the users themselves to realize how to manage it and to guarantee a sustainable use of it. The majority of objects and equipment launched into space for the last half century have stayed there, endlessly orbiting our earth, without any proper guidelines to regulate them or without major incentives to do so. Space debris, as these residuals are known as, are not only staying but also growing in quantity, as far more missions are being launched every year that will, at some point or another, leave their trace in the space they share.

An aggravating factor amongst all possible space endeavors is that of small satellites and satellite mega constellations. With the promise of compactness, streamlined production and standard parts that made satellites accessible to far more operators and easier to produce massively, came the concept of a small satellite with an equally massive deployment of projects and missions that are scheduled to be launched with a purely commercial purpose during the next decade into Low Earth Orbit in congregations known as constellations, concentrating thousands of small satellites in an orbit where considerable quantities are needed in order to achieve coverage. This raises far more concerns about the safe accessibility and use of space for further missions, which need to use the same orbital region as well as to pass through it in order to achieve higher orbits, without taking into consideration that at any point conditions ca be met for any of these objects to fall back into Earth, exposing the risk of human casualties and affectation of private properties.

CURRENT STATE OF SPACE DEBRIS:

After many years of ignoring the issue, only recently has space debris and terminology related to its study, as well as related to space sustainability, began to emerge in multiple forums. Nevertheless, this initially did not come from carelessness but rather of the industry not fully comprehending the stakes as well as not being able to measure them. Space is generally agreed to be a medium that needs to be kept in a sustainable state, as the implications of not doing so might prevent the industry to keep from existing because of high risks and elevated costs of operation. Debris themselves are a byproduct of any human-induced activity within space and they emerge out of any part of the lifecycle of a spacecraft, because of normal operation tactics or because of incidents related to collisions from other space debris. The costs associated with debris colliding with specific spacecraft are also known and documented by the mission operators. As humanity, we currently have the technological tools and the acquired knowledge to understand, measure and estimate the causes and impacts of space debris.

The current level of space debris is growing exponentially, as thousands of new satellites are being released in the wake of the space constellations boom. With over 500,00 objects estimated in 2012, 5 times more than the previous decade, the situation does not seem to get better, and the possibility of debris growth becoming self-sustainable (known as the Kessler Syndrome) is low but existent. However, we do not have the legislation or agreed rules to control the build-up of debris in orbit, and any standards released currently released by, for example, U.S. agencies, are only suggesting mitigation actions without addressing root causes, and some of the suggestions included within the objectives are clearly outdated.

For such reason, space debris can be, without a doubt, be called a contemporary tragedy of the commons, and one which humanity is lagging to timely and properly address. It is precisely because of this lack of controls that, even though catastrophic events have not yet happened, the possibility of it happening exists and requires proactive actions to prevent them. If at any point in the future, Low Earth orbit becomes so crowded with debris and operating satellites that missions cannot be launched in a safely manner, the downfall of the industry will come.

Thankfully, several other tragedies of the commons are well documented and have been studied for years and even centuries. Humans have, in some cases, emerged as a unity, created agreements and jointly enabled actions to prevent and correct the issues that emerged from uncontrolled exploitation of resources that consequently led to the tragedies being considered as such. For this reason, certain comparable scenarios of tragedies of common were extracted from the literature review in order to be included in the discussion.

ADDRESSING A TRAGEDY:

Taking all of the aforementioned issues into consideration within a literature review, this research intends to, more than answering a research question, come up with strategic recommendations for satellite operators and manufacturers to plan and act accordingly with the tragedy of space debris in mind, embedded into their business plans for the future. This will be approached by extracting insights, lessons learned and shared knowledge between and from other comparable scenarios of tragedies of commons into the scenario of space debris, addressing such insights from the perspective of a space stakeholder and tracing comparisons for each. As an outcome of the research, managerial recommendations are given for decision makers to have a set of tools that can help them to think, act and react towards their current use of space, before it comes to a strict enforcement, before a catastrophic point or no return is reached, or both.

LITERATURE REVIEW

1. THE SPACE DEBRIS DILEMMA

1.1.THE NEW SPACE ERA

During the first decades of the space age which started in 1957 with the launch of the first artificial satellite, historical landmarks such as space flights and moon missions destined for orbiting and landing became the most significant outcomes of a time in which political and military interests were the driving forces for innovation in the context of the Cold War between the US and Russia, which at the same time became the competing powers in the so-called space race. Only governmental agencies could afford and had interest in launching an object in orbit. Moving forward in time, after the end of the Cold War, a commercial market was born out of what was left of the technologies developments previously achieved. Behind were left the years of protectionism of defense ministries and space agencies that left out external suppliers from the market (Dos Santos Paulino, 2020). Space access became open and democratized, and any player with a profit-making interest out of space and, as one of many examples, its information-sharing capabilities via satellites, could now enter the competition for the conquest of it.

The New Space era was born and with it, several new technologies and use cases came into the picture while creating a totally new market of possibilities for business and innovative companies, paving the way for small satellites and satellite constellations to emerge. At the same time, it also further cemented the dependency of humankind on space technology: Using technologies facilitated by space is now so crucial to the daily activities of civilized humans and everyday society that many aspects of what is considered “normal” in the world would simply cease to function without an uninterrupted access to it (Freeland, 2020). This is only expected to become more evident for future generations, making the protection of space and its normal functioning as an enabling medium of our modern society more relevant as well.

A small satellite, by definition, is a satellite which weighs less than 500 kg. Satellites bearing comparable weights had in fact been launched into space way before the New Space era as the very first satellites that were launched between the 50s and the 60s, namely the Explorer 1 or the Sputnik 1, corresponded to this category if they were to be classified according to modern standards. At the time of launch, such classification was not existent, and their sizes and weights were in reality defined by what could be fitted into the launchers of that time. But as time went by, new use cases emerged and new technologies came into play to satisfy the needs for those use cases, turning satellites into much more complex and bigger pieces of technological equipment and that continued to be the case for the second half of the 20th century. Jumping forward to the start of the 21st new century, universities and research institutes started to design their own experimental satellites with fully functional prototypes that had less functions, a more compact build, and more standardized and commercially available parts (Pelton & Madry, 2020). A new, further interest was awakened in regard to miniaturization of satellites as well their key components with the intention of achieving reduced manufacturing costs and faster and more streamlined manufacturing processes, giving birth to the contemporary concept of small satellites, which comprehends not only its size but also the compact design that goes with it.

At the same time, a drastic new approach to design began to emerge, in parallel to the "Silicon Valley" mindset that has been a main driving force in the New Space revolution through the first 2 decades of the new century, granting the industry with a more entrepreneurial and more agile approach to engaging in business and producing and launching spacecraft. The trend has been, in general, that fast innovators in the aerospace industry have developed new technologies and new business models across several sectors of the industry that have mutually enabled each other to grow and become profitable. For example, one of the main enabling technologies behind the New Space boom has been launch services. Launch service companies, acting as startups, have come up with radical solutions such as reusable first stage rocket components, as proposed by SpaceX or Blue Origin, or small launchers specifically targeted to missions carrying small satellites, as proposed by Rocket Lab. (Logue & Pelton, 2020). All of these new launch services, independently of their offered technology, have managed to jointly drive down launching costs and forced traditional players, such as Arianespace, Boeing, or Lockheed Martin to come up with competitive solutions of their own. The main outcome has been, in this context, that new launching options have enabled small satellite companies to even consider getting them to orbit in the first place, at lower costs and with higher frequencies, without depending on the higher costs and lower frequencies of shared payloads offered by traditional launchers.

Around 2012, the number of small satellites being launched into space started to increase on a yearly basis, as start-up companies such as Spire and Planet started to deploy a vast amount of commercial satellite constellations within their expansion strategies, acquiring a lead both in terms of market share and launches, though they have been recently joined in the top positions by SpaceX. 1731 commercial small satellites were launched between 2012 and 2019, with 899 launched for commercial ventures (Bryce Space and Technology, 2020). Figure 1 shown below gives an overview of the increasing frequency of small satellite launches as well as their representation in percentage within the overall launches of spacecraft in general.

Today, over 20,000 commercial satellites are proposed to be launched within the next 5 years, with most of them belonging to the small satellite category led mainly by OneWeb and SpaceX Starlink constellations and joined even more recently by Amazon's Kuiper. Most if not all of these objects are planned to be launched into Low Earth Orbit (LEO), greatly modifying the mass distribution in that orbit and rising concerns about the possible effects of such saturation and the interactions between the objects themselves as well as with any object crossing through the zone. Figure 2 shows the projected traffic congestion forecast for LEO within its range of altitudes, clearly showing what could only be called a "mass congestion" over a wider range of the space system (Logue & Pelton, 2020).

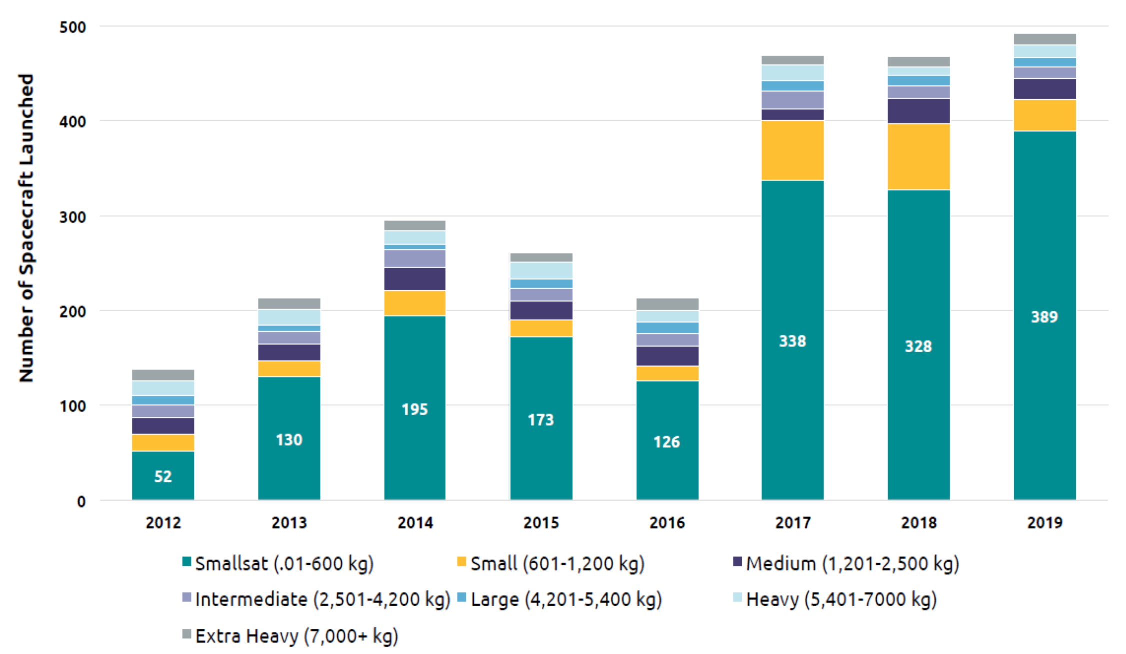

Figure 1. Spacecraft launched from 2012 through 2019, by mass (Bryce report, 2020

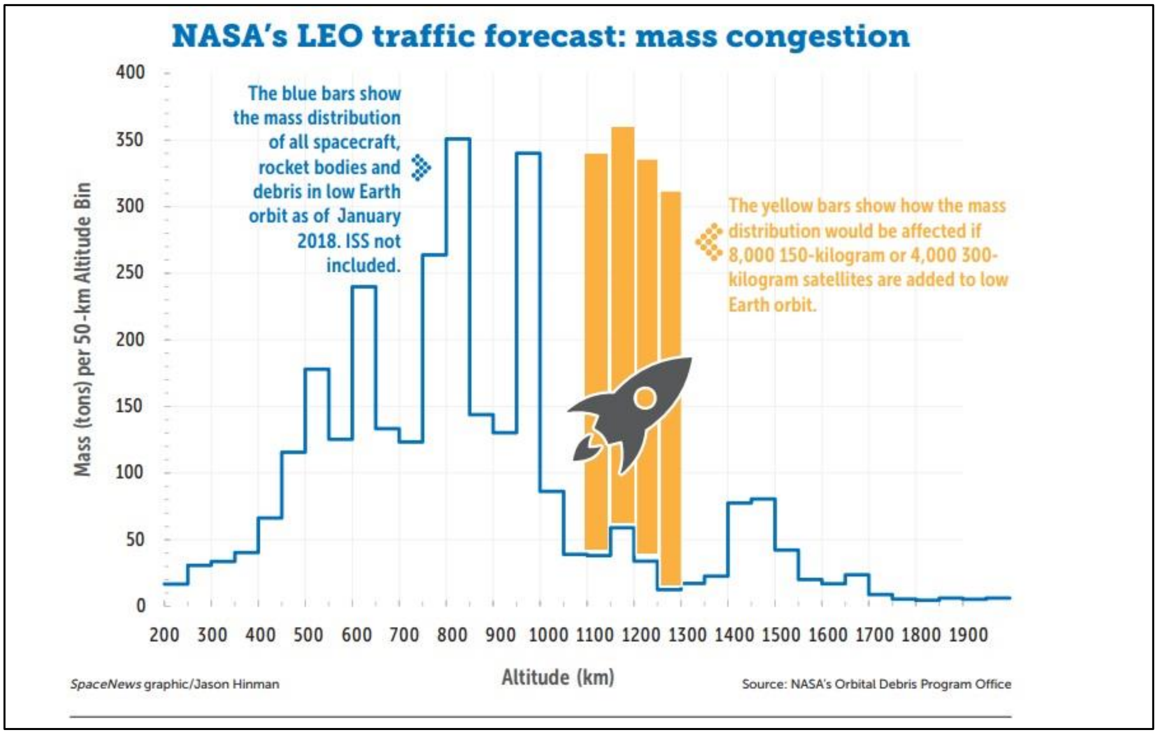

Figure 2. Projected traffic congestion forecast in the range of LEO orbit altitudes (SpaceNews, 2018)

1.2.SPACE DEBRIS AGAINST SUSTAINABLE SPACE

It is precisely the vastness and openness of space and how far it seemed to be from the human eye that could explain why it had always been thought as a sustainable medium, or even less, led to not even consider a debate of space sustainability at all for that matter. Also, decades ago, the act of launching objects into orbit was a difficult task already to even consider what was going to happen after. With those objects being launched into a totally unknown and dark region, out of humanly boundaries, further lessened the worries. As space exploration progressed, the variables were understood and the picture of space occupation became clearer, the real implications of having objects endlessly orbiting around the Earth, which were not initially meant to be there, started to take shape.

Sustainability, amongst many of its possible definitions, finds one that fits well in this context when it corresponds to "development that meets the needs of the present without compromising the ability if future generations to meet their own needs", which was appropriately adapted by The Secure World Foundation as "ensuring that all humanity can continue to use outer space for peaceful purposes and socioeconomic benefit now and in the long term" (Pope et al, 2004). At the same time, terms and concepts such as situational awareness, traffic management and safety started to be applied to space and to be included in academic research, space forums, government agencies and even the United Nations. It has become agreed that sustainability in space demands all participants that engage in activities of space utilization have to mitigate the impact of their missions in orbit and reduce their footprint, ideally, in order to prevent upcoming generations to incur in expenditure to clean up what the past generations did not address (Newman & Williamson, 2018).

Stating that space is the next frontier represents simply the next logical step in the human race towards conquering one more Earth domain. What started with land, progressed into sea, and finalized with air, has just been the progression of humanity utilizing its available mediums to supply power and transportation, as well as being strategical points of interests for its many factions to exert territorial dominance and ultimately hold political power. But in the same way that humanity has left overgrazed and deforested regions over land, mountains of non-decaying garbage floating at sea, and endless fumes of polluting agents released into the air, space has become the new domain in which to leave a set of traces that need to be addressed, commonly known as space debris. (Powell, 2017).

Space debris are a byproduct of virtually any human activity in space, and depending on how they are originated can be classified accordingly into (Taylor, 2011):

- Inactive payloads: Mainly satellites that are no longer functional and non-maneuverable. Because of their masses, collisions involving one of these elements can bring devastating effects on the debris count. As an example, in February 2009, Iridium 33, a functional American telecoms satellite collided with an inactive Russian payload, releasing an estimated 402 pieces new orbital debris which correspond to a 25% of cataloged on-orbit space objects. (Weeden, 2012).

- Operational debris: Elements released during normal space operations, either from satellites or manned spacecraft. This category can include separated launch stages, propellant tanks, bolts, straps, between others

- Fragmentation debris: Caused by collision between 2 man-made objects, and it is thought to be the most common type of debris currently orbiting around Earth.

- Microparticulate debris: Gas or liquid particles that are released into space that, even though existing at a small scale in comparison to the previously mentioned types, can still impact outer surfaces od spacecraft. As an example, a Space Shuttle windshield was cracked by a paint chip of 0.2 millimeters.

Over 100,00 objects between 1 and 10 cm were estimated to be orbiting around Earth in 2004. This number grew to an estimated 500,00 objects by 2012. (Pelton, 2020). Figure 3, provided by NASA, brings a graphical representation of known objects around the globe. But, of all known objects to be in space at any given time, not all of them are actually properly identified. Of the previously mentioned 500,000, only 23,00 are being tracked in terms of location and origin, and most of them are located within the same orbit, signifying an elevated density.

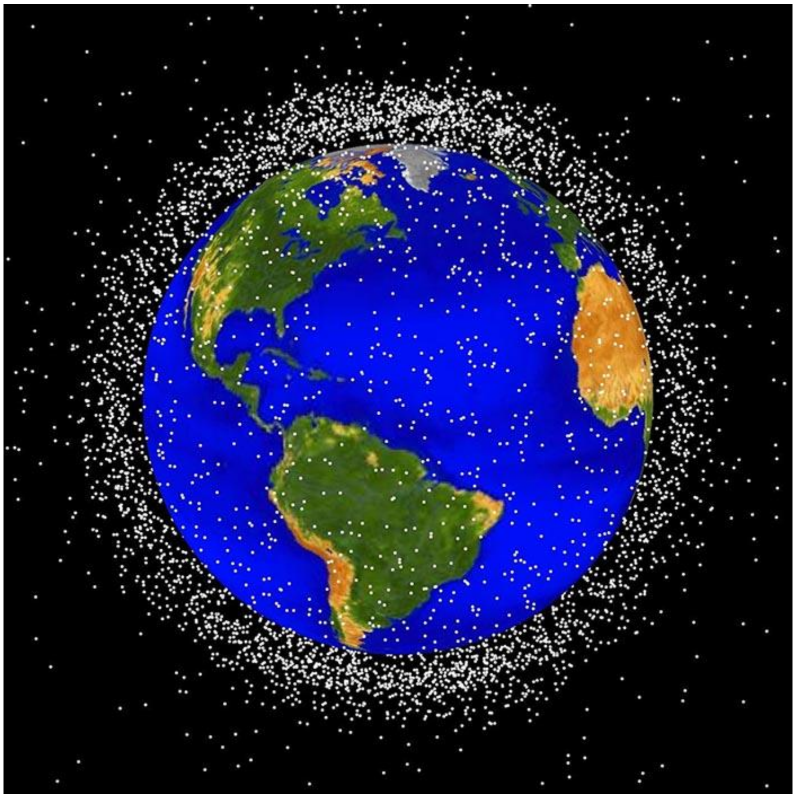

Figure 3. Graphical representation of debris orbiting at LEO , the most concentrated area for orbital debris. Credit: NASA ODPO

The rapid pace at which new missions are being launched into space is expected to only keep on increasing the already present build-up of space debris in orbit and elevate the risk of collision, which can at the same elevate projected costs of space missions, which come from different sources. The first and most important cost to be considered comes from a space debris collision resulting in total loss of functionality for a satellite, representing costs of monetary value coming from the manufacturing costs and lost revenues but also costs in time to build and to launch, as an ordered satellite by an operator will take years before actually being in space generating profit. This is highly likely as space debris hitting a critical and highly exposed component, such as a solar panel, has happened and will continue to do so. Figure 4 shows the effects of debris collision on a solar panel. Another potential cost to be incurred is that related to orbiting debris reentry with unfortunate outcomes of human casualties or property damage, as well as human personal participating in any kind of space mission.

Satellite and spacecraft manufacturers can implement shielding devices and additional protections to lower the risks of damage after collisions, but this, in the same manner, is an associated cost as well. Maneuvering tactics are also executed in order to actively avoid collisions when the conditions are met and the alerts are timely given, but this requires the use of fuel that could otherwise be used to support the functions associated with the intended mission of the aircraft (Taylor, 2011) (Rao et al, 2020).

Debris buildup could end up making Low Earth Orbit operations economically unviable and missions targeted at the range to not be feasible in the long run. The worst-case scenario corresponds to debris growth becoming self-sustainable, once a certain threshold is reached, as debris will keep on colliding with debris creating far more smaller pieces that also continue to collide, creating an unbalanced system known as the Kessler Syndrome. However, this theory seems far-fetched at the moment and remains highly uncertain in reality (Rao et al, 2020).

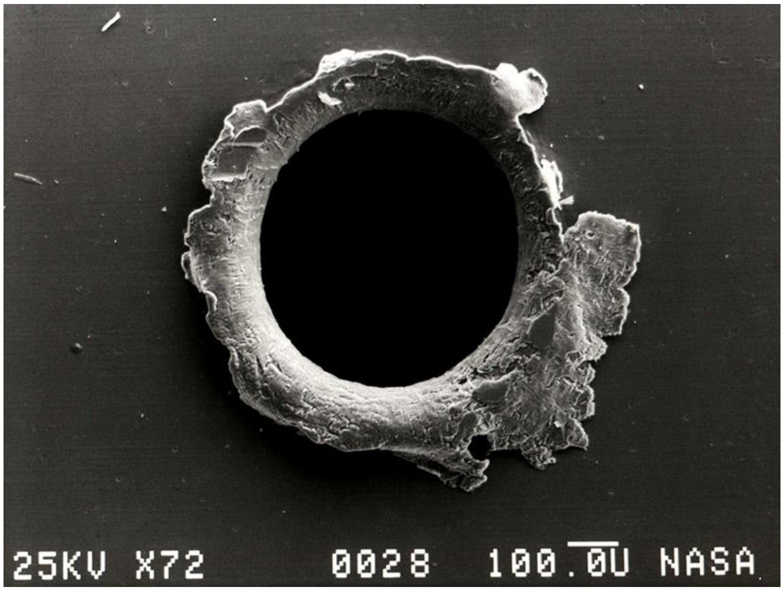

Figure 4. View of an orbital debris hole made in the panel of the Solar Max experiment. Credit: NASA

1.3.CURRENT REGULATIONS ON SPACE DEBRIS FOR SMALL SATELLITES

In the case of the U.S., the agencies most concerned with controlling the growth of space debris are NASA, the Federal Communications Agency, the Department of Defense, the Department of Commerce, the Department of Transportation, the Federal Aviation Agency, and the National Space Council (Pelton, 2020). As of November 2019, the latest version of the U.S. Government Orbital Debris Mitigation Standard Practices (ODMSP) has been released, adding an additional objective to cover additional issues regarding small satellites and the deployment of large constellations (NASA, 2019). For the case of large constellations, the suggested practices are:

- Each spacecraft belonging to a large constellation should have a success rate of post mission disposal at a level above 0.9 with a target of 0.99.

- The preferred disposal for final mission orbits should be by maneuvering the spacecraft to remove if from earth orbit into either a direct reentry trajectory (with a controlled risk of human casualty of 1 in 10,000) or heliocentric Earth escape orbit. It is encouraged to also consider measures such as design-for-demise, reusability, and targeted reentry to further reduce human casualty.

For the case of small satellites, the suggested practices are:

- Any spacecraft classified as small satellite in LEO “should be limited to an orbital lifetime as short as practicable but no more than 25 years”.

- “Total spacecraft object-time in LEO should be less than 100 object-years per mission.”

NASA further states that the new ODMSP “updated standard practices are significant, meaningful and achievable” but recognizes that it is intended to be updated and refined in the future in order to address further advancements in technologies and policies. It also encourages operators to “consider the benefits of going beyond the standard practices and take additional steps to limit the generation of orbital debris”.

Considering an analysis made by Pelton (2020), the debris removal guidelines in place today stating that defunct satellites shall be removed from orbit within 25 years of their end of life are clearly outdated, as it was originally calculated based on the time that takes debris to go through 2 solar max cycles, occurring every 11 years and exerting the maximum atmosphere drag on debris. As of now, LEO small satellites have an expected lifetime of 5 to 7 years, meaning that constellations containing thousands of small satellites, such as the ones currently planned on being deployed, would take an immense number of years to be removed from orbit.

2. SPACE DEBRIS AS A TRAGEDY OF THE COMMONS

The term “commons” first acquired the meaning it is currently bearing when used by Garret Hardin’s *Tragedy of the Commons* (1968), where he exposed the management challenges imposed by users of common pool resources. He proposed a scenario in which a pasture is open to all, and each of the herdsmen that use it for their cattle to feed on is expected to keep as many cattle as possible on the common grounds. With each of them seeking to maximize its individual gain and not thinking about the negative impact of their choices on others’ interests, none will think twice before adding far more cattle to the grounds with their own benefit as the commanding rationale, infinitely increasing the number of consumers of the resources which are, naturally, finite. The outcome is that after the land is congested, each cattle will end up having less feeding opportunities and the system will collapse: Both the resources and the users are left empty. In his article, he stood by the belief that overpopulation is the main source of environmental degradation and the depletion of common shared resources and that freedom in a common is what brings ruin to it. Starting from that time on, not only its academical utilization became widespread but also its notion and relevance within real world situations became more apparent. Thanks to its widespread use, many more approaches came to challenge the initial concept and its implications, giving way to a whole new school of thought regarding management of resources (Rosenbloom et al, 2019).

At the time of its publication, Hardin’s article proved to raise a wide controversy about what was later referred to as the “population bomb” as well as wide criticism for not considering other points of view rather than what stemmed from his field of study, which was of biological sciences. For example, contemporary works from economists pointed out that overuse of commons can emerge from the divergence between what each member calculate as their own individual costs of using the resource, based on past averages of users, and the real cost of using such resource, which will be different when subjected to the pressure of more users arriving to the system to consume the resource in question (Rose, 2020). This, between many others, proved that Hardin’s assumption was somehow radical and not robustly sustained. Nevertheless, it opened up the way for the concept and the notion of community management of resources to be fed with far more academic research.

A third concept that is worth bringing into the research it the one relating to externalities. It makes sense and seems intuitive to think that any user involved in the exploitation of a resource should be paying for having any inputs into the specific process. Directing a cost towards that user’s sphere of responsibility creates a sense of fairness and ownership, as having to pay for a service instead of freely accessing it should end up limiting its usage down to pure necessity and out of greed (Vandermeer, 1996). The main point of discussion about capitalizing on a right to use a commons is that it is directly privatizing such common, and it has become the preferred option for modern capitalism. Turning the selfishness that initiated the overexploitation of the resource in the first place, or at least assuming that the user will be acting as such, into a positive attribute of the user when it can indeed responsibly manage the privatized paid-for section of the commons, becomes the winning scenario. This will, inevitably, end up bringing even more externalities to the table, as competitive pressures will demand it, and thus it becomes the main critique of private ownership of commons.

As stated before, blaming overpopulation was Hardin's approach, but it clearly left out of the equation any feasible intention from its users to actually do something about its conservation, leaning more towards pointing to humanity as mindless resource eaters. It is true that resources are finite, meaning that in reality the number of humans is only part of the question to start with. But only pointing to overpopulation as the answer leaves out that communities can and have been proven to be capable of sustained management of commons. There is evidence that throughout human history, communities have found equitable ways to organize their individual tasks within a collective context without needing a central authority, leading to, and relying on, self-sustainability at a scale. Elements such as local knowledge, clear and widely understood rules, effective communication, constant monitoring of the resources, trust, and paths for conflict resolution, have been a constant throughout human history co-living with natural resources, and have proven to work in communities related to, but not excluding, agriculture, fishing, communal gardens or self-owned corporations.

By denaturalizing the commons and changing the paradigm and structure of how the resource is consumed has led humanity further from long-term natural resource management and leaving out proven ways of collectively engaging with environments in a holistic manner (Lozny & McGovern, 2019). This evidently more social and humanized approach to managing commons was brought to light by the works of Elinor Ostrom, starting with her research Governing the Commons (1990), in which she drew comparisons and extracted shared knowledge from several ancestral community-based management of the commons, such as forestry in Japanese villagers and grazing in alpine settlements. But such work was not left without its detractors, as different authors have pointed out that the potential weaknesses of community-based norms lie in their inability to be easily scaled up and get lagged when catching up with technological developments (Rose, 2020).

Bringing the aforementioned notions of commons management to the case of space debris, connections are easily made. Space has increasingly become a much more valuable resource to humanity as a society that is highly reliant on technology and this particular case, on satellites, enabling their use but leaving their users to take it for granted. It is within this case that the possibility of using space itself becomes a question more than an answer, as the usage and the utility of space itself depends on the extent of whether or not it can be continuously accessed. It is for this very same reason that space debris enters the commons equation as a threat, posing an increasing risk on the future access to the space medium and consequently limiting the extent to how it can be used for what it is expected to provide to humankind. Space does check all the elements of a commons, and even though no space debris collision yet has been catastrophic enough to render it useless or to disrupt its current functionality and availability even partially, it can already be classified as a tragedy of the commons for the very same reason of why space debris exist: Its unregulated, or least poorly regulated, use. Since the chance of a catastrophic event exists, though low, the event is imminent and by the mere existence of its possibility, the categorization is valid, especially when considering the imbalance between how important it is space and how poorly it has been addressed up to this point.

Regardless of the advance technological and engineering achievements and the state of the art regarding the overall estimation of objects in space and their foreseeable impact, current international guidelines that try to govern the use space and control the further creation of space debris do not enforce or restrict, but rather suggest actions by setting usage and disposal standards. Instead of managing, or acting, it still opens up the chance that space can be used a common property resource accessible by any entity, public or private, that has the technological and/or financial capacity to do so. On the other hand, no country or entity that produces space debris faces any cost for producing or owning such space debris, thus none is having a real incentive to proactively limit its space debris production. For such reason, the continued use of space will only get it closer to the moment when a real tragedy of the commons materializes, a statement that is strongly backed when considering that almost any human-derived activity done in space has the actual potential of creating further debris as it can happen at any stage of the lifecycle of any spacecraft. If left unregulated, as infinite as it may appear to be, our usable space might eventually become unusable.

3. INSIGHTS FROM OTHER COMPARABLE TRAGEDIES OF THE COMMONS

The tragedy of the commons is not an issue exclusively tied to space debris. As it can be understood from its theoretical definition and the universality of its concept, this phenomenon has been almost ever existent since the dawn of man, right from the moment in which a rational and socially organized species decided to move outside from its naturally established boundaries in order to seek resources for survival, in that manner putting in risk the survival of other species lacking such cognitive capacity and adaptation skills, as well as multiple ecosystems with all their corresponding natural resources. At that moment in time and through most part of human history, there was no real notion of the finiteness of natural resources, consequently leading to a gradually increasing depletion of water sources and forests in order to supply the demand for grazing lands, agriculture, urban establishments, and many other indispensable elements that organized human settlements have always needed. According to the original article published by Hardin (1968), the issue of human overpopulation is the main factor behind environmental degradation, but it is not considering the fact that communities sharing those commons being actively degraded are the ones being incapable of approaching a sustainable usage strategy, as Earth’s resources have been and will always be finite.

Jumping forward several thousand years of evolution, land domination and industrial revolutions, the human race has found itself making immense jumps in technological advancements to keep supplying the energetic demands of its population, and with such advancements, even more complex tragedies of commons have arisen in terms of their causes and their potential solutions. This is, partly, good news for the space debris issue, as humans have already had to come up with solutions to many of these issues whenever they have fallen out of control and, even though they correspond to different scenarios with different stakeholders and different finite resources, there are similarities to be found with the space debris dilemma. Nevertheless, many other common resources being over exploited still stand without a major agreed solution due to technological or political reasons.

Several industries during the last 100 years have already faced challenges similar to the space debris problem, having been able to deal with them in a successful manner. According to Baiocchi and Welser (2010) in their study “Confronting Space Debris” and from which most of this sub chapter is taken from, out of all other possible tragedies of the commons that can fall into a field of comparison, only some can actually be comparable to the space debris tragedy by assessing that they possess at least these following 4 characteristics:

a. That the current cultural norms which define acceptable behaviors within the specific industry dealing with the commons are, only by themselves, not sufficient to provide any reasonable solution to the problem. Such cultural norms should, in theory, discourage the majority of stakeholders from practicing the undesirable behavior under question, but in reality, they are still executed regardless of its recognition. For the case of space debris, most of the players in the space industry publicly acknowledge and agree that creating further debris is not acceptable and are aware of its damaging consequences, falling almost into a category of universal and unquestionable belief. Even so, debris continue to be placed in orbit and the issue continues to grow.

b. That there is a significant risk that if the problem is not properly addressed and contained, the actions of one player will after the others, bringing collateral damage to their properties. Thus, a common plan has to be devised and implemented to protect the interests of all the stakeholders. In space, a satellite orbiting out of control owned by one player can directly impact another, creating a chain reaction that can consequently and exponentially increase the threat to other third parties, their satellites, and their business interests, by dampening their capabilities and affecting their sources of revenue.

c. That there will always be “rule-breakers” present in the system. Rule-breakers, are, by pure definition, the perpetrators of the infringement of the cultural and behavioral norms stated in the first point, regardless of their intention (by accident or not). Space debris have been created both by accident and intentionally. For example, the first case applies for situations such as rutinary decommissioning of components (or the entire satellite) or weight-loss operations, and the second case, for when two satellites collide while orbiting and consequently generate debris. Even if the intentional creation of the debris is properly agreed, regulated, and eliminated, the already existing satellites in orbit can fail by accident and collide. Both the uncontrolled satellites and their loose parts become the endless supply of rule breakers for the space system.

d. That the root cause is considerably difficult to control or eradicate, meaning that the problem could never be considered completely solved in practical terms. This stems normally from the actual root cause elimination being either too expensive, technically challenging or both. Transferring this to the space domain, there is currently not a feasible and proven combination of a technology and a methodology to eliminate or extract orbiting debris out of harm. Moreover, if the root cause was to be defined as the usage the space environment itself, then the decision to not use space at all would not be acceptable by any means by any actor of the space industry. Under this scenario, a more feasible agreement would be to approach the issue with a controlled usage rather than seeking prohibition, trying to reduce all the effects mentioned in this and the last 3 points to a level that is considered as bearable.

Using these set of characteristics, which also serve the purpose of stablishing a methodological characterization to the debris problem itself, the authors narrowed down the possible scenarios to 9 comparable problems from which to gain and summarize mutual insights, which are listed along with a brief description:

- **Acid rain**: An increase in the natural acidity in the raindrops, cause by the presence of air pollution in the atmosphere. It is harmful to all living beings mainly because of the change of pH levels in water sources, as well as affecting and degrading human-made structures.

- **Airline security**: The threat of terrorist attacks within the domain of commercial air flights, posing a direct threat to the users of the service in addition to the targeted entity.

- **Asbestos**: A main component of insulating materials and fire retardants for construction. Several studies linked its exposure to humans with cancer and other life-threatening illnesses.

- **Chlorofluorocarbons**: A main component of aerosol products during the second half of the 20th century. Several studies linked its release to the atmosphere with the depletion of the ozone layer and global warming via the greenhouse effect.

- **Hazardous waste**: The uncontrolled and irresponsible disposal of waste produced by humans that can be harmful to living organisms, such as radioactive byproducts of nuclear operations or untreated human waste.

- **Oil Spills**: The spilling of oil on a water body from its transportation vessel, such as ships, or from its extraction platform overseas. The 2010 Deepwater Horizon Oil Spill is used as a case study to obtain further lessons learned.

- **Radon**: A byproduct of Uranium decay, with several studies linking its exposure to humans with lung cancer.

- **Spam**: Unwanted and possibly malicious emails arriving at an individual's mailbox, as well and pop-ups appearing while browsing the internet.

- **Border Control**: Corresponds to the enactment of controlled entry to a territory, in this case, the United States with its Customs Border Patrol, with the intention of actively addressing incoming threats of terrorisms, illegal immigration and drug dealing.

Before progressing with the findings, it is necessary to differentiate between 2 different classes that group all possible set of actions towards space debris management, as the different insights are to be classified in accordance: Mitigation and remediation. The first class refers to actions that are set to reduce the impact, by means of rules and regulations or any other standard that may not block the generation of space debris from further happening but will rather slow their growth, reduce their frequency and their potential impact in a preventive manner. The second class corresponds to actions that are set to stop the event from happening and lead to a reversal of the impacts towards a progressive improvement of the system, by means of technical innovations that react to events that have already happened. In this case, the action of reacting can also be understood as correcting, and for space debris, this means to actively eliminate its orbiting population. With this in knowledge, the insights from both classes are presented in the domains where the practical examples were observed:

3.1.INSIGHTS REGARDING MITIGATION

The set of actions classified within mitigation efforts are inherently preventive, not treating the cause but acting upon its consequences. Thus, three approaches to mitigation efforts are to be defined first in order to organize the insights coming from the other comparable tragedies of commons:

Command and control approach:

In what is traditionally abbreviated to as "C2", a community behavior control structure is delivered by penalties, with a set of commands that is issued and then enforced to exert control over inappropriate behaviors. The execution of such behaviors, which would then constitute a transgression over the issued commands, is punished directly with fines and legal actions and indirectly with social and cultural pressure. As in the case of Acid Rain, fines for surpassing the limits of industrial emissions issued by the governing entities has been one of the most typical deployments of this approach, as well as any of the other previously described cases in which a contaminating agent is released by a company or individual.

Its simplicity makes it easy to understand and implement regardless of the culture, so it tends to be one of the first strategies that is always implemented. If the set of regulations is correctly deployed, it will usually address the majority of the interests of its stakeholders. This approach works well independently of the size of the system or the number of players, and due to this scalability, a bigger population or system size will then require a larger infrastructure to guarantee appropriate coverage and enforcement, or vice versa. But, with larger populations, a bigger pool of varied interests can come into play, thus enlarging the scope of the enforcement infrastructure, and making it too costly and difficult to manage. Finally, by the nature of this approach which simply stablishes a limit, there are no further motivations or incentives to push innovation or strategies towards further reduction from what is needed to strictly comply with the norm in order not to pay.

Market-based approach:

Continuing with the previous development, for larger or far more diverse populations, the command-and-control approach might allow for gaps in which players can commit undesirable behaviors without facing fines or any other of the imposed penalties. A market-based approach then can come into play, first by recognizing that the problem currently exists, will continue to exist, and that up to a certain extent its occurrence can be acceptable. Then, the approach establishes an allocation scheme for the right to execute such undesirable behavior. This approach requires an even more robust infrastructure than a command-and-control approach, as well as a 100% participation of all stakeholders, in order to be effective, but in reality, they do not end up helping much towards the elimination of the problem itself.

Performance-based approach:

Much like the market-based approach, by accepting that the problem will continue to happen enables this approach to also acknowledge its inevitability by assigning quotas to stakeholders, meaning a maximum level of the undesirable behavior (polluting emissions, for example), in which they can engage and fulfill in any desired manner. In terms of environmental control, this approach is useful to fully identify and measure the polluting entities as well as their participation in the overall pollution levels.

With the previous 3 definitions established, the main insights that can be taken from some of the tragedies of commons that share traits with space debris are from:

3.1.1. THE CASE OF AIRLINE SECURITY

In its simplest form, the approach to this problem is a Command-and-Control one. All the security measures and screenings that one might find when entering an airport are there precisely to enforce acceptable behaviors inside the premises of the boarding gates and to guarantee the safety of passengers. This applied approach brings the following lessons:

- In order to be completely prepared for potential threats, the control infrastructure has to operate effectively and efficiently. All exchanges of information must rely on a robust and timely communication platform and all involved personnel must have clearly defined roles with a clear knowledge of its tasks and place within the whole operation.

- Mitigation strategies evolve through time. Newly detected threats and terrorist tactics discovered over time have led to the implementation of new or updated security measures as well, through an ever-evolving process of continuous improvement.

- A Command-and-control approach relies on clearly defined jurisdictions within the enforcing organizations. In airports, several different teams work simultaneously to guarantee safety all over the airport. Apart from the organization enforcing security at the gates, which is the TSA, private security companies enact similar actions in the other, publicly accessible areas of the airport as well as local police enforce safety in the areas surrounding the airport. Thus, all participating parties must know how to act if an incident occurs within their own premises, respecting the previously agreed jurisdictions.

3.1.2. THE CASE OF RADON LEVEL CONTROL IN THE U.S.

The mitigation approach to this problem relies initially on a Command-and-Control approach as well, with the U.S. implementing a standard and setting limits for radon levels in homes, but further relies on the users of such homes to measure the radon levels when exchanging ownerships which if found to be over the permissible levels, will not turn out into a fine but rather will prevent the current owner from being able to sell the property, thus forcing him to act upon solving the issue. In this way, it partially relies on individuals to address the problem by themselves. This applied approach brings the following lessons:

- Nonregulatory approaches to mitigation increase public awareness but do not necessarily achieve high levels of compliance. As each individual can ultimately and independently decide whether or not to act upon finding out about the presence of the problem, doing nothing is still an acceptable outcome. In the radon case, not acting to lower radon levels on a specific property will not affect the radon levels on the property of its neighbor or other people in the region. Nevertheless, in the space debris case, where actions executed by an individual affect every other member of the system, nonregulatory measures are not likely to succeed in making any difference.

- Mitigation strategies evolve through time. Newly detected threats and terrorist tactics discovered over time have led to the implementation of new or updated security measures as well, through an ever-evolving process of continuous improvement.

3.1.3. THE CASE OF ACID RAIN

The approach of the US to mitigate the release of sulfuric components and nitrogen into the atmosphere has been to combine both a Command-and-Control strategy with a reinforcing Market-Bases approach. Initially, a set of standards deployed by the government sought to control its release by instituting fines to any entity not respecting the guidelines. However, the mitigation approach continued to evolve as the initial approach did not prove to be sufficient, thus growing towards including a control program with an allowance strategy to fill the gaps left open during the first attempt. The current caps on emissions imposed to polluting industries have effectively manage to reduce the present of the contaminating agents in the atmosphere. This applied approach brings the following lessons:

- An assessment and classification of risks is necessary to successfully implement a wide-scale Command-and-Control strategy. Different levels of relative risk have to be defined and the consequences and symptoms of the problem have to be categorized within them, ranging from the negligible to critical. Each level must have a corresponding set of guidelines, incentives, and penalties, as it happened with the Radon case. Following this, resources can be more efficiently distributed, clearer action plans can be predefined for each level and boundaries between stakeholders and the controlling entities can be established.

- A market-based approach is more effective if it is put in effect after a Command-and-Control strategy has already been implemented. As stated before, from their definition, the former complements the latter by filling its gaps, but implementing them in such order helps a smoother transition as a comprehensive Command-and-control strategy takes time not only to be developed but also to be deployed.

3.2.INSIGHTS REGARDING REMEDIATION

The set of actions classified within remediation efforts are inherently reactive, designed to reverse and fix events which often come into effect after catastrophes have already happened and propagated. Thus, two approaches to remediation efforts are to be defined first in order to organize the insights coming from the rest of comparable tragedies of commons, classified depending on how they address a certain problem:

Relocation versus Elimination techniques:

An undesired object can either be moved to a location in which it no longer poses a high risk, or it can be completely eliminated. Taking as an example the case of an oil spill, both approaches are enacted. On one hand, a technique called skimming can capture the oil floating on the surface of the ocean in order for it to be transported to a processing plant. At the same time, the oil platform will try to cut the oil flow directly from the source, which might not be possible if the same spill comes from a ship vessel. In general terms, the decision between one and the other depends on the risk tolerance of the system and its stakeholders as well as which one more sufficiently covers the specific needs. In the case of space debris, there is known “graveyard orbit” located several kilometers outside of the GEO belt, in which the space community is known to send some of its aging missions without interfering with operational satellites.

Targeted versus Dragnet techniques:

An undesired object can be relocated or eliminated by using strategies that can be either targeted or dragnet. For the case of targeted removals, techniques are used to execute the action over a single object. On the other hand, dragnet techniques act over a wider group of objects that fall into a particular set of characteristics.

Targeted removals are effective to attack the root cause of any problem. Coming back to the case of an oil spill, a targeted approach will be the one used to eliminate the oil leak directly from the source. On the other hand, a dragnet approach will be the one used to collect the oil from the surface of the sea via the skimming method, as in the action it will also collect any other particle that falls into its physical boundaries and that can be effectively trapped by it. It is important to mention, as a take-away, that targeted solutions then have to be heavily customized in order to be able to effectively target and act upon the root cause of the problems. This will then prove it to be successful against the specific issue, within a certain set of conditions, but will probably fail to be as effective if the cause of the problem slightly changes and the proposed design no longer works.

With the previous definitions established, the main insights that can be taken from some of the tragedies of commons that share traits with space debris are from:

3.2.1. THE CASE OF OIL SPILLS

There is a particular case of significant interest within this domain that corresponds to the Deepwater Horizon oil spill, which happened in the Gulf of Mexico in 2010. An explosion occurred on the oil rig that caused the largest oil spill in US history and a set of remedies were devised and put into action in order to halt the further propagation of the oil outside of its initial zone of influence. This particular case study brings the following lessons regarding remediation strategies:

- Remediation techniques must be tested and proven to successfully function under the expected operation conditions. During the first 40 days of the oil spill, 10 different attempts were made to stop the oil flow into the ocean without making a major impact regarding that objective. These attempts did not imply using new technologies at all, they had already worked before to remediate similar accidents. Instead, they had not simply been tested at the depth in which this event occurred. The same goes for any up-and-coming removal technique for space debris, which have to be launched and tested first before starting to be deployed.

- The system will only start supporting new remediation strategies when the risk becomes unacceptable. The techniques being used for this accident were the same used for the past 5 decades, meaning that the apparent risks perceived by the community was not deemed as high enough to justify the development of new remediation techniques. This is clearly the case for space debris, as the community as a whole has not widely perceived that the risk of collision is not high enough yet to come up with the solution itself.

- Dragnet solutions are critical in dealing with the aftereffects of a catastrophe. This was shown to be the method most widely deployed to treat the oil spill in question and several different techniques with such characteristics were used in order to contain it. In the case of space debris, this will probably be one of the sought-upon approaches to remediation.

- Targeted solutions will still be necessary to remediate a catastrophic event. Even if the dragnet solutions act against the aftereffects, targeted techniques will still need to be deployed in order to execute actions towards eliminating the root cause. In this case study, even after the dragnet solutions were proven to be effective, the oil leak itself still had to be treated and sealed for good under the harsh conditions of such a deep drilling installation. For satellites, this will probably not be the case unless a catastrophic even is left to happen in the first place, but still, a targeted solution to be launched into space to deal with one highly specific issue would most probably not be cost-effective.

- Remediation strategies must constantly evolve to adapt to the new challenges. As was mentioned for the case of mitigation strategies as well, remediation techniques are also expected to change as the problems and their root causes continue to evolve themselves and become more complex to manage. For the case of this oil spill, as mentioned in one of the previous insights, the techniques employed had been in place for almost 5 decades, but they had not been readapted to work at the deeper operating conditions that newer oil drilling platforms and newer drilling technologies had come to achieve in the later decades. The remediation technology simply did not keep up with the innovation pace of the technologies that would create the problem in the first place. In space, such strategies have to be constantly adapting to be able to deal with even more debris, different distributions, different orbits, or different technologies that might imply treating them differently, in consequence.

DISCUSSION

Taking all previously mentioned insights from other industries, key points can be transferred to the domain of space debris as an experience-based knowledge basis towards building cooperative solutions that might truly and effectively address this tragedy of the commons. For the case of satellite manufacturers and operators, being the main engagers of space debris creation within their market, any decision made, and any new regulation imposed would directly influence their business strategy as they would need to comply to the controlling measures without affecting their operations and their revenue streams, especially in the wake of the large satellite constellations era and the starting full deployment of small sats.

When comparing the space debris tragedy against its similar counterparts, it is safe to state that the understood level of risk is not yet high enough for stakeholders to act as if a catastrophe was imminent, which also explains why governing bodies and regulating entities have not yet come up with radical rulings to enforce control over further space debris generation. Most probably, only when the public risk perception surpasses a critical limit that could easily be crossed when a space collision with debris happens with disastrous effects for the involved parties as well as a wide media coverage. Moreover, with the current shift from government and military controlled space market towards a private-based approach in which commercial interests are prime, any new technical advancement will be mostly driven by a commercial interest itself, meaning that it will be deployed in order to increase their value as a consequence. There is not a clear incentive for space companies, as well as for satellite operators and manufacturers, to develop solutions for an issue for which there is no perceived risk and no financial motivation.

The U.S. has already taken an active part in trying to control the further creation of space debris by ensuring the removal of space missions at their end of life, mostly targeting mitigation practices that try to lower but not eradicate future creation of debris and are directly related to the operation and decommissioning of the satellites. By establishing practices such as achieving a high post mission disposal probability of any spacecraft that integrates a large constellation and limiting the orbital lifetime of small satellites in LEO as well the space debris generation as an outcome of their servicing operations, it is understood that if taken in consideration by satellite manufacturers, they should consider such factors within the design of the satellite itself and when taken by satellite operators, they should adapt both their supply requirements (by demanding such design factors to be included from their satellite suppliers if a purchase agreement is to be made) as well as their mission and operating conditions themselves.

Apart from these, more obvious decisions that act upon current guidelines, the main insights that can complement them, gained from the outcomes of the other scenarios of tragedies of the commons are:

- Stakeholders must be in total and constant awareness of the scope of the debris population at all times in order to be able to act accordingly. By also knowing how the evolution of such population would turn into further or more strict regulations, the actions regarding their own strategies and mission designs would be more preventive. For this to happen, global metrics have to be implemented first so that the monitored variables are widely understood and known at all horizontal and vertical levels of the industry, also helping to mitigate the effects of a false sense of security that comes naturally with issues for which its effects are not necessarily tangible on a daily basis.

- Mitigation and remediation efforts must continue to evolve. This holds to be especially true as satellite constellations are beginning to be deployed on a wide scale. Such different approach to space exploitation will consequently change the approach to which mitigation remediation efforts are designed, tested, and deployed. Even normative behaviors and culturally established beliefs must adapt to the changing times.

- Accepted risk levels must be agreed upon industry wide. Requiring first a critical approach towards understanding and classifying the risks by a governing entity, all stakeholders must agree on such levels and their implications in order for, one side, have stakeholders adapt their strategies to the risk tolerance level they are willing to take on and on the other, have the governing entity establish proper incentives and penalties that adjust to the agreed levels, including the remediation actions and the associated costs that have to be deployed in higher levels of risk On that level, mitigation strategies led by private companies can be more easily measured against the potential counterpart of having to incur in an investment on a remediation action or paying a penalty.

- The space community needs to be prepared for the catastrophic outcome. Technologies must be devised and tested, ideally in real operating conditions, before the actual event happens. For this to happen, a good choice would be to constitute a global association of space stakeholders that is financed by several interested parties, taking the lead in developing the solutions at an industrial scale, up from the current academic and laboratory approach. It would help to take into account the interests of most stakeholders and come up with a technologically feasible portfolio of remediation options, each with a contingency plan and proposed used case. As it was mentioned before in the literature review, remediation technologies tend to be highly customized and are designed to operate under very specific set of circumstances, meaning that more than one technology has to be developed and tested.

MANAGERIAL RECOMMENDATIONS

For stakeholders in the space industry engaging in businesses within the domains of satellite manufacturing and operations, these recommendations stemming from the current research are given, with the first two having a possible profitable outcome and the last one mainly targeted towards prevention and regularization:

1. To take an active role in research towards more robust mitigation technologies without a proper financial interest. This will mostly be directed towards players in the satellite industry such as Amazon's Project Kuiper, which within its silicon-valley business and strategic mindset can more easily contemplate investing in research efforts without expecting an immediate return of investment, rather than just acquiring knowledge to raise their innovation capacities as well as their shareholder value, or simply taking pride of holding the flag of an industry sustainability leadership, much like happened with electric cars or reusable rockets for Tesla and SpaceX, respectively. Nevertheless, such a company can still opt to sell said research outcomes or patents to other industry stakeholders if the implementation of robust mitigation capacities within design stages of satellites ever becomes enforced by governing bodies.

2. To take an active role in research towards more robust remediation technologies and engage in first mover advantage with their proprietary solutions. Eventually, the market will call for these technologies to be actively deployed, especially after an accident with severe consequences occur. Keeping the development constantly updated and tested, the leasing or selling of its operating equipment can become a business model of its own. This, as well, might be directed more towards a Project Kuiper-like business, with enough capital and research power to engage in a self-financed innovative remediation venture that can come up with customizable solutions to cover a wide portfolio of potential circumstances, or at least covering the ones which are more like to occur.

3. To take a leading role in establishing and fund industry-wide research efforts towards an agreement on debris metrics, debris visibility platforms and debris risk level assessment and classification. Regarding the first 2, currently, operators have access to preventive alerts regarding potential collisions involving satellites of their property so that tactical maneuvers can be executed, which help them prevent losses on their property. But a wide visibility of the scale of the debris distribution, without tactical and corrective purposes but rather more informative and preventive purposes, is not fully deployed. This is helping build a false sense of security towards the overall scope of the issue.

   Finally, a clearly understood, agreed upon and widely implemented debris risk level classification can help decision makers in satellite companies to assess whether or not they can manage to operate within certain risk tolerance levels knowing what will happen if the limits within one and another are crossed. If at any point, the threshold crossings are enforced and incentivized/penalized, such knowledge can help them decide whether or not to invest in mitigation or remediation alternatives at any given point based on their current location within the scale in contrast to having to pay for fines, as an example.

CONCLUSION

Based on the executed literature review and the points addressed in the discussion, valid comparisons could be traced between the space debris tragedy of commons and other comparable scenarios belonging to different industries. This enabled shared insights and acquired knowledge to be extracted and discussed, leading to managerial recommendations to be given regarding the most important key elements that can apply to the business interests of satellite operators and manufacturers. Such recommendations are summarized as:

1. To take an active role in research towards more robust mitigation technologies without a proper initial financial interest but opening up to profiting from it when the regulations become stricter by selling technologies to interested parties.

2. To take an active role in research towards more robust remediation technologies and engage in first mover advantage with their proprietary solutions portfolio. It is a matter of time before the market needs effective remediation technologies to act upon any accident involving a collision involving space debris.

3. To take a leading role in establishing and fund industry-wide research efforts towards an agreement on debris metrics, debris visibility platforms and debris risk level assessment and classification. Not any easily visible return on investment can come from this recommendation but will help managers to strengthen their decision making based on updated knowledge and visibility of the scope of the problem, as well as enabling them to assess their risk tolerance more easily.

The insights used for the study were taken from other examples of tragedies of the commons that were deemed as comparable and were shown to share traits up to certain extent, according to the main literature source for the analysis which established a comprehensive identification scheme and comparative framework from which to extract the shared knowledge. But by not corresponding to the exact same industry and having other notable differences, the derived recommendations are subjected to limitations. It is necessary to address that the main limitation of this study corresponds to the space debris tragedy having such a wide variety of stakeholders subjected to complex relationships, having different commercial/political interests, belonging to both public/private sectors, having diverse approaches to their space business and with very heterogenous financial capacities and wealth distributions. This wide spectrum might lead to think that any other scenario will fail in comparison as the scale is not addressable, and that reaching wide agreements and approaching global solutions, one of the main points in the recommendations, currently is and will continue to be a difficult task. Even if the latter statement might hold truth to it, all revised problems involved reaching agreements between multiple parties with their own individual interests, which holds value regardless of the scale and adds weight to the comparison, even more so when considering their already proven positive outcomes on the control of their respective problems.

The managerial recommendations given as an outcome of this research hold key elements to decision makers in the industry towards the start of the construction of joint efforts that lead to effective strategies to help space debris stop being a risk for the sustainability of future space ventures and their own business interests. The same individuals that have led to space utilization become a tragedy of the commons, are the ones with the main responsibility of taking it back, but only via joint and holistic efforts that leave aside individualistic financial and political interests and recognize space business as a community rather than a system, themselves as members rather than competing players and space itself as its most valuable asset rather than just the medium through which their businesses can be run.

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