Analysis of the Environmental and Socio-Political Parallels Between Orbital and Marine Debris

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Section I: Debris-Ridden Environments and Literature Review

Introduction

Rapid technological growth in recent years has led to a proliferation of debris both orbiting our Earth's atmosphere and floating in our oceans. This sudden rise in the number of debris disturbing these two vastly different environments has disrupted the nature and balance of ecosystems and poses significant risks to both human activities and wildlife.

Currently, there are more than one hundred million pieces of debris floating in Low Earth Orbit (LEO), or approximately two hundred to two thousand kilometers above Earth's surface (Douglas, 2023). Unexpectedly, a vast majority of the orbital debris within Earth's sphere of influence is untraced by the National Aeronautics and Space Administration (NASA). Federal space agencies only trace debris above ten centimeters in diameter due to the need for a robust, scalable system for smaller orbital debris (Douglas, 2023).

Marine debris is another environmental issue that has plagued our oceans and watersheds for much longer than debris in space. These plastic particulates along with other waste cause problems in coastal watersheds because they easily come into contact with the surrounding ecosystem. Thousands of aquatic animals get caught and strangled by floating debris each year (Whitman, 2002). This type of debris has also been deemed expensive for coastal communities as littered beaches must be closed for cleanup. These issues associated with oceanic debris have led to the development of laws, regulations, cleanup committees, and many other mitigation measures to ensure our watersheds remain as pure as possible.

Both forms of debris, oceanic and orbital, contribute to their environments in similar ways through the lens of Bruno Latour's *Actor-Network Theory*. This sociotechnical theory suggests that human and non-human "actors" form relationships and influence the assemblage of a network of such actors, ultimately leading to the growth and development of technologies (Latour, 1992). For instance, the human body consists of several organs that work in tandem to accomplish the common goal of keeping the body functioning. The organs can be thought of as actors and the entire body represents the network in which the actors function within.

The subsequent sections will further demonstrate the relationships between orbital debris and oceanic debris, comparing their environmental and socio-political impacts through an *Actor-Network Theory* approach. The main purpose of this analysis is to prevent further harm to the orbital debris environment by understanding a more local and researched problem posed by ocean debris. By studying this local environment, policies and other mitigation strategies can be more easily applied to LEO, benefitting the orbital debris environment.

The Orbital Debris Environment

In its early stages, space exploration was viewed optimistically as there was an emphasis on technological achievement. Overtime, as the number of satellites and space missions increased, unintended byproducts, like orbital debris, began to accumulate. Space debris is classified as any orbital object ranging from paint flecks that have disconnected with a space station to large, decades-old, inoperative spacecraft. The European Space Agency (ESA) has reportedly traced approximately 29,210 pieces of debris as of August 2021, but there is an estimated over 120 million pieces of debris in LEO (Luke, 2021). Not only is the debris present, but it is also moving in various orbital patterns with some debris reaching extreme velocities of up to five miles per second.

The orbital debris environment may seem mundane, but there have been serious incidents regarding collisions with active spacecraft. For instance, a robotic arm of the International Space Station (ISS) was punctured by a small piece of metal leaving a gaping hole (Chow, 2021). The arm was left unharmed as it remained functional, but the threat of a high velocity object, travelling at speeds much greater than that of a bullet, has caused NASA and other international space organizations to become much more aware of the dangers space debris poses. In addition to space debris travelling at hypersonic speeds around the globe, there is also debris reentering the lower atmosphere due to Earth's gravitational force exceeding the velocities necessary to maintain orbit. Although most of this debris completely burns up during its reentry, larger fragments can survive the high temperatures associated with hypersonic motion through a more dense atmosphere than in space (Rand, 2018). These pieces of metal, or other materials capable of withstanding such heat, can impact the ground at such high velocity causing damage to critical infrastructure, or potentially cause injuries.

As a result of the risks posed by the fast-moving debris, many researchers have called for international action to mitigate these issues (Rand, 2018). Cooperation between nations could result in policy responses, better technologies for tracking untraced debris, and improved deorbiting strategies to ensure that future space activities do not lead to a further exacerbation of the current problem. For instance, the expansion of the Outer Space Treaty, used primarily to keep peace within nations in space, can enforce standards for debris mitigation (Howells, 2024).

To better understand the sociotechnical impacts of the orbital debris environment, the development of this issue can be analyzed through the lens of *Actor-Network Theory* (Latour, 1992). The non-human actors associated with this environment are the objects producing debris. These objects can include live spacecraft like rockets and satellites. Other non-human actors involved in the agency can include space debris, itself, and natural forces within LEO. These forces include gravity, drag, and other motion-inducing forces. The human actors and institutions involve the international regulatory bodies, private companies, and research institutions participating in the network. With the clear dangers associated with space debris, under *Actor-Network Theory*, the technical realities of orbital decay and reentry push for the creation of new policies or the redesign of satellites, and how these constraints are interpreted and applied by policymakers. Because the network analyzed is constantly evolving, policies need to be adaptive to respond to the new spacecraft, changing technologies, and shifting international relations. An *Actor-Network Theory* perspective would support the creation of frameworks that allow for continuous monitoring and real-time data sharing among actors in the network.

The Marine Debris Environment

The emergence and accumulation of marine debris can be traced all the way back to prior to the 1950s. Most importantly, following World War II, plastic production drastically increased as a result of innovations in polymer science including the developments of nylon and polyethylene (Rochman, 2020). Appendix A details the exponential growth in the plastic production following the end of World War II.

With the high-volume production of plastics and a poor waste management infrastructure, a significant amount of plastic entered oceans, rivers, and other bodies of water during this time. Major contributors include urban runoff as a land-based source as well as fishing gear and shipping as some maritime activities. With the quantity of plastic waste growing, its distribution also increased via ocean currents and winds. With the combined effect of increased input and a dynamic distribution mechanism, the marine debris environment has become a persistent and expanding problem.

The macro and micro plastics floating in our oceans pose adverse impacts on the surrounding marine ecosystems (Whitman, 2002). Marine creatures often mistake plastic fragments for food. Ingestion of plastic materials can cause blockages in the digestive systems of these animals leading to malnourishment or starvation. Plastic is also a toxic material that can lead to poor health in general. Moreover, discarded fish nets or other fishing gear can lead to the entanglement of marine animals. This constriction can harm wildlife due to restricted movements, impairing an animal's ability to hunt or evade predators. In the most severe cases, entanglement can result in death due to drowning or fatal wounds. Even further, floating debris has been found to serve as a vector for harmful pollutants. Plastics can break down in the water resulting in the release of chemicals which can disrupt delicate ecosystems. Ultimately, marine species can have their reproductive and developmental stages interrupted.

In response to the ever growing marine debris environment, there have been policies and organizations put in place to mitigate the persistence of the problem. For example, the federal government has issued the Marine Debris Act establishing a comprehensive framework for the reduction of oceanic debris conflicts (NOAA, 2024). The National Oceanic and Atmospheric Administration (NOAA) has led the way on the efforts posed by the Marine Debris Act. The law ensures that this administration monitors and assesses the presence, sources, and impacts of marine debris across coastal and ocean environments. It also promotes strategies to reduce the generation at the source through collaboration with local industries in attempts to improve waste management.

To further transform our understanding of the marine debris environment, *Actor-Network Theory* can be used to describe the complex network of our oceans. Some key non-human actors within the network are the macro plastics, micro plastics, and all other forms of marine debris. These actants play a significant role in how debris persists in the environment while adversely interacting with the marine ecosystems. The natural forces like ocean currents, winds, and waves also act as agents by being the main source of transportation for the other non-human actors. The human aspects of the network include industries responsible for the mass production of plastics, waste management systems, environmental regulatory agencies, and the individuals that contribute to the dispersion of the debris. Some consumers may not play strictly negative roles in this network, but may also contribute to mitigation strategies, helping the environment. Based on Latour's concept of "translation," the interests and capabilities of different actors are aligned. In the context of the current problem, technological innovations to improve recycling techniques or removal of debris represent efforts to realign the agency of human and non-human actors towards reducing oceanic pollution. In a similar way, policies like the Marine Debris Act have been constructed and reconstructed to encourage collective action on the topic of mitigation techniques.

Methodology

The following section will detail an in-depth analysis of environmental and socio-political parallels between space debris and marine debris. In order to fully understand some of the trends associated with the growth and distribution of debris, several graphs have been produced and analyzed to demonstrate parallels. The data collected and presented in the appendices stems directly from the literature referenced. To even further grasp these trends, it is important to also analyze the social and technological pressures associated with the graphics as these factors led directly to the information presented.

In addition to the quantitative data, there will be qualities between the environments that have significant parallels. To draw conclusions about the corresponding qualities, space debris and marine debris will be analyzed through the lens of *Actor-Network Theory* where several agents within the networks are alike, playing key roles in the many aspects of both debris distribution mechanisms and the socio-political pressures applied to governments and other organizations.

Some limitations associated with this analysis include the very slim amount of information and research available regarding the orbital debris environment. This is a relatively new topic with few researchers dedicated to thoroughly investigating its long-term impacts and mitigation strategies, resulting in a reliance on preliminary data and theoretical models that may not fully capture the complexity of the issue. Moreover, the study relies primarily on secondary data, so its scope is limited by the availability and depth of existing literature. Additionally, the comparative framework may not capture every nuance unique to each debris environment, though it provides a robust basis for identifying notable trends and challenges.

Section II: Environmental and Socio-Political Parallels - Results and Discussion

Accumulation Overtime

Both types of debris, marine and orbital, exhibit parallel trends as a result of technological progress. A striking similarity can be found with the accumulation of debris overtime. Plastic production following World War II increased drastically leading directly to the accumulation of marine debris in oceans. Correspondingly, the technological boom in the aerospace industry resulted in the increase of satellites, rockets, and other spacecraft in LEO, directly leading to the accumulation of space debris. According to the graph in Appendix B, the marine debris concentration located in the Great Pacific Garbage Patch has grown with an exponential trend (Lebreton, 2021). Similarly, the observed and forecasted increases in the number of objects in LEO is defined by an exponential growth as demonstrated by Appendix C (Abramova, 2019). Based on the correlation between the exponential growths of debris accumulations, it is reasonable to conclude that there is a consistent trend in the technological booms leading to a rapid increase in the unwanted objects in both the marine and space environments.

Transportation and Distribution of Debris

Another similarity between the demonstrated trends between the two debris environments is the method at which the junk is transported and distributed. All pieces of orbital debris are subject to the gravitational forces of the Earth dictating their orbital mechanics. Some debris may reenter the Earth's atmosphere, others remain in a high velocity orbit where there may be some unpredictable drifting. Due to the nature of orbital forces, there is a disparate distribution of debris in LEO depending on altitude. Based on the graph shown in Appendix D, there is an approximately Gaussian distribution of debris centered around eight hundred kilometers of altitude (Nock, 2013). Marine debris gets carried around by ocean currents, wind patterns, tidal forces, and other natural forces leading to the distribution of plastics. Due to the nature of the currents, these forces lead to the concentration of debris in specific regions, such as the subtropical gyres, but also facilitate its spread to remote areas and deep-sea environments (Rochman, 2020). Based on these higher pockets of debris along with the mechanisms in which objects are moved around their respective environments, there is a clear parallel between marine and orbital debris.

Environmental and Safety Risks

Furthermore, the presence of debris presents environmental and safety risks to the surrounding area. In space, there is a much greater risk of spacecraft collisions with the growing amount of objects in LEO. Such impacts can damage critical space infrastructure which not only jeopardizes communications or mission intentions, but contributes even more to the growing space debris problem. Marine debris can cause harm to the surrounding ecosystem as a result of the inherent toxicity of plastics. Marine animals can ingest debris or become entangled in it, causing injury, illness, or in some cases, death. Toxins from the plastics may also be introduced into the environment disrupting habitats, and even affecting human activities like fishing and tourism. In comparison, the active spacecraft in LEO draws significant similarities to the marine animals in the ocean. Active satellites, or other spacecraft, can be destroyed as a result of fatal collisions with high-velocity debris just in the same way as marine animals can be critically injured due to the ingestion of oceanic debris, thus demonstrating a further parallel.

Policy and Governance

Finally, the parallel environmental pressures associated with the two debris types has garnered attention from governing bodies to help mitigate both issues. To combat the problems associated with orbital debris, International organizations, such as the Inter-Agency Space Debris Coordination Committee (IADC), have been created to enforce mitigation strategies (IADC, n.d.). The main goal of this organization is to establish communications between international space agencies like NASA, the European Space Agency (ESA), and others, as well as regulate space activities to prevent further debris generation. Policies like the aforementioned Marine Debris Act provide frameworks for monitoring, preventing, and removing debris from oceans. These regulatory figures, whether that be specific policies generated or organizations created, are alike in the sense that the goal of debris mitigation is paramount. This indicates a socio-political parallel between the emergence of space debris and marine debris as both environments have directly resulted in the creation of policies and organizations to outline effective frameworks to prevent further environmental harm.

The Role of Actor-Network Theory

Through the lens of Bruno Latour's *Actor-Network Theory*, both environments are understood as complex socio-technical systems where both human and non-human actors interact dynamically. Under this framework, human actors such as regulatory bodies, industrial manufacturers, and academic researchers are embedded within a web of influences. Policies, technologies, and practices are shaped by the characteristics of the non-human actants. For instance, the natural forces like the ocean currents and Earth's gravitational pull help dictate the distributions of debris. To explore this even further, space debris and marine debris have natural occurring instances of higher spatial densities in their respective environments. As previously explored, the Great Pacific Garbage Patch (GPGP) and the eight hundred kilometer range of LEO are similar as the physics of nature dictate pockets of higher concentrations of debris. This is a direct indication of the similarities between the networks as prescribed by *Actor-Network Theory*.

To add, humans have researched for decades to find adaptive solutions to the persistent issues. Because the networks of debris are so complex, humans have concluded that it is necessary to take an integrated approach to the mitigation strategies, accounting for the policy changes, technological upgrades, inherent material properties, and even the naturally occurring movements of the debris. For example, aerospace engineers could integrate more naturally degrading materials into the designs of spacecraft to induce a more natural deorbiting mechanism. This may also work for the oceanic environment as engineers can look to produce plastics that break down less harmful than other plastics currently afloat. The *Actor-Network Theory* approach emphasizes that these networks are dynamic and thrive off of change. The exponential accumulation of debris shows directly the changes both environments endure, but mitigation strategies and their implementations also dynamically alter the system in a beneficial way.

Section III: Concluding Remarks and Appendices

Conclusion

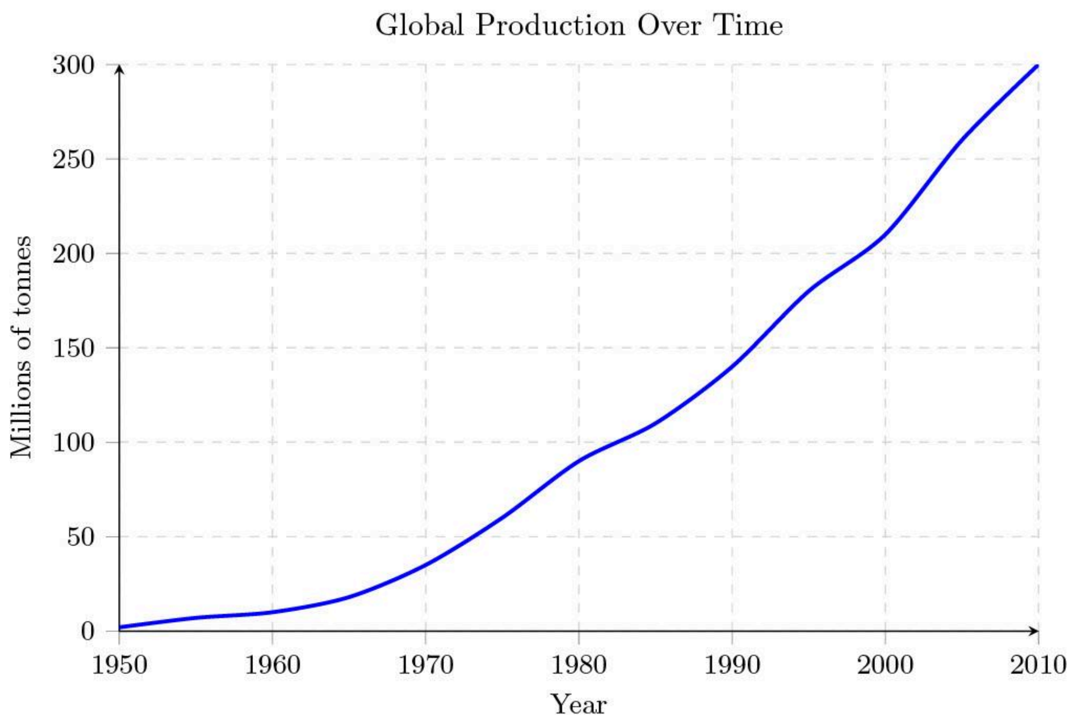
The comparative study of the orbital and marine debris environments through the lens of *Actor-Network Theory* highlights the intricate and interconnected natures of both issues. Briefly, the two networks share common properties in their accumulation processes, distribution mechanisms, and the complex interactions between human and non-human actors involved. Orbital debris has been an inevitable part of the technological breakthroughs associated with space exploration within the past few decades. On the other hand, marine debris is largely driven by the mismanagement of waste along with human consumption. These two systems are governed by physics, whether that be the materials they contain or their motion within their respective environments. Policies and the behaviors of humans also dictate these systems as some acts are aimed at the direct mitigation of such debris.

The insights and conclusions drawn from these parallels help to prevent issues that may be seen in the future for orbital debris. By analyzing the trends associated with the accumulation of marine debris along with some of the strategies taken to decrease this environmental pollutant, humans can play a much more significant role in the prevention of further space debris harming the orbital environment.

Appendix

Appendix A

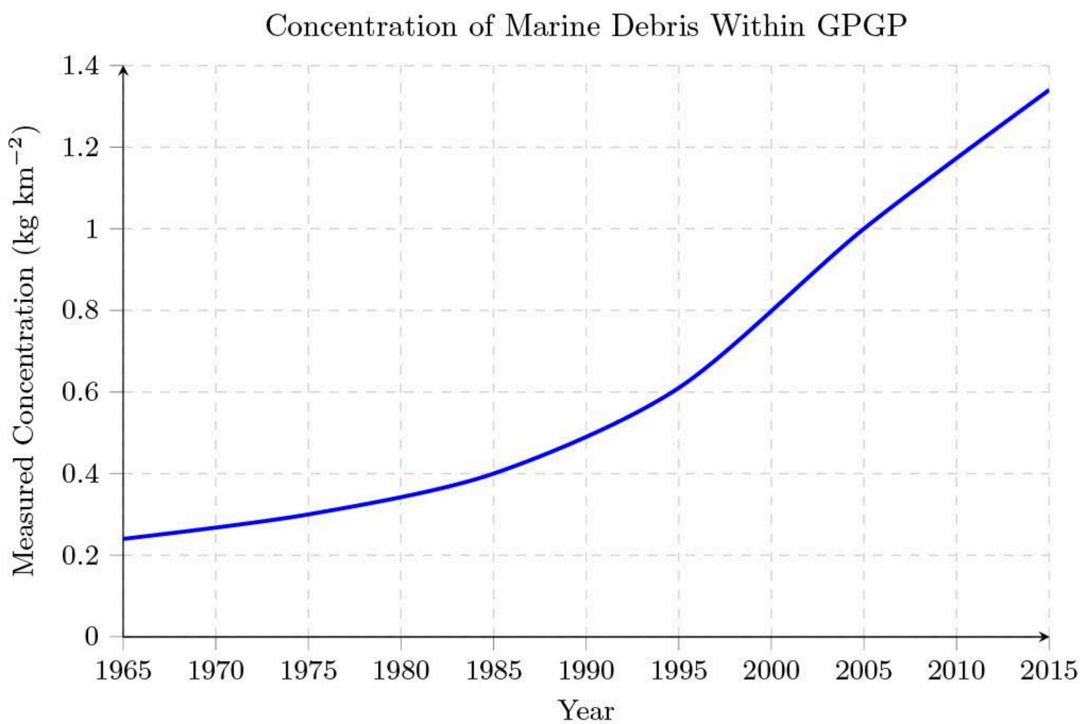
Increase in Global Plastic Production from 1950-2010 (Bergmann, 2015)



Note. The figure above details the exponential increase in the amount of plastics produced during the years following World War II.

Appendix B

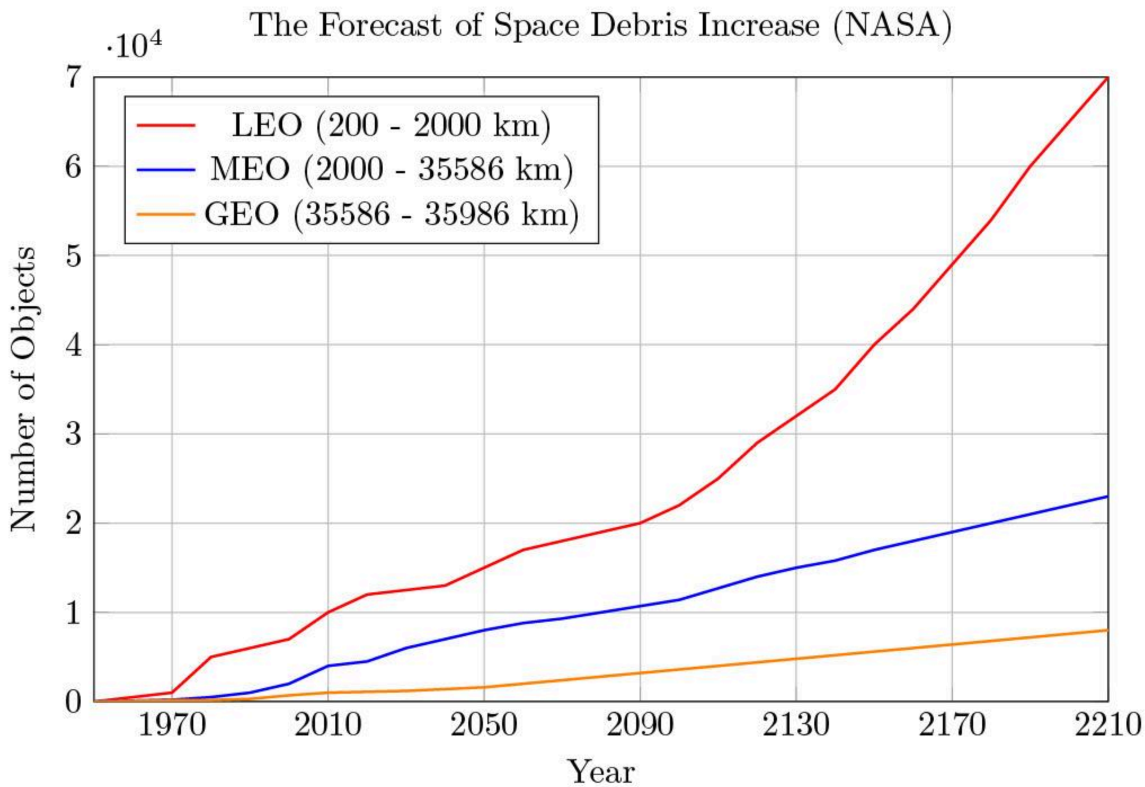
Increase in Marine Debris in the Great Pacific Garbage Patch (Lebreton, 2021)



Note. The measured concentration is for the Great Pacific Garbage Patch, only, but demonstrates the trends necessary to understand exponential growth of debris overtime.

Appendix C

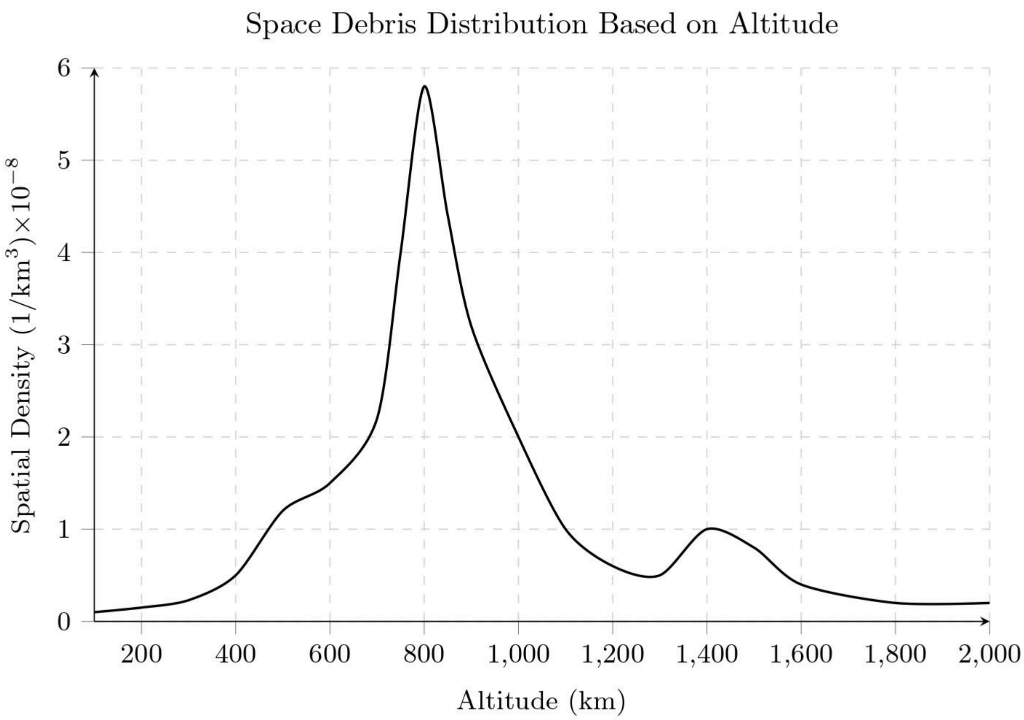
Measured and Forecasted Increase in the Number of Objects Orbiting Earth (Abramova, 2019)



Note. The concentrations shown relay data measured between the years 1950 and 2010. The forecasted data is the information following the year 2010.

Appendix D

Spatial Density Distribution of Tracked Orbital Debris as a Function of Altitude (Nock, 2013)



Note. The spatial density of orbital debris is not constant with altitude within LEO. The highest spatial density is within the 750 to 850 kilometer range.

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