**Halting Orbital Pollution: A Study on Air Pollution Regulation as a Means for Regulating Orbital Pollution**

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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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## Trajectory of Orbital Pollution

As of right now there exist over 170 million pieces of orbital debris in Earth's orbit larger than 1mm in size (*ESA - How Many Space Debris Objects Are Currently in Orbit?*, n.d.). Any orbiting object larger than 1mm can cause serious damage to subsystems aboard a spacecraft. For context, the average object in Low-Earth Orbit (LEO) orbits at approximately 7.8 km/s, or roughly 17,000 mph from a ground observer. Needless to say, these debris have the potential to cause a lot of damage, and with damage to spacecraft comes fragmentation of parts – more orbital debris. Coupled with the advent of technologies like mega-constellations for satellite internet, reusable rockets, commercialized spaceflight, etc., our access to Earth's orbit is increasing rapidly, creating more opportunities for in-orbit collisions to occur and debris to exponentially accumulate. Without proper methods of halting this increase in debris accumulation, there is real potential for this issue to grow catastrophic, ultimately leaving Earth's orbit unusable.

Orbital debris accumulation is an issue that can be mitigated, perhaps even be completely tamed, with proper coordination between the space agencies and private companies utilizing Earth's orbit. However, as of right now there is little to no regulation regarding how satellites should be placed. Demonstrating the need for this cooperation as early as possible will ensure that the problem is being addressed in as reversible a state as possible. The purpose of this paper is to give rise to this issue by exploring a crucial question: how should these companies and technologies be regulated to control the accumulation of space debris? In response to this question, the intent of this paper is to explore regulations that have been successful in mitigating atmospheric pollution, in an attempt to draw comparisons and determine the applicability of these regulations to the technologies and organizations contributing to the rapid increase in orbital pollution. To do so, an analysis of power-plants and of mega-constellations are juxtaposed to gain a better understanding of these sociotechnical systems, and to gauge the transferability of regulation on power plants, to mega-constellations.

## Establishing the Need for Oversight

Mega-constellations perhaps pose the biggest challenge when it comes to increasing our usage of Earth's orbit while maintaining control over debris accumulation. Sources vary, but some estimate between 6000 and 7000 Starlink satellites are currently in operation (McDowell, 2025). Companies and space agencies such as the European Space Agency (ESA), Iridium, and Amazon are currently developing their own constellations to match Starlink's orbital real-estate capacity. Each of these cover a vast footprint in orbit, and it is apparent that lack of cooperation between organizations will almost assuredly lead to a dramatic spike in the rate of debris accumulation. According to Our World in Data, there has been a noticeable increase in the number of debris along with the increase in the number of satellites launched (*Tracked Objects in Low Earth Orbit, by Type*, 2024). Alongside this, spacecraft attempting to travel past these constellations will have a much narrower window to travel through, further increasing the risk of debris accumulation.

It is without a doubt that regulation needs to be implemented in these organizations, however where to start is often the biggest challenge. To gain some insight into successful regulation and policy that could be applied to space companies on their constellations and other technologies, a study of power plant regulation is the trajectory of this research. To prospectively draw meaningful comparisons, policies that resolve an issue *as similar* to that of orbital pollution need to be chosen, to have the best chance of finding some useful translatability of the policies on one issue versus the other. Defining the criteria to determine the similarity of an issue to that of orbital pollution is key in achieving a useful comparison.

Atmospheric pollution was the apparent choice, as policy against power companies has taken course since the Clean Air Act of 1970, when the U.S government's role in the control of air pollution control shifted to enforcing regulations (Rogers, n.d.). Also, atmospheric pollution because of power plants has been and is currently a pressing matter on the global scale, with organizations possessing global authority (i.e. United Nations) arguing and creating policy on climate change. The intensity and global attention given to climate change, along with the long-course of regulation over the past half of a century or so has allowed for many cases of policies to have been either proven successful or unsuccessful. The broad scope of policy renders power plant regulation a bountiful resource for ideas on how to regulate space organizations.

## Utilizing Actor Network Theory for Comparison

According to the American Lung Association, "Power plants that burn coal, oil and gas are the largest source of carbon pollution, the biggest driver of climate change" (*Electric Utilities*, 2024). Because of the inherent cause of pollution stemming primarily from power plants, and more generally technology, studying technology is the first step in analyzing how pollution should be controlled. However, the primary focus of this research is to analyze regulations on power plants. In doing so, the relationship between technology itself, power plants, and the organizations that are regulated and enforce regulation need to be studied and understood. To accomplish this, this study utilizes Actor-Network Theory.

Actor-Network Theory is a complex philosophical framework that attempts to give some structure to the relationships between technologies and their influences. The primary figure in Actor-Network Theory is Bruno Latour, who has changed his opinions on how Actor Network Theory should be viewed over his lifetime. However, Latour's emphasis on this framework is that "actors" in this network of relationships and influences on technologies and society, aren't as binary as is common thought, meaning the actors should not be limited to "human" and "non-human" (Elder-Vass, 2019). Latour in *Reassembling the Social* makes an argument that attempts to define the social relationship with technology "have of late become too cheap, too automatic . . . this is why we must make sure that every entity has been reshuffled, redistributed, unraveled, and 'de-socialized'" (Latour, 2005). Latour's view is that there are so many factors to consider in a sociotechnical network, that it is paramount to view all aspects of the network. This way of thinking is vague and creates complexities when trying to find a utility for Actor-Network theory. Regardless, Actor-Network theory is insightful in that this philosophy encourages attention to *any* source of influence on how people interact with the technology they are using, and that this influence, material or non-material, is an actor in the network.

Actor-Network theory is particularly useful in this case, because maintaining this philosophy while analyzing policy on power plants allows for a broader consideration of the actors in the network surrounding power plants. A broader possibility of the actors involved around power plants will allow for more possibilities to determine how regulations have affected the relationship between energy companies and the power plants they operate. Secondly, Actor-Network theory can provide a glimpse of structure in a sociotechnical network, particularly of the primary actors in a system, i.e. power plants and energy companies. A better understanding of the relationships in an actor-network can allow for the possibility of similarities to be drawn between these networks, in this case the networks surrounding power plants, and satellite mega-constellations.

**Research Goal**

To reiterate, the question that this research intends to explore is: in order to better control the rate of orbital debris accumulation, how should companies and technologies within the space industry be regulated? To explore this question, research was guided toward finding an example of legislation in the past that has been successful in mitigating a *pollution-oriented* problem. The reason to choose to research legislation on pollution specifically, is due to the nature of the problem that is facing the space industry, the legislation chosen being the Clean Air Act passed in 1970. Thus, the resources utilized in this research were primarily documentary research and policy analysis regarding the Clean Air Act. The assumption made before research was that analyzing organizations affected by the legislation chosen would reflect how the space industry might respond to similar laws. The results of the research are discussed in the next section, where Actor-Network Theory is applied to elaborate and corroborate the insights that are made from the Clean Air Act, and their applicability to the space industry. The rest of the section dives into the arguments made from this research, and the limitations this research has.

**Results & Discussion**

**I. Overview**

The claims made from the research conducted are based upon the following idea – that evaluating policies from the Clean Air Act that have proven effective in mitigating environmental pollution can likely have similar outcomes when applied to the space industry. This idea is due to inherent similarities within the sociotechnical networks that encompass the use of energy and space technologies.

To elaborate with an example, within the mega-constellation industry, the key actors are the satellites themselves, between one company and another, the satellite operators (SpaceX, OneWeb, Iridium) who build and control these satellites, and the regulatory bodies (FAA (Federal Aviation Administration, NASA (National Aeronautics and Space Administration)) that allocate orbits, set licensing rules, etc. Accumulating orbital debris is an issue that affects all of the satellite operators equally, as Earth's orbit is a shared resource, so regulatory bodies need to take this into account when establishing regulations. These regulatory bodies thus need to find solutions to questions like: Should regulations be implemented equally or unequally? How should debris mitigation be regulated, and on what metrics? How to create regulations that are fair and don't give a competitive advantage to any one entity?

The sociotechnical network around energy technologies is similar – there are the power plants (the emission creators), the energy companies that run the plants, and the regulatory bodies (EPA (Environmental Protection Agency), DOE (Department of Energy)) that limit their use. The issues that these energy-based regulatory bodies are facing are very similar to those that the bodies like the FAA and NASA are facing, in that atmospheric pollution is an issue that detriments a shared resource, the Earth.

However, the advent of mega-constellations and reusable rockets, the catalysts for implementing technology into space, are recent, and management of these technologies is uncharted territory. The arguments that follow are based on the premise that there is much to be learned from legislation of a similar nature. The breakdown and comparison of the sociotechnical frameworks mentioned above is conveyed to reinforce this idea. The results from research are organized into two key arguments/insights that can be made for space debris legislation based on the research conducted on the Clean Air Act.

## II. Key Insights

### Argument I: Consolidating Authority

A major roadblock in the effort to mitigate orbital debris pollution is the lack of accuracy in our tracking software. An effective software is crucial for simple reasons, to better manage the placement of satellites and any space technology relative to tracked object and debris. Lack of accuracy in tracking software simply leads to increased risk of in-orbit collisions

Currently, there exists regulation that companies must adhere to, such as disclosing collision risk and post-mission disposal plans, however this only solves part of the issue (Mitigation of Orbital Debris in the New Space Age, 2024). Clement Hearey, in a comment published in the *Administrative Law Review* on the Federal Communications Commission's (FCC) recent orbital debris mitigation regulations, claims that these regulations "fall short of placing affirmative requirements on operators to: share data with each other and space traffic management entities; take specific steps to assess collision alerts; and employ more comprehensive tracking technologies." (Hearey, n.d.). A lack of data sharing amongst other companies and space management organizations is where potential issues arise. Without proper guidelines administered by a single overhead organization, these many separate regulatory bodies will have to take collision risk management in their own hands to an extent. Hearey again argues an issue with autonomy in collision risk management is the increasing competition between these organizations, insinuating companies have the liberty to cut corners on regulations to stay competitive. Responsibility to assess collisions and develop effective debris tracking software is split amongst all of the organizations, and there are many sets of rules and regulations over various groups of operators, depending on which regulatory body's authority they fall under. Needless to say, consolidation in legislative authority over space debris management would be hugely beneficial to better mitigating the accumulation of debris.

One of the main strengths that the Clean Air Act had was that The Environmental Protection Agency (EPA), established in 1970, was backing it. The EPA had the legislative authority to enforce the Act's policies nationwide, over all energy companies and in turn their power plants. Simply put, the EPA had consolidated authority, meaning the streamline of policy was tightened, thus the output that power plants could produce could be held with a tighter grip through the government. The space debris mitigation effort would immensely benefit from this, as one of the primary issues, as mentioned earlier, is the chaotic nature and lack of oversight on space debris management.

Emulating the EPA, a suggestion would be for national and international organizations to consolidate authority to a singular organization. The similarity in social frameworks between space and energy technologies suggests that consolidating authority could yield benefits akin to those of establishing the EPA: less roadblocks and indecision interfering with control over the orbital pollution that mega-constellations and other space technologies spread. Fortunately, there are already examples of sub-groups and committees within high-authority organizations that are meeting this problem, which will be discussed in the next section.

**Argument II: Stronger Enforcement of Regulations**

The last section demonstrated the need for consolidation within the regulatory bodies that govern technology use in space. However, a single regulatory body is only effective if it withholds proper authority over, in this case, satellite operators. In the last section, the issues that arose from the lack of universal standards for all operators to follow were established. These issues being, a lack in data sharing and coordination between space operators, resulting in the potential for operators to cut corners on their own self-imposed space debris mitigation standards for a competitive advantage. Consolidating authority to a single legislative body would hopefully alleviate this issue, and there are high-profile organizations, like UNOOSA or the FCC, that aim to accomplish just this.

Hearey argues that the FCC withholds the authority to expand and strengthen their disclosure regulations, on the premise that the FCC can grant a license "upon a finding that the 'public convenience, interest, or necessity will be served thereby"' (Hearey, n.d.). He further argues that strengthening orbital debris mitigation standards is allowable because it suits the FCC's obligations to serve public interest, as "Orbital debris poses a threat to public safety and impacts the scarcity of orbital space" (Hearey, n.d.). Alongside the FCC, The United Nations Office for Outer Space Affairs (UNOOSA), for one, has compiled space debris mitigation standards, though are still in discussion amongst the committee and within the UN (United Nations Office for Outer Space Affairs, n.d.)

These pushes for strengthened standards and regulations are worthwhile, and have been proven to be successful in creating change. The Clean Air Act is a prime example of the successes regulatory bodies can have when they practice stronger enforcement and establish standards for which to follow. The Clean Air Act (CAA) was actually established in 1963, though the EPA was not yet established at the time. The CAA of 1963 was known to have done little in terms of enforcement of pollution control: "Enforcement under the 1963 CAA was virtually nonexistent. Only a handful of requests for federal intervention were made between 1963 and 1967" (Clay, et al., 2021). Even in 1967, after the passing of the Air Quality Act, there were still no universal standards, much less enforced standards, over power plant emissions and pollution control (Rogers, 1990)**.** Enforcement did not really exist on power plants until 1970, when the Clean Air Act of 1970 was enacted.

The CAA of 1970 was enacted after a strong surge of public concern arose regarding environmental pollution, and after the legislations that were passed throughout the 1960's proved ineffective. The basis of the Clean Air Act of 1970 is summarized as follows:

> The 1970 CAA established the National Ambient Air Quality Standards (NAAQS), which classifies areas as in versus out of attainment for several criteria pollutants. Such designations depend on whether pollution levels are below or above the relevant standard. Power plants located in attainment counties are subject to limited regulation while plants in nonattainment counties are pressured by state and local regulators to take costly actions to reduce pollution levels (Clay, et al., 2021).

The first important piece of the CAA of 1970 is the establishment of national standards, for which all state and local regulators must abide by. Second, is the attainment and nonattainment designations, and the subsequent authority passed to state and local regulators to enforce "costly actions to reduce pollution levels".

The gains from the CAA are hard to define, as there were short-term losses from power-plant production from plants in nonattainment regions due to penalties like having to switch to alternative, cleaner fuels, or having to decrease energy output outright to cut emissions. This led to estimated annual losses around $3.5 billion measured in 2020 dollars (National Bureau of Economic Research, n.d.)**.** However, the total gains from the CAA of 1970, again hard to define exactly, were estimated to be of economic value in “ranges from $5.6 to $49.4 trillion” (Environmental Protection Agency, 1997)

The national standard (NAAQS) established by Congress combined with the delegated authority to regulatory bodies ensured that these standards could not be interpreted any other way. Emissions from power plants could be held with tighter control by the government, ultimately meaning that public interest can ultimately be reflected more effectively. This granted less power to the individual regulatory bodies, but in turn assured the output of pollutants from power plants could be more handedly controlled by the government, following the public interest at the time.

The problem the regulatory bodies within the space industry are having could be remedied by this principle that the CAA of 1970 set – the principle of setting universal standards and enforcing them more sternly over satellite operators. As discussed earlier, the sociotechnical frameworks between the space and energy industry are similar, and the way that the CAA of 1970 affected the relationships between actors in the energy industry, could have the same effect on the actors within the space industry. The effect being that greater authority granted to the regulatory bodies yields tighter control over pollutants (satellites and irregulated in-orbit technologies).

## III. Limitations of this Research

Perhaps the limitations of this research are that, while these insights from the Clean Air Act and EPA are derived from proven policies, tackling a problem of similar nature to that of the orbital debris accumulation problem, one can never be sure how exactly these policies will fare within the sphere of space technologies. The fact that these arguments will apply well to the regulatory bodies within the space industry is speculation, or a best educated guess. One can truly break down all of the hundreds or thousands of individual actors that are at play within each one of these spheres, but such a task is one that is most likely too complex. Such is one of the primary limitations of Actor-Network Theory in the first place, that the actors that are at play within a sociotechnical network can be broken down to the point of chaos. However, this does not mean that this Actor-Network theory approach to a comparison policy study should not be carried out, as is evident, this can still yield important insights.

## Conclusion

This paper does not aim to create a new foundation for regulation over the space industry, but instead aims to utilize past examples of regulations that have already been proven over time. The Clean Air Act is a landmark piece of legislation within environmental protection. Thus, this research aims to draw important insights from the Clean Air Act that can be applied to the rising issue of orbital pollution, and the actors involved within the sociotechnical framework that surrounds this issue. The insights this research highlights are the need for consolidation of authority within the already existing regulatory bodies that govern satellite operators, and the necessity for practiced enforcement of universal standards that all of the operators must adhere to. The engineering mind is often allured by the idea of inventing the wheel: to start from scratch and create something revolutionary. However this is not always the most effective, or efficient answer to every problem. To draw on our successes of the past is of vital importance, and can serve as guidance to questions that may seem too complex to answer.

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