On the Dangers, Implications, and Future of Low Earth Orbit Pollution

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In the lower orbits of Earth, thousands of speeding bullets are flying overhead every second. What if you were told that this field of projectiles is creating a severe threat to the most important and influential technology currently in use in the modern world? From providing defense and surveillance capabilities to militaries worldwide to supplying citizens with countless communication methods, satellites are undeniably influential and useful on a global level. Arguably, they are the most pivotal piece of technology in the digital world, and there is a serious issue threatening the future use of these modern, man-made marvels. This issue is known as low Earth orbit (LEO) pollution.

Most of the satellites in orbit around our planet operate at an altitude between 160 and 2000 kilometers above Earth's surface, a zone known as low Earth orbit (Williams, M). As the number of objects in this zone increases, so too does the risk of the pollution of this space becoming a real concern to the safety of existing and future satellites. Ultimately, there are many players at stake when it comes to the issue of low Earth orbit pollution. From people who use satellites every day, to scientists studying the dangers and trends of LEO pollution, to lawmakers whose job it is to create policies that prevent further pollution, the actors involved are numerous. It is for this reason that the framework known as Actor Network Theory has been applied in order to analyze the complex problem of LEO pollution to ultimately answer the question: how does LEO pollution's threat to satellites impact society?

What are the actors involved in relation to LEO pollution and its threat to satellites? This problem is a complex system with many players involved. Scientists studying the problem of LEO pollution, the public who use satellites and satellite services regularly, and politicians and

legislators whose job it will be to form law to protect the LEO environment from pollution are the three main actors involved here. Thus, to tackle this complex problem with many moving parts, Actor Network Theory (ANT) is the tool of choice. This Framework, coupled with Documentary Research of news articles, information from government run websites, and scientific journals, provides a full and informed view on the facts and perspectives of each actor involved in the problem and helps to frame the intricacies of LEO pollution. These documents have been grouped together and analyzed together based on the actors they are associated with. For example, documents pertaining to the use of satellites in every day life have been grouped together to get an accurate picture as to how satellites impact the actor that is the everyday public. Documents regarding scientific discoveries relating to LEO pollution and scientific opinions regarding LEO pollution and its risk to satellites have also been grouped and analyzed together. So too have documents been grouped that pertain to legislation regarding LEO pollution policy. These groupings ultimately are created to establish a discussion of the three main actors involved in the network. A discussion of each of these actors' place in the network ultimately aims to show how LEO pollution is a threat to satellites, and how this threat to satellites poses a risk to modern society as well.

Actor Network Theory is not perfect; studies using this framework, in the past, have been criticized as being too descriptive and failing to provide links or explanations to more broad social procedures ("Criticism of ANT", 2010). ANT is descriptive, but in the case of LEO pollution, it is the description of the different actors within the network that allows one to see the social implications of the problem. To understand the importance of satellites and why they must be protected, a description of the public's use of satellites is necessary. To understand current scientific opinions on the issue and measures being taken to mitigate it, descriptions of each from

the perspective of scientists is necessary. These descriptions of each of the main actors in the network and their relationship to the central problem is the heart of ANT, allowing the reader to draw conclusions as to how many different people within society both effect and are affected by the network.

In 1957, the first man made satellite was launched into space by the Soviet Union. Since then, the number of satellites in orbit of Earth- especially those in LEO- has dramatically increased (Labrador, V, n.d.). The growth trends of objects in orbit predict that this constant increase isn't going to stop anytime soon (Kramer, H. J., n.d.). Take, for example, the figure below, showing the number of objects in Earth's orbit since the launch of Sputnik by the Soviet Union in 1957.

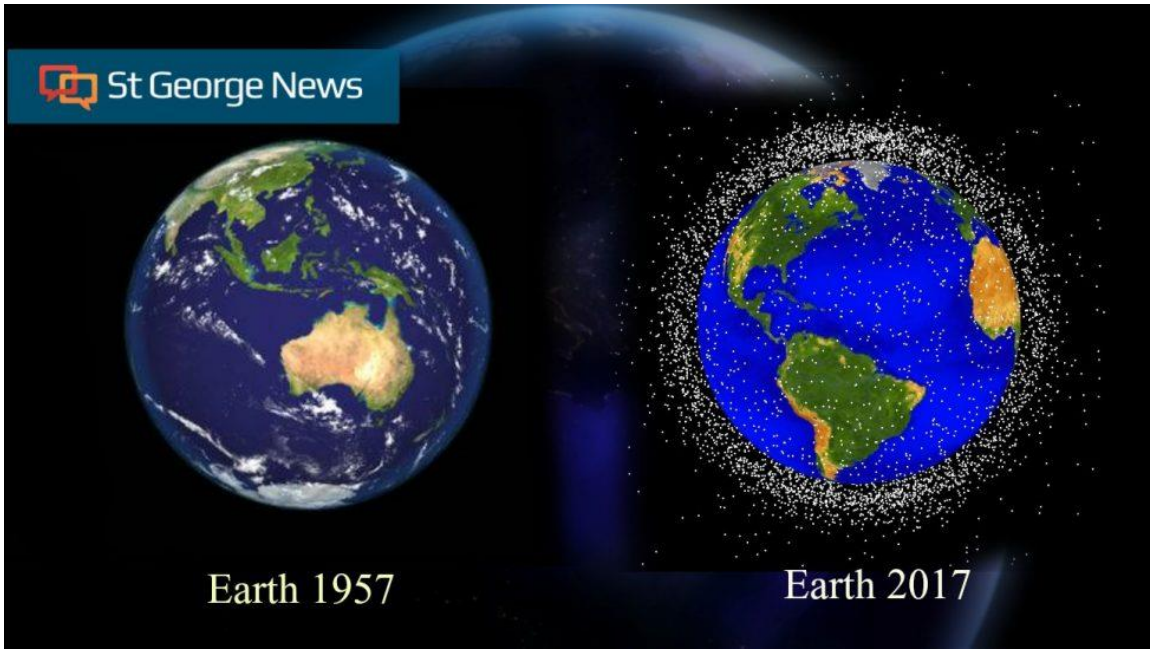

Figure 1: Growth of objects in earth's orbit from 1957 to 2017
Retrieved from stgeorgeutah.com, courtesy of NASA, St. George News

There are over half a million objects currently in orbit of the earth that are being tracked by NASA in an attempt to avoid potential collisions. However, in addition to these 500,000 or so

larger objects, there are up to several million more particles and objects also in orbit that are too small to be tracked (Garcia, M., 2015). Each of these objects, whether trackable or not, are traveling at over 17,000 miles per hour, and have the potential to be completely devastating if they come into contact with any spacecraft. Thus, it is reasonable to see why the problem of pollution in LEO is not to be taken lightly. Satellites are among the most vital technology linking our modern world together, and as more and more are launched, more and more will we find that they are in danger.

LEO pollution was widely brought to the attention of NASA as a serious issue in the late 1970's via a paper released by scientist Donald Kessler (Seidler, 2017). What Kessler proposed in his paper was essentially the idea that as more and more artificial satellites are launched into LEO, inevitable collisions between said objects will cause a domino effect that will spiral out of control. This idea went on to be known as the Kessler Effect (Ratner, P., 2018). When two sizable objects in orbit- such as two satellites- collide with one another, the enormous force of the impact shatters the two spacecraft into thousands of smaller bits, each with the potential to cause more devastating collisions in orbit. Thus, as collisions begin happening, it is stated by the Kessler effect that more and more collisions out of the control of spacecraft operators will exponentially begin popping up as well.

As of right now, there are multiple organizations looking at the issue of LEO pollution, but there have yet to be any drastic measures taken to halt the growth of objects around our planet. The Japanese Space Agency JAXA is currently looking into building a device which will remove dead satellites from orbit, and multiple conferences on the risks of LEO pollution have been held by notable bodies such as NASA and ESA, but there has been no one effort that has begun effectively solving the problem as of yet ("Ensuring the Safety", n.d.).

How does LEO pollution's threat to satellites impact society? Answering this question begins with a comprehensive report of the importance of satellites to one main actor within the network: the general public. Articles from reputable publications citing the uses and importance of satellites to the everyday lives of normal people- from the perspective of scientific experts- were first collected and analyzed. From there, more information on the current state of LEO pollution was brought together through documentary research of articles produced by news outlets and government-run space agencies. This information was synthesized in order to present the viewpoint of the next main actor: scientists studying LEO pollution. An accurate account from the scientific community of the risks LEO pollution poses to satellites can be extrapolated to see how that risk extends itself as a threat to the way of life of the general public. A final round of documentary research and analysis was then performed to look at the shortcomings of current LEO pollution prevention policies and a discussion of the third main actor: legislators and governmental bodies. This was followed by a look at how various players within the network may alter their behavior in the future to help relieve and potentially counteract the dangers of future LEO pollution.

LEO pollution actively threatens the future use and launch of man-made satellites and thus threatens the future society of Earth's people. It is the role of scientific experts in the field of LEO pollution to provide their expertise and information regarding the potential dangers of space debris to man-made satellites. Then, it is the role of larger bodies within the network, such as governmental space agencies and private space corporations, to take this information and use it for positive change. Such actions include the funding and research of methods to remove debris from orbit and use of judgement and safe practice when it comes to putting more satellites and spacecraft into LEO. Finally, it is the role of Governments and legislators of the world to

establish clear legislation which will prevent the future accumulation of space debris and formulate a path forward for the safety of Earth's satellites. Cooperation between these different actors is the solution to keeping a technology alive that positively impacts the lives of people across the planet daily.

This leads to the first main actor involved: the average member of the public. While perhaps not at the forefront of the average persons' mind, the risk imparted on satellites by increasing LEO pollution is one that can and will seriously impact all walks of life. Thus, it is important to gain the perspective of scientists and professionals who study satellites and LEO pollution in order to have a clear understanding of how all human players, both scientific and nonscientific, are at risk in this network. According to scientists at the Canadian Space Agency, satellites affect the lives of normal people in many more ways than most realize. Watching television, using the internet, paying for goods and services with a bank card, checking the weather, and utilizing GPS technology are just a few of the important everyday services satellites provide to the public ("10 Ways that satellites helped", 2018).

Farmers use satellite data to watch over their acreage, to collect data on hard-to-measure characteristics such as soil humidity, and to run their farms and produce crops with greater overall efficiency ("Space in service of agriculture", 2020). Governments use satellites for surveillance and military applications in order to keep their countries and citizens safe from potential threats. Satellites even play a vital role in helping developing countries nurture their future generations through enabling the widespread broadcast of knowledge. India, for example, has used its budding space program to create satellite broadcasts that have televised lessons in math to over 11,000 rural schools within the country (Gottschalk, K., n.d.). With this information in hand, it is easy to see just how many actors within this network are affected by satellites. In

the words of Lisa Parks, an MIT professor studying satellites and their cultural effects, it is important “to think of the satellite not only as this technology that's floating around out there in orbit, but as a machine that plays a structuring role in our everyday lives." (Dizikes, P., 2018). Thus, with this in mind, it is of great importance to look at how these vital machines are at very serious risk due to the issue of LEO pollution.

Next, a look at the opinions of the scientific actors involved in the network is necessary. Alarmingly, some experts believe that the critical mass of satellites that defines the onset of Kessler Effect has already been reached at some points of LEO, namely in the range of 560-680 miles above Earth (Corbett, J., 2015). Specific examples of the onset of more and more collisions in orbit have been more readily apparent in recent years, suggesting that the problem in LEO is in fact growing. Take for example the 2009 collision between U.S Satellite Iridium 33 and Russian Satellite Cosmos 2251. This is a fairly recent example of an event in which two satellites were completely destroyed by a collision which resulted in thousands more particles being formed, each with the potential to collide with and destroy other healthy satellites in orbit (Wei-Hass, M., 2019).

Government-run space agencies, such as NASA and ESA, have taken the problem of LEO pollution into consideration via their tracking systems, which log and trace objects as they orbit the Earth. While a decent preventative measure, these tracking systems are not a final solution when it comes to the line of defense for satellites in orbit. If an object being tracked has the possibility of colliding with a spacecraft, the collision may only be avoided if either of the objects at risk have the capability to maneuver themselves out of the way. This capability is one usually only available to larger and more expensive satellites, leaving smaller satellites such as CubeSats without any line of defense at all. This problem is only compounded by the fact that, as

previously mentioned, the tracking systems of NASA and ESA only are capable of tracking objects larger than about 10cm (D. Mehrholz et al., 2002). Thus, all the smaller debris in space poses very real threats to active satellites and does so in complete silence with no warning. It is safe to say that, while important, simply tracking the growing number of objects in LEO is not enough to protect our satellites from danger.

Other attempts to mitigate the amount of debris in LEO are currently being researched, though none have yet come to fruition or begun reversing the threat looming over the satellites of the world. For example, the Japanese space agency, JAXA, has developed a "space tether" designed with the goal in mind of collecting old satellites and debris and bringing them back into Earth's orbit to safely burn up. Unfortunately, the space tether tests performed by JAXA were underfunded and ultimately failed (Powell, C. S., 2017). Ideas such as the space tether are vital to the future of satellites in LEO and deserve to be funded appropriately. In order to begin addressing the problem at the heart of this network, it is apparent that players such as government run space agencies and growing private space companies need to step up and begin formulating more well-funded ideas to clear debris in LEO.

Private companies, such as Space-X and OneWeb, also play an important role in preventing the future accumulation of satellites in LEO via their upcoming plans to launch. Both of these companies have set the stage to launch thousands of satellites into LEO in the coming years as a means of providing internet coverage over more places on earth. While large-scale satellite projects such as this would indeed benefit the population of earth, it is the responsibility of companies such as Space-X and OneWeb to look at the potential ramifications of crowding LEO with such a large number of new spacecrafts. As of right now, one of SpaceX's satellites in the planned constellation already came close enough to an ESA operated satellite that it was

forced to maneuver out of the way (Grush, L., 2019). Private companies continuing to launch large numbers of satellites into orbit without any plans of how to take old satellites and debris out of orbit are without a doubt contributing heavily to the onset of the Kessler effect.

This leads to the final main actors in the network regarding LEO pollution's risk to satellites and society: legislators. Another large problem at play in the safety of satellites in LEO is the lack of legislation preventing buildup and prevention of debris. According to NASA, there currently exists no international law regarding the responsibility to clean up debris in LEO (Keeter, B., 2018). This has left LEO pollution as an issue that each space-faring country can deal with in whichever way they please. With only suggestions as to what proper etiquette looks like in regards to protecting LEO from oversaturation, one cannot ever expect the problem to get better. In order to truly combat the problem facing the future of our satellites, all the players involved in sending spacecraft into orbit must agree on a set of rules and work together to better the environment of LEO. Ideas for laws such as mandating that upper rocket stages be released at lower altitudes to burn up more quickly would be a good start. Regulations towards private companies venting fuel from upper stage rockets or disabled satellites would also play a large part, as exploding fuel plays a big role in producing large amounts of orbital debris. Regardless of what the specific laws are, it is vital that governmental bodies come together to establish clear legislation to prevent LEO pollution from permanently damaging the ability for future satellites and spacecraft to function and thrive.

This research paper, conducted over the course of about 6 months, ultimately only scratches the surface of the complex intricacies within the network of satellites in relation to LEO pollution and society. For future research, a greater time period within which to collect and analyze data would be optimal in order to collect a more wholistic view of the network and

actors within. Perhaps interviews with notable scientists and researchers who study either satellites' importance to society or the risk that LEO pollution poses to satellites could be conducted in order to gain first-hand information of the issue discussed within this paper. The use of other notable STS frameworks to organize and synthesize information relating to the topic could also prove useful in order to assess the relation of LEO pollution to satellites and society from different angles.

Satellites are a key technology in the modern world, holding influence over governments and essentially all people from all walks of life. The pollution of space in LEO is a growing problem that actively threatens the future of Earth's satellites, and thus poses a threat to modern and future societies as a whole. Within the complex network comprising the issue of LEO pollution in regards to satellites, there are many actors involved. In order to combat the problem of LEO pollution, action on the part of all actors and cooperation between the actors is of utmost importance.

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