# Starlink: Societal Factors Affecting SpaceX's Satellite Internet Constellation

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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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## Introduction

Starlink is an ongoing effort by SpaceX and Elon Musk to combat disparities in rural broadband internet access. The goal of the project is to launch thousands of smallsat-class satellites as part of a mega-constellation in low-Earth orbit to provide continuous, high-speed internet around the world. SpaceX believes their technology can improve over the state-of-the-art through the use of shallow orbits. When compared to traditional satellite internet infrastructure in geosynchronous orbit, Starlink promises to deliver lower latency and better-quality connections to its customers (Starlink, 2021).

However, there could be long-term ramifications of the coming small satellite revolution - space debris. The term “space debris” encompasses natural objects (meteoroids) and man-made objects (orbital debris) (Garcia, 2017). The European Space Agency (ESA) estimates there are over 900,000 pieces of space debris over one centimeter in size, which can travel at speeds up to 17,500 miles per hour (European Space Agency [ESA] Space Debris Office, 2020). At that speed, even debris as small as a fleck of paint can damage a spacecraft (Garcia, 2017). With every new launch, new debris is added and the problem worsens. Kessler Syndrome predicts that there will eventually be a critical mass of spacecraft in orbit such that collisions between satellites create a cascading effect wherein nearly all satellites are destroyed and the atmosphere becomes impassable with debris (Corbett, 2017). With little policy governing the cleanup of orbital debris, such as dead spacecraft, it may not be very long before the critical point is reached. From an STS Perspective, Social Construction of Technology (SCOT) will be used to examine Starlink, and its broader contribution to space debris, through a socio-technical lens.

## Background

### *Starlink*

Elon Musk and SpaceX have become household names around the world for their continuing efforts to usher in a new era of spaceflight. In 2012, the SpaceX Dragon project became the first private spacecraft to deliver cargo to and from the International Space Station. In 2015, they again made headlines as their Falcon 9 rocket successfully reentered the atmosphere and landed itself on a landing pad. SpaceX followed this act with a successful landing of Falcon 9 on an autonomous barge at sea in 2016. Since then, they have been able to perfect this technology to the point where Falcon 9 rockets are continuously being reused after launch and landing (SpaceX, 2021). In 2015, Elon Musk first set his sights on a new goal – to completely reshape the broadband internet industry under the moniker of Starlink (Mann, 2020).

According to Musk, the Starlink project is akin to "rebuilding the internet in space" (Mann, 2020). The goal of Starlink is to provide "high-speed, low latency broadband internet" with near global coverage (Starlink, 2021). These lofty goals are not without a plan, however. Starlink will achieve its global coverage using a mega-constellation of thousands of small satellites. Initially, the project was approved by the FCC for 12,000 total satellites in low-Earth orbit, but new paperwork was filed in late 2019 for an additional 30,000 units (Henry, 2019b). Each satellite weighs approximately 500 pounds and would orbit nearly 350 miles from the surface of the Earth. Current satellite internet operates through much larger spacecraft in orbits over 22,000 miles from the surface, leading to historically poor connection quality (Mann, 2020). Once complete, the volume of satellites and their shallow orbits would provide high speed internet to customers in virtually any location in the world. The biggest selling point of the project is the ability to serve rural and remote areas which have been excluded from traditional broadband infrastructure

(Starlink, 2021). However, Starlink may be inadvertently accelerating the growing issue of space debris.

*Space Debris*

The Department of Defense (DoD) is currently tracking over 20,000 pieces of space debris larger than a softball, and the European Space Agency (ESA) estimates there are almost one million objects in orbit over one centimeter in size (Garcia, 2017; ESA Space Debris Office, 2020). Each of these objects has the potential to damage or destroy critical satellites and space stations. The International Space Station (ISS) must maintain a dedicated tracking system for predicting debris trajectories and performing avoidance maneuvers. For debris collision probabilities greater than 1 in 100,000, an avoidance maneuver will occur unless the maneuver would impact ISS mission objectives. For probabilities greater than 1 in 10,000, an avoidance maneuver will occur unless it would create additional risk to the crew. (National Aeronautics and Space Administration [NASA], 2009). With every new spacecraft, rocket bodies, shards of material, flecks of paint, nuts, and bolts are thrown into orbit and the problem worsens (Kwong, 2020). Eventually, the probability of collision may be too great to operate the ISS at all.

There is currently no international regulation governing space debris and its production or cleanup. Some countries have voluntarily agreed to follow non-binding guidelines such as those put forth in 2007 by the Inter-Agency Space Debris Coordination Committee (IADC) (Inter-Agency Space Debris Coordination Committee [IADC], 2007). The United States adopted Orbital Debris Mitigation Standards in 2001, and NASA has maintained their Orbital Debris Program since 1979 (Kwong, 2020; Keeter, 2019). However, there has still never been a concerted, international effort to reduce, rather than slow the production of, orbital debris. There is some good news; as new technologies and ideas have begun to emerge in order to remove debris from space. As of yet, very few of these technologies have made it to space. In 2021, Rensselaer Polytechnic Institute plans to launch their Obsolete Spacecraft Capture and Removal (OSCaR) CubeSat which will use a combination of nets and tethers to deorbit debris on a budget (Wall, 2019). In addition, a planned launch in 2025 by the ESA would grab hold of a defunct rocket and push it into the atmosphere where it will disintegrate (ESA, 2019). However, until rigorous, enforceable regulations are imposed at an international level to control space debris, the world must rely on space users voluntarily adopting debris mitigation standards.

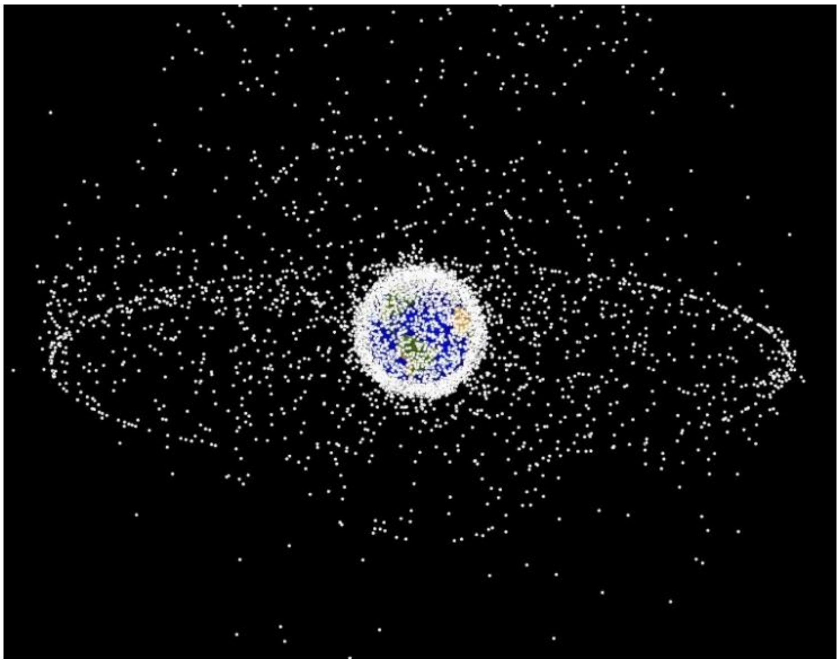

*Figure 1. Rendering of Space Debris as Seen from High Earth Orbit (NASA, 2019)*

## The Social Construction of Technology Framework

Proponents of Social Construction of Technology (SCOT) theory argue that the adoption of new technologies is dependent on how society views the technology. This argument is built around the notions of relevant social groups, interpretive flexibility, closure, and stabilization (Pinch & Bijker, 1987). Relevant social groups include those which interact with the technology in some form, whether users, producers, or observers. These social groups will possess an inherent interpretive flexibility, wherein one group's interpretation of a certain technology's advantages and disadvantages may be radically different from another social group. A design which meets the needs of one social group may be entirely wrong for another group. Wiebe Bijker and Trevor Pinch, two early proponents of SCOT, illustrate interpretive flexibility through the design of the bicycle. Men, women, recreational users, athletes, producers, and repairmen all reacted differently to competing designs. Successful versions were dependent on solving perceived problems related to safety, manufacturability, ease of repair, speed, handling, and comfort (Pinch & Bijker, 1987).

Closure and stability occur as social groups unite in a number of ways around their preferred design and use of a technology. Closure can be the result of designs actually solving the problems of the relevant social groups, causing them to naturally coalesce around said technology. However, closure can also occur when the relevant social groups simply perceive their problems to be solved by a particular design, regardless of its actual effectiveness, as the result of advertising and social forces, such as the bandwagon effect. Finally, closure may also be the result of a shift in the root problem. If social groups start to redefine their problem around a new metric, previously unfavorable designs may enter the mainstream, and previously favorable designs may be left behind. As such, closure and stabilization does not have to be a permanent state. Over the lifetime of a technology, new discussions may arise among the relevant social groups to cause a movement towards new designs. In a general sense, SCOT argues the success of a technology cannot be attributed entirely to a superior design, but also to complex social forces.

Starlink provides an enlightening case study for investigation under the lens of the SCOT framework, especially within the broader context of space debris. The three relevant social groups, commercial companies, consumers, and the scientific community, all have a unique interpretation of Starlink technology. Their competing interpretations of this new broadband internet philosophy is actively serving to influence the design and operation of Starlink satellites. As the discourse progresses, and as SpaceX works to satisfy each of the relevant social groups, the beginning of closure and stability can be observed.

## Relevant Social Groups

### *Scientific Community*

The first relevant social group to Starlink is the scientific community, particularly astronomers. Since the initial launch of 60 Starlink satellites in May of 2019, astronomers have complained about the constellation's effect on their ground-based telescopes. Astronomers have primarily been concerned with the brightness of the devices, which are easily visible with the naked eye. As the satellites pass in front of sensitive telescopes and measuring equipment, the brightness of the objects can ruin astronomers' data (Foust, 2020). The brightness problem is evidenced in Figure 2, which shows the signal pollution from Starlink satellites during a 333 second exposure at the Cerro Tololo Inter-American Observatory (National Optical-Infrared Astronomy Research Laboratory, 2019). Each streak of light across the image is a single Starlink spacecraft. The problem will continue to get worse, as SpaceX continues to launch thousands of new Starlink satellites into orbit, and other companies such as Amazon and OneWeb are looking to enter the market as well (Thompson, 2020). At this rate, it will soon become virtually impossible for telescopes to avoid these broadband internet satellites interrupting their images.

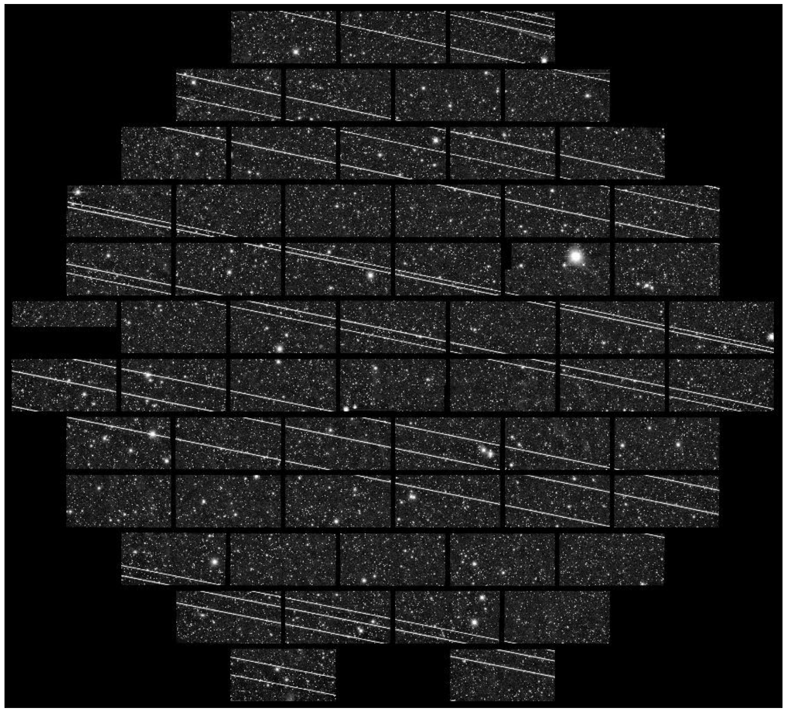

*Figure 2. Image from Blanco 4-meter telescope at the CerroTololo Inter-American Observatory. Image contains at least 19 streaks created by the second batch of Starlink satellites launched November 2019 (National Optical-Infrared Astronomy Research Laboratory, 2019)*

In an ideal scenario, astronomers would have preferred if Starlink had never come into existence. SpaceX has responded to the mounting pressure from the scientific community by promising to solve the brightness problem associated with Starlink (SpaceX, 2020). Early prototypes of a so-called "DarkSat" seemed promising, effectively reducing the brightness of the satellite by about 50% (Foust, 2020). However, astronomers have maintained that even the DarkSat design is still far too bright (Zhang, 2020). In response, SpaceX has halted development of the DarkSat in favor of other albedo reduction methods which may prove to be more effective. Their recent efforts have focused on the development of a sunshade which will limit reflected light, but early brightness studies have indicated it is only marginally more effective than the DarkSat technology (Clark, 2020; Cole, 2020).

SpaceX has also assured that they have planned for Starlink's contribution to the growth of space debris. They advertise themselves as "on the leading edge of on-orbit debris mitigation, meeting or exceeding all regulatory and industry standards" (Starlink, 2021). In theory, satellites in the constellation will use an on-board propulsion system to deorbit at end of life, burning up in the atmosphere as they fall. SpaceX also claims that failed satellites, which would no longer be able to receive instructions to deorbit, will naturally fall into the atmosphere to burn up within five years. Three of the 60 satellites launched in May of 2019 have already failed. This led to concerns that similar failure rates could result in hundreds of dead spacecraft as the project ramps up (Foust, 2019).

Even satellites still under control by SpaceX have caused controversy in the scientific community. In 2019, the ESA's Aeolus spacecraft had to perform an avoidance maneuver to avoid a grouping of Starlink satellites. SpaceX blamed the near miss on a bug in its paging software, which keeps track of collision probabilities. The bug prevented SpaceX from performing appropriate avoidance maneuvers for their satellites, despite a collision probability in excess of 1 in 1,000. The industry standard is to perform avoidance for probabilities higher than 1 in 10,000. This was the first time the ESA has ever had to perform such a maneuver to protect one of their satellites (Brodkin, 2019).

*Commercial Companies*

Despite the concerns of the scientific community, SpaceX clearly wants to push forward with Starlink technology. Other companies are also pursuing the idea of broadband internet via low-Earth orbit satellite constellations. OneWeb aims to be a direct competitor to Starlink, providing high-speed internet around the world via their own satellite network, through a joint venture with Airbus (Wattles, 2020). In 2015, Samsung also announced plans to develop a global internet network to bring 200 gigabytes of internet per month to customers via 4600 low-Earth orbit satellites (Gershgorn, 2015). Even Amazon have announced plans to enter the market with a similar constellation through a subsidiary, Kuiper Systems (Henry, 2019a). All of this investment into this technology leads to the second relevant social group: commercial companies.

The biggest hurdles for global internet access via traditional broadband infrastructure are areas of low population density. In densely populated areas, providers can quickly cover the cost of equipment due to the volume of users. This strategy no longer works in rural areas, as the cost to install the necessary infrastructure far exceeds the potential profit from the small number of users. Existing satellite internet networks attempt to solve this problem via large, powerful satellites in geosynchronous orbit over 22,000 miles from the Earth. Their primary limitation is ingrained in fundamental physics – the speed of light. Signals traversing 44,000 miles round trip to utilize geosynchronous orbit satellite internet takes time, and this additional time creates latency which negatively affects the quality of the connection (VSat Systems, n.d.). The very idea behind Starlink is to create a constellation orbiting over 50 times closer than traditional satellites, massively improving connection quality.

Surprisingly, the idea of low-Earth orbit satellite internet networks as an alternative is not new. In 1994, Teledesic planned to create a broadband satellite constellation using low-Earth orbit with funding from Microsoft. However, the ambitious project quickly ballooned in cost, and without significant demand, it was abandoned entirely by 2003 (Chan, 2002). In an age where internet access is quickly becoming regarded as basic human right, increased demand for global high-speed internet has renewed interest in the sector. SpaceX has the potential to capture an enormous number of rural users looking for high speed alternatives to their current providers. They estimate that Starlink will generate as much as $30 billion in revenue per year by 2025. This influx of cash would allow SpaceX to pursue some of their other, less lucrative ventures (Etherington, 2017).

However, other commercial companies are more wary, with Rocket Lab CEO, Peter Beck, saying they are “starting to feel the effects of congestion in outer space” (Thompson, 2020). As more satellites go up, the likelihood of a clear launch path goes down, and the problem of space debris worsens. With the number of satellites expected to launch as part of Starlink and other competing mega-constellations, it will significantly reduce the expected timescale for Kessler Syndrome to occur. This theory predicts that with a critical mass of spacecraft in orbit, collisions become impossible to avoid. As the satellites collide, they generate more and more debris as part of a cascading effect which would eventually destroy nearly all satellites in orbit around the Earth (Corbett, 2017). Due to the global reliance on satellites for far more than just internet access, commercial companies are also incentivized to reduce risk to their space-based investments.

*Consumers*

Consumers make up the final relevant social group to the analysis of Starlink. For many in the general public, a reliable, worldwide broadband connection would be a dream come true, especially for those in rural areas. In 2018, the Pew Research Center reported that 58% of rural Americans believe access to high-speed internet is a problem in their area, compared to 43% in urban areas. In the same report, 78% of rural adults said they use the internet, compared to 92% of urban adults, and 58% of rural adults said they subscribe to home broadband, compared to 67% in urban areas (Anderson, 2018).

The Starlink website is plastered with testimonials from early customers and beta testers, such as this quote from Jody Merrill in Wisconsin:

> "Fantastic system/service. Finally able to use the Internet like a regular person. [They] won't update 50 yr old copper lines in my state. This is a life saver" (Starlink, 2021).

The Hoh Tribe, a Native American group located in rural Washington state, is equally impressed by Starlink:

> "What a difference high-speed internet can make! Our children can participate in remote learning, residents can access healthcare. We felt like we'd been paddling up-river with a spoon on this. SpaceX Starlink made it happen overnight" (Kan, 2020).

The Starlink public beta program, which began in October of 2020, prices their services at $99 per month with an additional $499 one-time cost to cover the cost of the equipment. In February of 2021, SpaceX reported that their Starlink network had over 10,000 users despite its current limited service. Before the launch of the public beta, SpaceX indicated it had received interest in Starlink from almost 700,000 consumers within the United States (Sheetz, 2021). As a whole, the majority of consumers seem to support the roll out of Starlink satellites, valuing the convenience of fast, reliable internet over other factors.

However, some consumers consider the Starlink mega-constellation to be a massive cultural blow. The International Dark-Sky Association (IDA) has already voiced their concerns to SpaceX over the brightness of Starlink, in order to "represent the people who want to have that experience of being presented with nature in its raw beauty." Ruskin Hartley, the executive director of the IDA, asserts that "no one individual can protect [the night sky] and, on the flip side, no one individual should be allowed to despoil it" (Foust, 2020).

**SCOT Discussion**

The process of refining the design of a new technology based on feedback from social groups is an example of stabilization and closure. In the case of the scientific community, feedback from concerned astronomers has directly impacted the design of Starlink satellites. Now, all new satellites launched by SpaceX will include a sun visor to reduce reflectivity. In addition, they have started publishing predictive data of satellite locations to help astronomers schedule streak-free exposures (SpaceX, 2020). The focus on visor technology and scheduling, rather than simply raising satellite orbits, clearly illustrates the conflict between the relevant social groups within SCOT. While a higher orbit would help astronomers tackle the brightness problem, it would hinder SpaceX's mission to provide low-latency, high-speed internet. Consumers overwhelmingly favor a design which would allow the fastest, most reliable network possible for an affordable price. SpaceX vows to minimize their effect on astronomy while still meeting the needs and expectations of their customers. Once a final satellite design is selected to meet brightness thresholds, closure can progress. In the years to come, iterative designs will attempt to stabilize as SpaceX and others converge on a solution that compromises with all of the relevant social groups to a satisfactory degree.

**Conclusion**

Societal factors are actively influencing the design of the emerging Starlink constellation. Under the Social Construction of Technology framework, the conflict between the relevant social groups involved with Starlink and their ongoing discourse allows direct observation of the closure process. The combination of the analysis into Starlink with the technical project gives important insight into the challenges faced by spacefaring vessels in the 21st century and beyond. Upon conclusion of the course, the Spacecraft Design Capstone team hopes to lay down a detailed framework for a CubeSat constellation that can meet the needs of as many stakeholders as possible, while remaining mindful of its potential impact on the night sky.

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