The future risk of space assets and contested environments increases the intrinsic and actual cost of geostationary orbit slots

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1. ABSTRACT

As new threats to critical space assets emerge, the US and its allies need to be creative in adapting to previously negligible vulnerabilities. Large, solitary satellites that provide essential services to us on the ground are uniquely assailable. One solution under consideration would be launching constellation systems comprised of multiple, smaller satellites, which would purportedly decrease the likelihood of any one strike from crippling those essential services. However, this approach is unsustainable, accelerates the risk of decreasing access to space, and increases the threat of debris. A large number of debris creates hazards for critical Space Situational Awareness ("SSA") and Space Domain Awareness ("SDA") of on-orbit assets and adds complexity for ground observers to track and lose sight on important assets.

An alternative solution would be utilizing On-Orbit Services ("OOS"), which helps solve not only the vulnerability of individual satellites, but also externalities created by the threat of debris. This research will explore the notion that the intrinsic value of Geostationary (GEO) orbital slots is increasing as LEO orbital spheres are more contested and threatened by debris.

In GEO, OOS promotes resilience to large assets by providing additional life to these satellites. With OOS, space-based assets now have the ability to be taxied, repaired, and have a mechanism to respond when the spacecraft itself does not respond. Since GEO satellites are the most difficult to target in an ASAT capacity, these services are essential to protect GEO assets from harm. With GEO servicers from multiple companies ready to service these spacecrafts if something goes wrong, this should ultimately deter any attack on the critical assets. In addition to fixing, refueling and moving satellites, these servicers are also capable of In-Space Situational Awareness (ISSA) providing vital intel through inspection and imaging of any incoming and unwelcome spacecraft on a trajectory to a critical GEO spacecraft.

GEO assets currently in space are prime real estate. The assets that are in operation on orbit will steadily be increasing in their value as LEO becomes more congested. Considering the average cost of launching a new satellite can range from $10 M to $505 M, by choosing to service a satellite in need and increasing it's expected life, you not only save the launch cost, but avoid any unforeseen licensing or regulatory issues concerning the launch. This research investigates how externalities will become value drivers on GEO. With 6,370 successful launches in the last 65 years, 32,300 pieces of tracked debris have been created. By choosing to service a satellite, instead of contributing to the throwaway culture on-orbit and simply launching a new satellite, the number of future debris can start to steady. Building and launching new assets comes with enormous costs to governments and commercial operators who utilize highly technical payloads, costs that will be avoided with OOS.

Since previous ASAT tests have resulted in large debris creating events, OOS provides a new capability to satellite operators that allows for new freedom of maneuvering in LEO. A spacecraft's need to constantly move out of the way of debris forces increased fuel consumption which decreased the assets expected life. OOS takes on the burden of delta-V maneuvers and refueling so assets on-orbit can continue operations securely.

Ultimately, the increasing risk to LEO assets through growing debris fields and ASAT test capabilities, accelerates restricting access to space over critical GEO assets. These GEO orbital slots will increase in value with the restriction to access to space that is caused by growing debris in LEO. Instead of contributing to the problem by launching more constellations, government and commercial operators should consider other solutions, such as servicing the already operating assets in valuable slots in GEO.

This economic analysis of GEO slots will show the safe and sustainable future for all space-based assets, including SSA and SDA, involves determining the value of GEO slots to help operators make the decision to service the assets that reside there, instead of creating more debris by launching new ones.

Future research is required to collect enough data to place an intrinsic value to a GEO slot. This research used values such as cost of a satellite and launch to GEO to make a high-level assessment of the "cost" of a GEO slot.

2. BACKGROUND

A. The current space economy

The current space economy and infrastructure hasn't seen a significant cycle disruption since the first satellite orbited the earth in 1957. Satellites undergo expensive and robust testing on the ground to launch and operate immediately. After 25 years of nominal and completed satellite operations, the satellite will deorbit from LEO, or need to expel its remaining fuel to move itself to the graveyard orbit in GEO. Assuming the launch is successful, if the satellite is non-responsive after launch, this spacecraft turns into a hazardous nuisance occupying a desirable orbital shell or slot. In LEO, the satellite will undergo gradual decay over several years, whereas in GEO, a defective satellite occupies an orbital slot, requiring new and costly construction and launch without receiving data it was designed to transmit.

A byproduct of this infrastructure is the growth of derelict satellites and space debris in LEO. The addition of uncontrolled objects in these orbits leads to operational satellites consuming extra fuel. This fuel, originally allocated for their mission, is now diverted towards performing Collision Avoidance Maneuvers (CAM) in order to avoid uncontrolled objects within the same orbital path. The increase in debris is tracked by multiple countries to provide detailed mission planning, and its evolution over time is demonstrated in Figure 1.

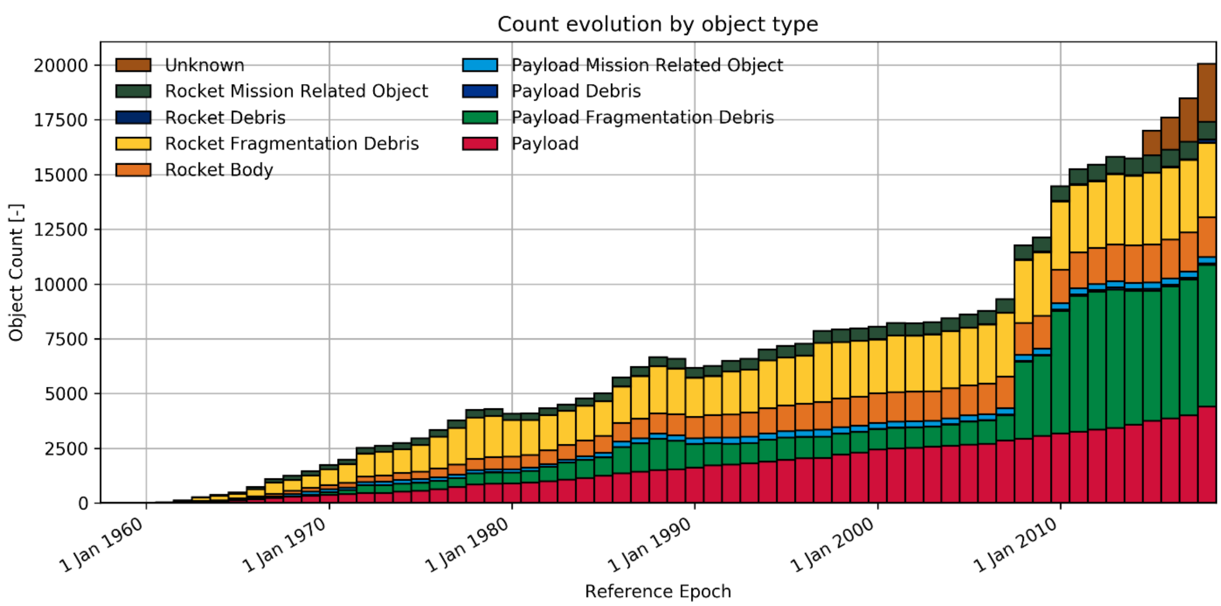

Figure 1: ESA's Space Safety Analysis of Space Debris

Similar to climate change's influence on rising sea levels or its effects on the real estate and insurance sectors, the growth of orbital debris has left its mark, with numerous forecasts outlining the potential for its impact to intensify. Ensuring a smooth launch trajectory is vital for commencing mission operations and conducting vehicle checks. The slight, increasing threat of orbital debris interference during this phase prompts scientists and engineers to reevaluate the space debris issue, acknowledging the need for models to adapt to emerging debris-causing events. Similar challenges posed by climate change correlate to the current impact that's predicted to exacerbate; this includes unforeseen consequences for day-to-day operations in the future. Most critically, if the growing concerns regarding the space environment affect new launches to GEO, alternative strategies for maintaining the existing GEO satellites will ensure their ongoing functionality.

Emerging markets, like the On-Orbit Service (OOS) industry, are changing how existing vehicles in orbit will operate. The current space economy and infrastructure is based on an unsustainable throw away culture. Satellites are launched, then moved to graveyard orbit when they are no longer needed. Instead of continuing this throwaway culture, OOS companies promote resiliency and give operators a chance to evaluate their orbital slots containing satellites, similar to real estate on Earth. When people are done using or living in a house, demolishing it and selling the land is considered a wasteful and expensive alternative to selling the house and land to a new user. The OOS ecosystem affords operators the ability to be taxied, repaired, and refueled. This significantly increases the lifespan of satellites.

Estimates show about 1800 satellites could be placed in GEO at about 90 miles apart without creating a navigational hazard to each other.[1] Communication satellites are grouped closer together over high population areas. The International Telecommunications Union (ITU) oversees assigning orbital slots to avoid radio frequency interference. Therefore, the assignment of orbital slots is limited. Early approximations show when GEO receives 1800 satellites will mark the point where it's necessary to start selling orbital slots.[2] Tongasat once sought to accelerate this renting and buying market of orbital slots by renting its slots to American companies for $2 M/yr. in the 1990s.[3] This action was reprimanded by the ITU per the Outer Space Treaty (OST) articles. The OST prevents any signatories from claiming sovereignty in space. The ITU predates the OST making it the oldest United Nations agency.[4] At present, according to Alex Joseph, "treating orbital slots as commodities is forbidden under ITU rules and the OST,"[5] however, this may not hold back investors in the space real estate market forever. If slots in GEO hold monetary values, or new requirements are created to handle the demand operators place on GEO slots, this paradigm may shift.

B. Real estate parallels to GEO Orbital Slots

The earliest known assessment of placing a value on property dates back to 6,000 B.C. and was used throughout the ancient world.[6] According to Carlson, "the primary focus of early property taxation was land and its production value." This principle is applied to GEO orbital slots in a similar way. The value of an orbital slot in GEO is its specific placement and the amount and consistency of data required by ground users. There's less interest in the GEO slots above empty space in the ocean compared to densely populated areas in the countries that launched a satellite in the high altitude above.

As society progressed from an agricultural society by migrating to dense, urban, industrial areas, vast farmlands have decreased in value. Now, the present value is used to estimate the value of land for real estate. Present value is the value of an expected income stream determined as of the date of valuation.[7] This principal rests on the concept that a dollar today is worth more than a dollar tomorrow since the present value is typically worth less than the future value. This complex evaluation had to be realized to estimate what can be financially gained from a plot of land.

Humans had to progress from basic value assessments of land, including its agricultural output, to more complex evaluations including future worth, output, and money-making ability of the land. Since people are new to

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[1] Welti, C. R. (2012). Artificial Earth Satellites. In *Satellite Basics for everyone*. essay, iUniverse.
[2] Joseph, A. (2022, December 6). The legal anarchy of space: What Tongasat means for the future of Space Investment. Disruption Banking. https://www.disruptionbanking.com/2022/05/30/tongasat-space-investment/
[3] *Id.*
[4] *"As International Telecommunication Union turns 150, Ban hails 'resilience' of oldest UN agency". United Nations. 17 May 2015.*
[5] *Id.*
[6] Carlson, R. H. (2004, September 1). A brief history of property tax - IAAO. iaao.org. https://www.iaao.org/uploads/A_Brief_History_of_Property_Tax.pdf
[7] Moyer, Charles; William Kretlow; James McGuigan (2011). Contemporary Financial Management (12 ed.). Winsted: South-Western Publishing Co. pp. 147–498. ISBN 9780538479172.

utilizing orbital slots, and given there are already satellites occupying these slots, one of the listed land evaluations could help with rising demand in GEO.

C. On-Orbit Servicing

Multiple companies are providing life extension and orbital transfer services in this new space ecosystem. Life extension and orbital transfers provide alternatives to launching a new satellite. A functional client satellite could choose to save fuel for specific maneuvers by hiring a servicer to alter its orbit. This enables the satellite to move to another orbital slot to meet new mission requirements, be relocated to the graveyard orbit, or undergo a controlled deorbit when its operational lifespan concludes.

For non-functional satellites, depending on the type of failure, on-orbit servicing can provide an alternate solution to adding the cost of the failed satellite to the overall mission. For example, if a satellite exhibits thruster failures, a servicer satellite could dock to the client and provide the thrust needed to continue the mission. Additionally, for satellites that have had power or communications failures, a servicer satellite can provide a power transfer or communication services for the client satellite. For the satellites that endure a launch failure in route to their intended GEO slot, a tug or transfer can get the client satellite in its initial intended slot. Future operations will most likely include manufacturing and damage remedies for any damage to the client satellite during launch.

Currently, insuring missions includes a large premium. The insurance market is concerned about paying out for failures if they occurred. In time, with a dynamic and more robust space economy, insurance can accommodate more satellites, launches, and become more affordable for more missions. With one servicing satellite launched to GEO and providing multiple services to multiple satellites, these services and insurance premiums will be significantly lower than the cost of launching a new satellite to GEO.

D. Warfighter Implications

The warfighter is understanding how this new OOS ecosystem will affect nefarious players and/or activity in all orbits. The ability to maneuver around space systems allows militaries to operate in unique ways compared to the present-day space domain. Space debris or derelict objects play a challenging role to the warfighter for the future of Dynamic Space Operations (DSO) and future access to space. As nefarious activities increase, such as Anti-Satellite Missile Tests (ASAT), or worse, the creation of space debris to make LEO inoperable for all users, reliance on existing GEO assets will only increase.

Extending the mission life of critical GEO assets, whether government or commercially sponsored, will deter actors from using space debris in LEO as a means to disrupt day-to-day life for users on Earth. Despite the operators' potential need to launch a new satellite, which may be hindered by LEO activities, extending the lifespan of GEO satellites can demonstrate that ground users remain unaffected by these activities. This strategy allows key stakeholders to establish dominance in the space domain.

3. THE PROBLEM

As GEO operators desire to get closer to the critical 1800 satellite point, the value of a GEO slot will create tensions amongst the users. If OOS allows users to disrupt regular operations, whether they end operations early or change the parameters of the mission, conflicts over the rights to original GEO slots may increase. Accessibility to these slots will become critical. Affordability in the increasing supply chain, inflation, geo-political and economically connected world may impose more tensions on whether a GEO slot should be given or taken away.

The accessibility question includes a combination of environmental factors in space which may make launch availability over time more difficult. One of the factors includes the increasing presence of orbital debris. The more congested LEO becomes, the narrower launch windows become, new operational challenges can arise. As of June 2023, 15,760 satellites have been launched into Earth orbit and 10,550 of these satellites are still in space.[8] In addition to the satellites alone, there are 34,190 objects tracked and millions of pieces too small to track. The need for space is not slowing down, and there is unprecedented growth in the sector; particularly with countries that have competing

[8] Space debris by the numbers. ESA. (n.d.). https://www.esa.int/Space_Safety/Space_Debris/Space_debris_by_the_numbers

objectives in the space sector. China has announced 13,000 new satellites they plan to launch into LEO to "suppress Starlink" starting at the end of 2023.[9] When mega satellite constellations start working to suppress one another, accidents and debris causing incidents are likely to arise.

The affordability question arises due to the growing costs of satellites and launches. While operators in GEO currently don't directly pay for securing a desired slot in GEO, there is still an intrinsic value to the slot. This intrinsic worth stems from factors such as spacecraft expenses, launch expenses, licensing, insurance, operation, and communication fees. The GEO slot itself holds inherent value for operators, particularly when they provide services or products designed for c to customers or users within the accessible geographic area. The new space architecture that includes OOS places greater value on recognizing the inherent value of a GEO slot. This combined intrinsic and inherent value could potentially prompt regulatory bodies to consider implementing fees or funding requirements for occupying crucial orbital positions.

4. METHODOLOGY

Understanding the value associated with an asset in GEO is critical to evaluating how much of an impact LEO activity and future costs could have to critical assets operators control in GEO. The first calculations require high-level assumptions to the GEO market.

A. Monetary Values associated with New Satellites in GEO

To assess the intrinsic cost of an asset in a Geostationary orbital slot, data on satellites launched (or failed to launch) to GEO were taken from Seradata and the costs listed were included in this overall cost found in Figure 2.

[9] Jones, A. (2023, March 28). China to begin constructing its own megaconstellation later this year. SpaceNews. https://spacenews.com/china-to-begin-constructing-its-own-megaconstellation-later-this-year/

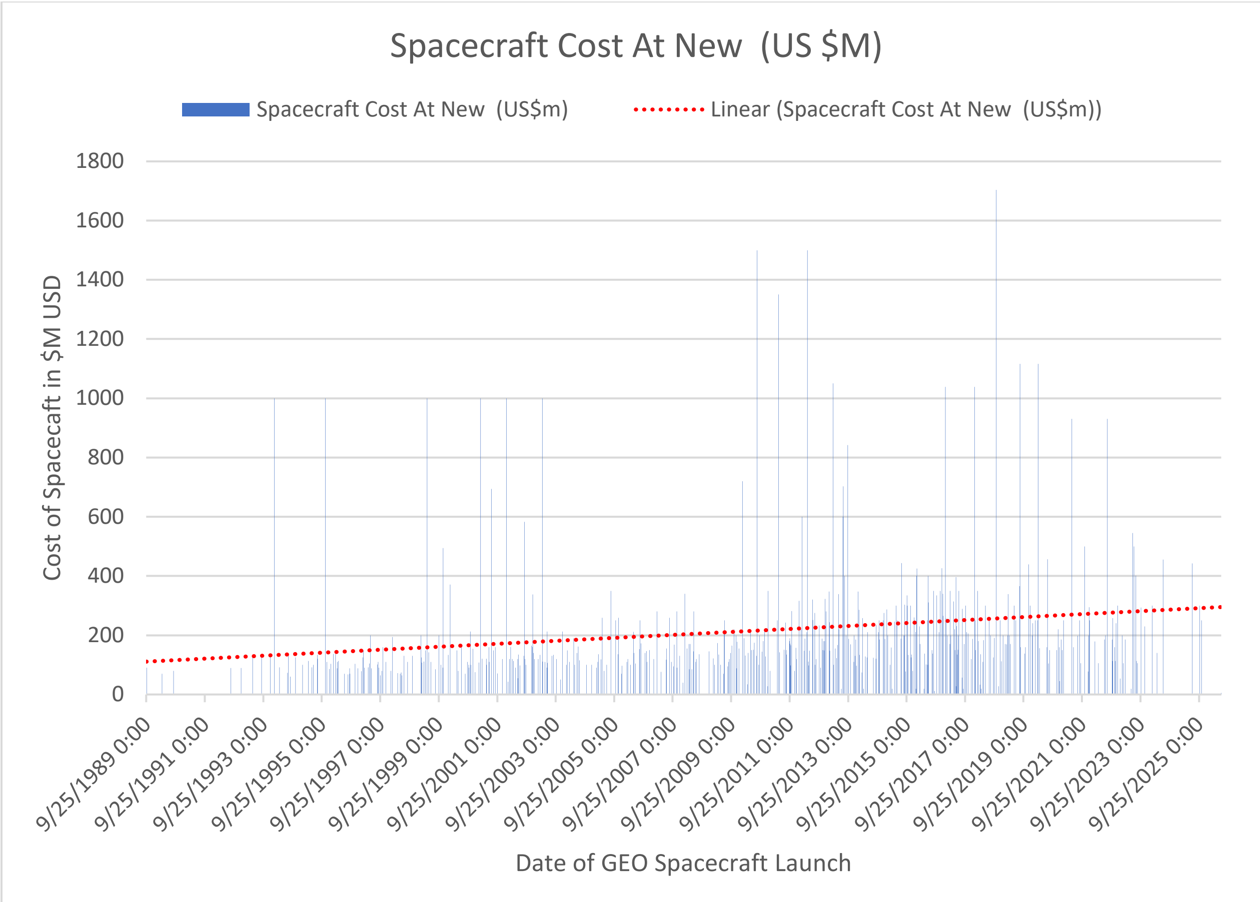

Figure 2: Cost of Satellites in GEO from 1989 to 2025 with a trendline over time

The average cost of a GEO satellite increased from the mid-2000s from $100M to $200M in the present day. This trend will most likely continue due to the general rise in inflation; new technological developments that provide added value and capabilities to satellites will add to this cost; and when the supply chain has problems, for example during the COVID-19 pandemic, this will add cost to a new satellite. The average cost for upcoming satellites (dated 2024 onwards) is ~$200M. This is a higher value compared to the trend that began in 1984. Factors such as supply chain disruptions during COVID, and inflation are not detailed by line item in this study. The costs that affect this average of $200M are included in the total launch cost found in Figure 3

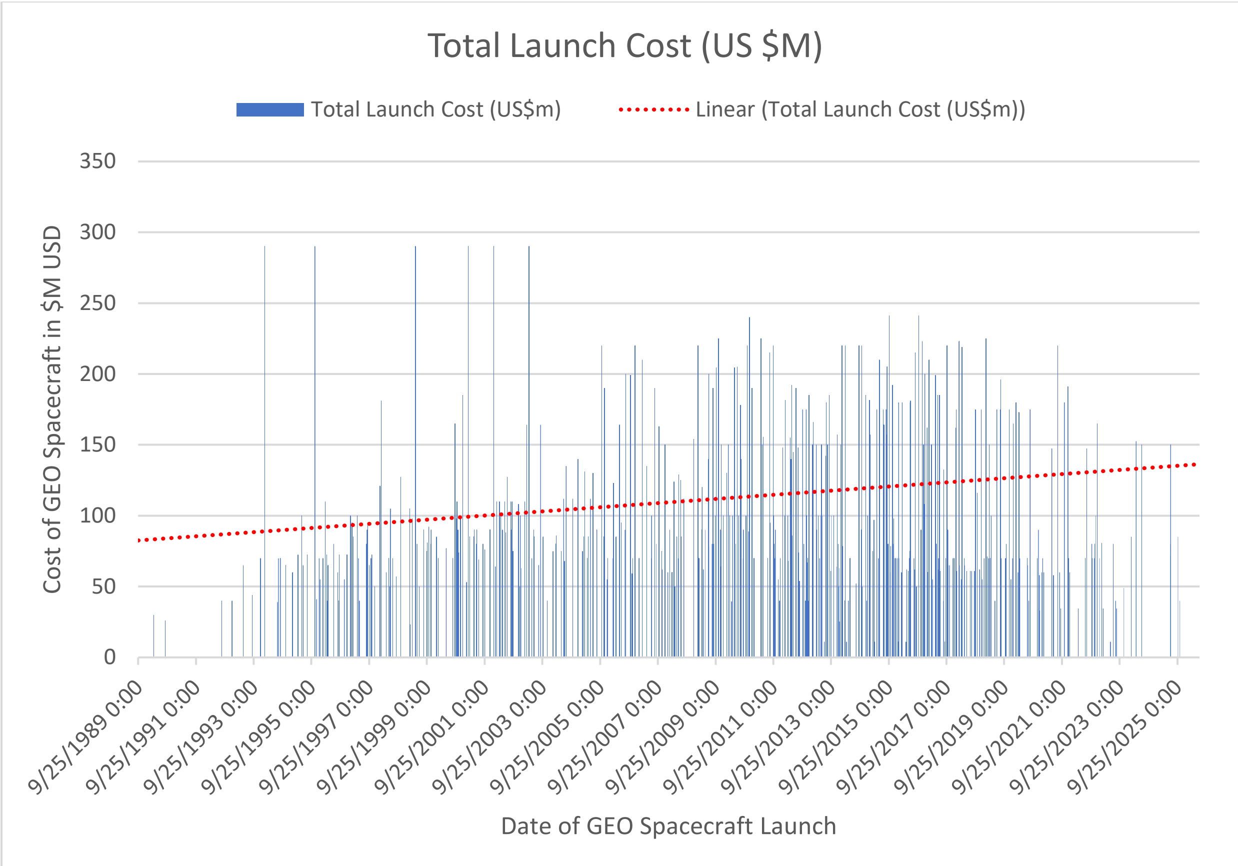

Figure 3: Cost of Launch to GEO from 1989 and predicted to 2025

For launches to GEO from 1989 to 2025, the cost on average ranges from $50-$100M. This trend, while showing upwards in Figure 3 opposite to the spacecraft build trend, is planned to decrease by 2025. Once the launches take place, this data is subjected to change and reflects increased costs.

Presently, most GEO satellites are not insured by the operator or user. This is a large cost to add to the mission budget.

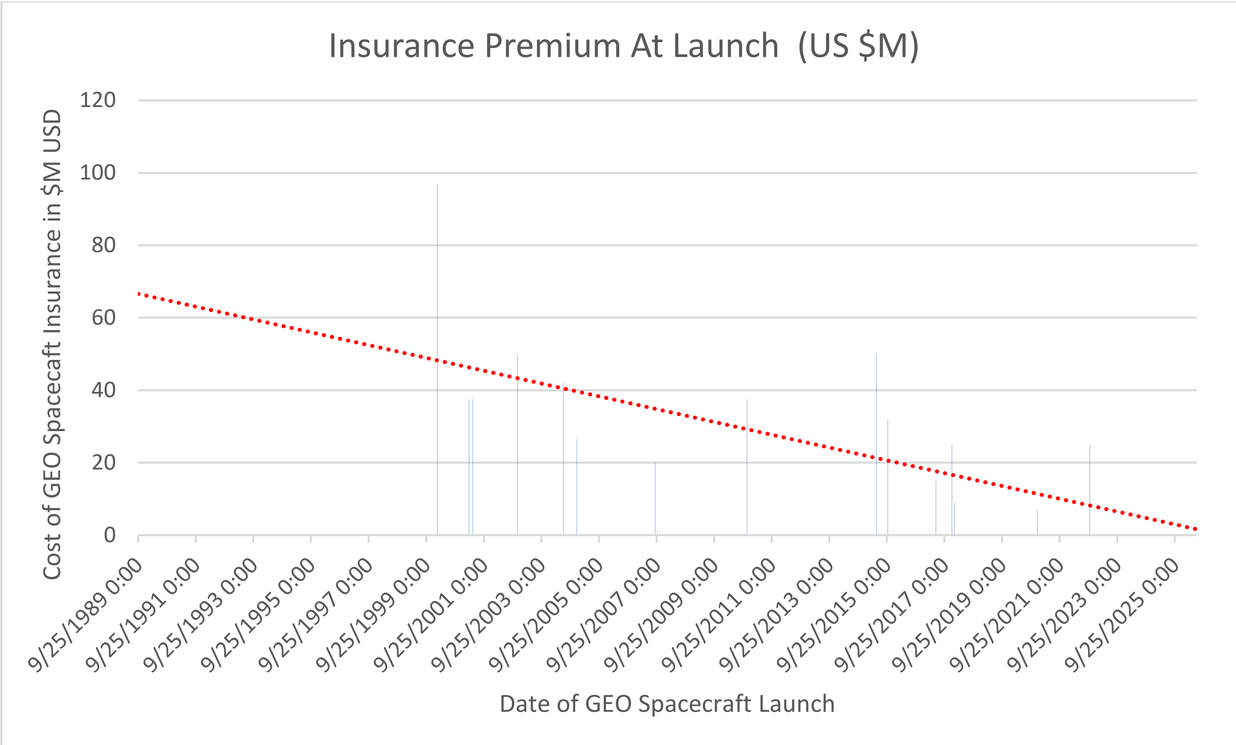

Figure 4: Cost of the insurance premiums for a GEO satellite at launch (if an operator chose to insure the spacecraft) from 1989 to 2025

The average cost for insurance for a GEO satellite (if an operator chose to insure their satellite) is $30M. This is overall trending downwards.

GEO launches and providers have seen 232 failures from 1989 to the present with far less satellites insured for its operations. The average cost of a satellite system failure was calculated from Figure 5.

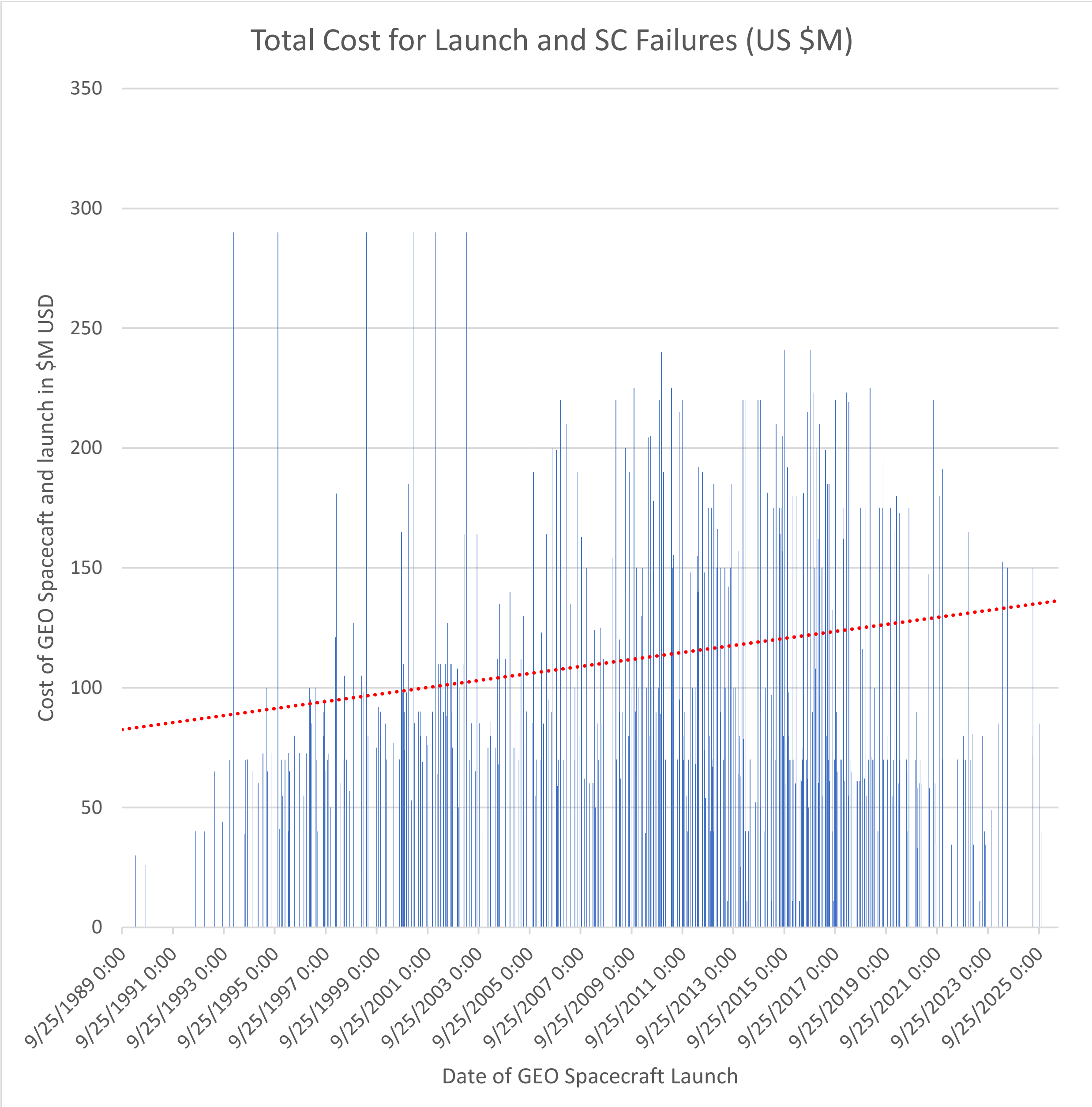

Figure 5: Cost for launches to GEO which include spacecraft failures from 1989 to 2025

The average total cost of a failed GEO satellite launch is $75M. If the satellite manufacturer experienced a failure and decided to build a new satellite, this can be considered an added cost to the overall mission. In general, this value adds monetary risk to the mission GEO operators originally designed.

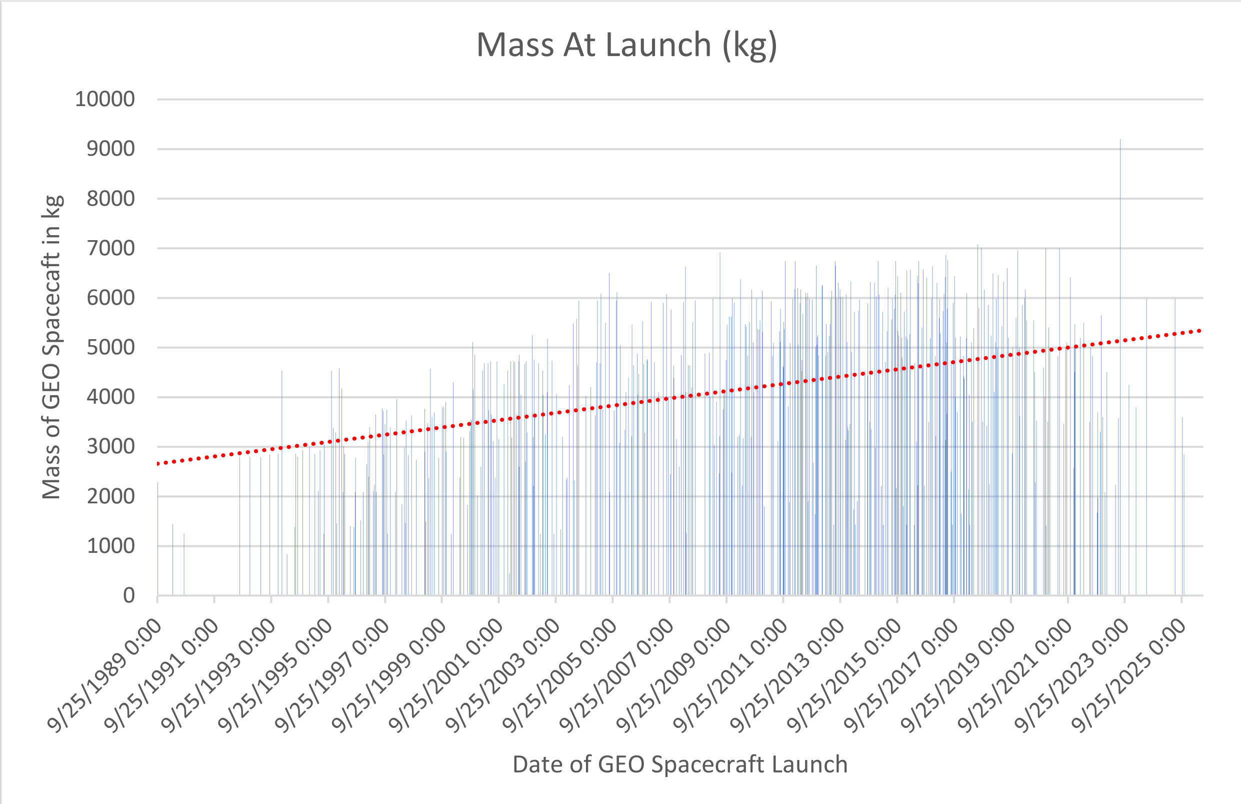

Figure 6: Mass of fuel to launch to GEO from 1989 to 2025

Figure 6 (mass at launch in kg) shows the increasing trend on fuel for launches to GEO. While the fuel type varies, on average, launch fuel costs $1M per kg. The average kg in fuel for a GEO launch is ~4700kg on launches from 1984 to 2023. On January 31, 2023, inflation was at 6.41%.[10] For 1 kg of fuel launched 2023 instead of 2022, $60,410 was added to the launch cost.

Future launches show an average of 3000 kg of fuel per launch. Seradata shows data on launches to GEO in 2024 and 2025. Assuming a consistent inflation rate of 6.41%, this adds an additional $60,410 and $120,820 respectively to the total price of launch. Geo-political crises also add to the rising cost of fuel for satellites. The 2022 Ukraine-Russian conflict raised the cost of Xenon from $3000/kg[11] to a minimum of $20,000/kg.[12] Xenon is used by satellites for ion propulsion and is the best solution for station keeping a GEO satellite. According to Tirlia, the average weight of Xenon, a GEO communications satellite may need is 300 kg.[13] If a satellite began construction prior to 2022, with a launch date from 2023 onwards, the budget for fueling on the launch pad was budgeted for an average of $900,000. Now it will be updated to an average cost of $6M. This 567% increase is intolerable for companies that didn't include this markup in the initial budget.

[10] https://ycharts.com/indicators/us_inflation_rate#:~:text=Basic%20Info,month%20and%209.06%25%20last%20year.

[11] Lauren Fuge (2021, November 17). *From the vault: Iodine-powered spacecraft tested in orbit for the first time*. Cosmos. https://cosmosmagazine.com/space/exploration/iodine-powered-spacecraft-tested-in-orbit/#:~:text=Bur%20xenon%20is%20rare%2C%20expensive,to%20fit%20on%20a%20satellite.

[12] The Economist Newspaper. (n.d.). *How rare-gas supply adapted to Russia's war*. The Economist. https://www.economist.com/finance-and-economics/2023/03/30/how-rare-gas-supply-adapted-to-russias-war

[13] Tirila, Vlad-George, Alain Demairé, and Charles N. Ryan. "Review of Alternative Propellants in Hall Thrusters." Acta astronautica 212 (2023): 284–306. Web.

Satellite related application fees to the Federal Communications Commission (FCC) will decrease from $137,000 to $4,000 in the future to reflect a new cost-based license application fee.[14] This cost is now decreasing over time thanks to new regulations by the FCC.

B. Launch window considerations

The launch window for getting a satellite into orbit depends on the launch site latitude and the inclination of the intended orbit. When the intended orbital trace overlaps with the launch site latitude, windows of launch opportunity are resultant. Since orbital traces are part of launch window availability, orbital traces of other objects may become a factor when creating new satellites and launching to GEO.

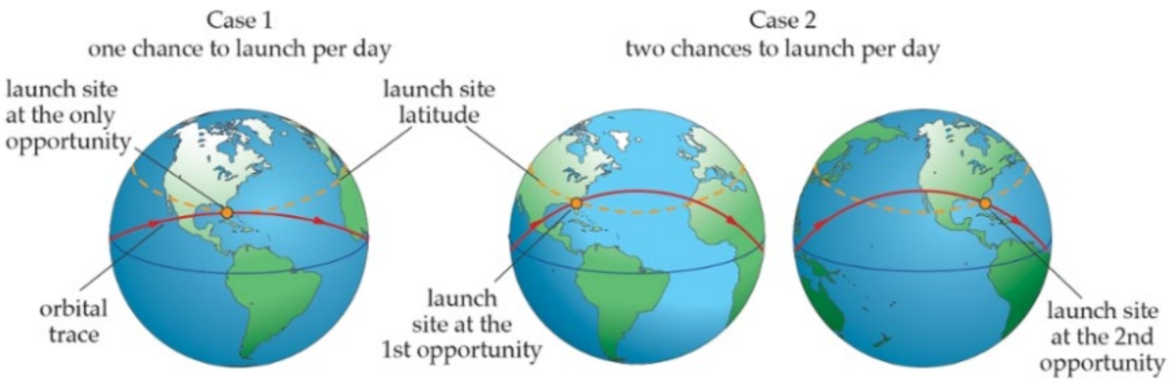

Figure 7: Opportunities to launch in orbit based on the orbital trace and launch site latitude[15]

Given the limited opportunities to launch a satellite to GEO, it's essential to track the orbital traces of other satellites and orbital debris to make sure the specific launch opportunities are clear for takeoff. In roughly a 3 hour period (8:50:00-11:50:00) on Wayfinder software, ~70 satellites and debris passed over Kennedy Space Center (KSC) on August 6, 2023.[16] While the altitudes and orbital paths of the satellites were not precisely monitored for this assessment, given the current number of satellites and space debris in orbit, there is a possibility that one to two objects could potentially pose a launch interference risk at KSC in one day.

C. Research items not included in the study

This study kept the data and analysis at a high level. Factors that were not considered include the correlation between the orbital slot location, satellite purpose, and cost of the satellite. The average life span for each GEO mission wasn't incorporated into the study. The cost of maintaining a satellite isn't publicized by operators; the average cost for this maintenance wasn't included in this study. Additionally, the military/commercial/civil space difference in cost was not considered for this study.

An incalculable figure to include in this study is the value added to an asset and its space in GEO once it is serviced and its life is extended in orbit. If an operator chooses to extend the life of an asset (station keeping or refueling) or place that satellite in a new orbital slot, this may increase the value of that orbital slot. The orbital slot identified as critical for extending the mission life of the asset that occupies it. At this time, the value and profits from a spacecraft that occupies a slot that is chosen for servicing is not public or available. This data will add to the total cost of a GEO slot, but would not be included in the average cost an operator considers for a new satellite. These activities add to the inherent value to the location of the slot in GEO and how the operators need to use it in order to continue essential operations on Earth.

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[14] FCC publishes new cost-based license application fee schedules, but new fees will not take effect quite yet. DLA Piper. (n.d.). https://www.dlapiper.com/en-US/insights/publications/2021/04/fcc-publishes-new-cost-based-license-application-fee-schedules

[15] Sellers, Jerry Jon et al. Understanding Space : an Introduction to Astronautics. Ed. Douglas Kirkpatrick. Third edition. New York: McGraw-Hill Companies, 2005. Print.

[16] https://wayfinder.privateer.com

5. RESULTS

The trends from the last three decades show that the cost of building and placing a satellite in GEO will increase over time. On average, in 2023, the generic cost of a new, insured satellite in GEO is $255 M. At a high level, if an operator wants to occupy a GEO orbital slot, they need at least $255 M in 2023. This implies an intrinsic value to each GEO slot and $255 M is required to occupy it. Without that median level of funding, one cannot use a slot in GEO.

Trends also show the mass at launch has steadily increased over time. The addition in mass equates to an addition in cost for fuel to get to GEO. As this cost increases, and inflation continues to rise, this cost will continue to contribute to the intrinsic cost of a new GEO slot beyond the average $255M. With the average launch cost hovering around $75M, the total cost of occupying a slot in GEO is estimated at $330M. This trend harms GEO operators launching new satellites due to the unpredictable cost fuel imposes.

As Geopolitical tensions and inflation continue to rise over time, the satellite and launch vehicle construction community will continue to be affected. The average cost of inflation on fuel equated to ~$60k. The additional cost to Xenon, which most GEO satellites use for long-term station-keeping, equated to an average of $6M. These figures add to the total, rounded, average cost of occupying a GEO slot to be $337M in 2023. This value is reliant on unpredictable increasing costs in the future. Operators will have to turn to a new fuel source to manage this increase in cost; otherwise, budgeting is difficult.

One more cost that wasn't quantified is the profitability for operating an asset in GEO, or the essential service it provides during operations. If this service is interrupted due to launch delays or inoperability in orbit, this can add to the cost of a satellite operator or the people that need the service. In addition to weather delays, the orbital debris increase may create launch window unavailability. While the statistical probability of the orbital traces overlapping with the launch window and orbital trace of a launch vehicle are low today, when debris continues to increase over time, this may be a more considerable factor for operators that need a new vehicle in orbit.

A. OOS Architecture Influence

The OOS ecosystem will prove beneficial to assets in GEO orbit, particularly the satellites that were not initially prepared for life extension and transportation services. When operators have the choice to extend assets' mission life, this will disrupt the usage of GEO slots. Part of the analysis to decide whether to extend an asset's life is the value of this GEO slot. Presently, this is based on the position in GEO and the access to the users on Earth. If this service cannot be disrupted or if an average cost of $337M is too high to replace an asset, an operator may opt to extend mission life. This could interfere with another operator's goals of obtaining that slot and using it for a new mission. Separately, if that operator wants to hold an asset in that slot until a replacement is on its way, this removes the ability to make GEO more dynamic. For example, instead of taking an unusable asset to the Graveyard orbit, an operator can choose to make sure no one else can occupy that slot.

These operations may result in disputes amongst operators that need a new GEO slot. These disagreements may require a regulatory medium that doesn't exist in today's industry. Nothing may change since the OST does not allow space to be treated as a commodity per signatory. Operators will not use the commercial market to change this system. Regulators, most likely at an international level due to the slot assigning duties of the ITU, would ultimately make a new system for operators if the value of GEO slots, and the availability of OOS, changes behavior in space. The FCC already showed operators that they can accommodate a dynamic space architecture by updating its fees required for a new satellite. This can happen again if a large enough dispute demands it, or if the operators encourage it.

While few GEO operators choose to include insurance for their spacecraft, the OOS architecture can update this cost and make it more affordable. If an insurance provider can use a servicer vehicle to fix an issue rather than pay out for the satellite, this remedy allows insurance providers to reduce the cost of premiums. The average insurance cost is $30M for the operator that chooses to insure in 2023. Since a small amount of users insure their spacecraft, this cost isn't included in the total, average cost of a new satellite obtaining a GEO slot. However, while this future, OOS insurance cost will add to the current $337M, a more reliable and affordable insurance premium will most likely result from the new servicing paradigm.

B. Real estate parallels

Instead of demolishing a house and rebuilding a new one entirely, it's more cost effective to do a remodel or extend the life of an asset on a high value plot of land. The real estate market trend indicates that space or land that once did not use "present value" to equate a plot's profitability now relies on this to assess value. The present value applied to a GEO slot would assess the value of the asset placed and use the predicted amount of profit for commercial satellites. For government satellites, the predicted profit value could equate to personnel needed to operate the satellite and use the data. This value can be used to inform regulators if they decide to start charging fees per GEO slot. With the new ability to perform maneuvers, and manufacturing in-orbit long term, regulators may consider a smaller fee for extending mission life and promoting sustainability over building a new satellite and launching to that slot. While fees are not imposed on operators today, this could change given long term mission needs by governments and industry.

6. SOLUTION

GEO operators understand there is an intrinsic value to a GEO slot by sending a new spacecraft to occupy an orbital slot; on average the cost is \$337M (excluding ground operations and additional costs). According to trends starting in 1989, and severe economic impacts to the space community over the last decade, GEO spacecraft operators can assume that costs to new spacecraft will continue to rise. While the economic impacts of servicing a vehicle to extend its mission life are not public in 2023, GEO operators will have the option to save \$337M on a new spacecraft and opt for life extension or transportation services at potentially $1/10^{th}$ of the cost.

When value is associated with slots in GEO, the tangible benefits and competition are apparent to the users that wish to occupy that slot. While previous attempts to rent these slots were unsuccessful, the upcoming OOS ecosystem may disrupt how operators are regulated to perform business in orbital slots. Regulations imposing time limits or prices on orbital slots would ultimately deter future bad practices by companies and operators in GEO during dynamic space operations.

Finally, the increasing risk to LEO assets through growing debris fields and ASAT test capabilities may further restrict launch access. These GEO orbital slots will increase in value with the restriction to access to space because of growing debris in LEO. Instead of contributing to the problem by launching more constellations, government and commercial operators can consider other solutions, such as servicing the operational assets in valuable slots in GEO. Otherwise, orbital debris mitigation is recommended to alleviate this growing concern. This may affect the value of GEO slots if they become more accessible once again.

While the economic benefits of this eminent and dynamic infrastructure don't exist yet, the space economy is about to change drastically in unpredictable ways. Ultimately, this OOS architecture allows the warfighter and commercial satellite provider to be flexible in the upcoming costs and potential threats to the space environment. These funds needed to occupy a critical GEO slot can be used for multiple on-orbit activities or be saved for better purposes.

6. FUTURE RESEARCH

Future research includes determining how much a launch window is affected by orbital debris. Comparing orbital traces and where they overlap for GEO launches would help operators understand how the growing, space environmental concerns may affect their future business.

Additionally, data that reflects an average cost and profit for a GEO satellite would help understand if delays in launch, service, or a failed spacecraft would cause severe, economic damage to a user. This would couple with the understanding that a future rise in space debris may have a negative effect on operators that wish to send a new spacecraft into GEO.

Furthermore, economic data reflecting the OOS impacts to the GEO community would change the values once this dynamic architecture is in place.