Space-Based Solutions to Virginia's Roadway Problems
(Technical Paper)

Societal Factors Influencing the Production and Cleanup of Space Debris
(STS Paper)

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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

Since the inception of CubeSats in 1999, these “nanosatellites” have allowed research groups around the world to rapidly launch space missions at relatively little cost (Loff, 2018; Innovative Solutions in Space, n.d.). The National Aeronautics and Space Administration (NASA) defines CubeSats in Units or “U” where 1U is 10 cm x 10 cm x 10 cm – typical CubeSats come in 1U, 2U, 3U, or 6U and weigh under three pounds (Loff, 2018). The standardization of CubeSats, and their ability to hitch rides on large launch vehicles due to their small size has led to an explosion in usage. Over 1,300 CubeSats have launched to date, and that number is predicted to double over the next three years (Kulu, 2020). 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.

The technical section of the thesis prospectus will describe the collaboration between The MITRE Corporation and the Virginia Space Grant Consortium (VSGC) to build one or more CubeSats which can address problems related to Virginia’s transportation infrastructure. Our group has been selected to focus on using a CubeSat to track and relay real-time weather data to drivers in order to warn them of changing road conditions. From an STS Perspective, Social Construction of Technology (SCOT) will be used to examine the political, economic, social, and technological factors surrounding the issue of space debris.

Technical Topic

Introduction

This University of Virginia spacecraft design capstone project will develop solutions to address Virginia's transportation problems using data fusion and remote sensing methods. In August 2020, key stakeholders from MITRE, University of Virginia, Virginia Tech, Old Dominion University, George Mason University, Virginia Transportation Research Council, Virginia Space Grant Consortium, Federal Highway Administration, and National Academy of Sciences met in the University Innovation Exchange (UIX)-MITRE Space Initiative Transportation Efficiency Workshop. Their discussion and deliberation identified three key areas to improve transportation efficiency and safety in Virginia: (1) Real time weather data to improve roadway safety, (2) Remote-sensing-enhanced non-destructive evaluation of roadway infrastructure, and (3) Management and tracking of truck parking (Kordella, 2020). University of Virginia students taking the spacecraft design course were divided into three sub-teams corresponding to the problems outlined above. A fourth area of interest, the effective use and interpretation of multiple data sources using open data and predictive analytics, emerged from the workshop (Kordella, 2020). It was determined this problem applies to all three sub-teams. During the project brief, MITRE provided us, the real time weather data team, with a preliminary problem statement described below. Since then, we conducted a literature review and refined the given problem statement, as discussed in detail starting on page 9.

Between rain, snow, sleet, and hail, Virginians have unforgettable experiences driving in adverse weather. Similarly, most Virginians know the frustrations of a rush hour traffic jam in Northern Virginia, Richmond, or Hampton Roads. Aerospace engineering students Arianna Asquini, Mici Cummings, Ian Davis, Rikia Freeman, Raeann Giannattasio, Allen Lang, Pranav Sridhar, Elias Topp, and Ethan Vicario, as well as mechanical engineering students Kyle Ebanks and Avery Walker will work together in the 2020-2021 academic year on the real time weather data sub-team. The goal of this sub-team, based on the first objective, is to help alleviate weather-related traffic congestion, and improve roadway efficiency and safety in Virginia.

This paper contains a summary of the problem assigned to the real time weather data sub-team. Then, we will discuss findings that emerged from meetings with key stakeholders and Subject Matter Experts (SMEs), as well as a literature review and state-of-the-art analysis. To follow, we will report the solution requirements, data streams and solution approach pertaining to this project. Finally, the paper concludes with a plan for the upcoming Spring semester and summary of the Fall semester.

Summary of the Problem

Picture a driver waking up, looking out the window, checking the weather, and pulling out of the driveway for the day. This morning ritual feels familiar. However, checking the weather before driving may not always provide as much information as drivers may think. The weather could differ between the start and end locations. A storm could blow in from elsewhere mid-drive.

A fallen tree or flooding could block a roadway. If the driver is travelling toward a storm, it may not have shown up on a weather app before departure. At this point, the driver cannot easily look for an alternate route in real time, and they may be stuck in weather-induced traffic, once again. These are merely a few examples of adverse weather contributing to road congestion. In many instances, the current method used by drivers to check weather information leads to inaccurate conclusions. By including a combination of real time weather, predicted weather and traffic data in the information sent to drivers and vehicles, roadway users could have a more accurate representation of the drive ahead.

While the benefit of simultaneous weather and navigational (GPS) data collection is apparent, current systems do not integrate the delivery of both streams to users. This shortcoming makes roads more hazardous as drivers cannot be appropriately warned of adverse weather conditions. Nearly all highway capacity approximations assume clear weather. For example, of all the publicly available data sets looked at by Yang, Lillian, and Pun-Cheng (2016), only two, ChangeDetection and Karlsruhe Institute include non-perfect weather conditions. Clear weather is an invalid assumption to make when performing traffic data analytics, considering the majority of states in the United States encounter inclement weather conditions for a significant portion of the year (Agarwal, 2005). Furthermore, it has been identified that adverse weather conditions contribute to many vehicle crashes each year. For example, Ashley, Strader, Dziubla, and Harberlie (2015) reported that in Fancy Gap, Virginia, excessive driver speed in dense fog caused 17 distinct crashes on March 31, 2013. In 2018, the economic cost of traffic crashes in Virginia amounted to $6.4 billion (TRIP, 2020).

Although roadway users usually rely on weather forecasts, the Virginia Department of Transportation (VDOT) uses road condition measurements, which could differ significantly from meteorological data reported to drivers via news stations and apps. For example, the roadway could be a couple degrees colder than the atmosphere, which could result in ice. These discrepancies lead to misinformation which contributes to accidents (Fontaine, 2020). Despite the wide availability of weather data via various sources, delivery to individual drivers is extremely fragmented. While many aviation and marine satellite navigation devices already have the capability to deliver weather data to end users, very few roadway traffic algorithms include weather data. Therefore, navigation sources such as Waze, Google Maps, and Virginia 511 offer different and sometimes conflicting information. Further, although VDOT consistently shares information with the local media, the public does not follow this information unless the report is catastrophic or sensational. Due to these shortcomings, drivers, autonomous vehicles, in-vehicle satellite navigation services, and vehicle to vehicle communication will also benefit from more accurate weather-related traffic data.

Key Stakeholders and Subject Matter Experts

In order to establish the state-of-the-art, as well as potential solution approaches for tracking real-time weather data, our team contacted a variety of key stakeholders and SMEs. We were able to speak with an expert on the relationship between weather and roadway safety, as well as stakeholders from VDOT, Emergency Services (EMS), and local government.

According to Michael Fontaine (2020), associate director for safety, operations, and traffic engineering at VDOT, the agency employs ground station sensors in specific trouble areas across the state. These sensors are essential because meteorological reports of atmospheric conditions often differ from circumstances on the actual roads. These stations relay information to VDOT so they can update electronic signs on the roadways to inform drivers. These ground stations produce high quality data but must be properly maintained, which is expensive. While this solution targets specific trouble spots, there is no consistent, cost-effective, and state-wide solution. For example, in many places across the state, supervisors manually drive on roads and report back the conditions they experience. This is a laborious and time-consuming process that would benefit greatly from a spacecraft design solution. Mr. Fontaine also described how VDOT exchanges information between partners. One example of a partner is the mobile navigation application Waze. With this service, users are able to report road conditions and events to display to other users. VDOT sends Waze reliable weather-related road reports, but users only receive this information if Waze has the same information for all fifty states. Another information exchange occurs using Virginia 511, which publicly relays adverse weather effects on roadways and traffic conditions to drivers via the Virginia 511 service. This service targets certain well-travelled roads to provide real-time weather data including air temperature, dewpoint, relative humidity, wind speed, wind gusts, wind direction, visibility, precipitation type, pavement temperature, and pavement condition. In addition, Interstate 77 uses technology to promote safety through electronic speed limit signs that adjust in real time based on sensor detected fog levels. These practices illustrate how weather data can reach and impact drivers.

Much of Michael Fontaine’s information and insight lined up well with information from Venkataraman Lakshmi (2020), a UVA Systems Engineering professor specializing in remote sensing. He explained how snow depth, water depth, and ice accumulation are still manually detected, and therefore, remote sensing would greatly improve these collection processes. Because of this, the most effective data accumulation will be a combined stream from sensing stations on the ground and satellites in space, but properly merging these data sets will pose a challenge for our team. In addition, the timeliness of reporting weather events is crucial, since thunderstorms can be as short as a few minutes. He reiterated the effectiveness of delivering information to drivers is through the navigation applications they already trust and use, such as Waze. Lakshmi also stated the importance of analyzing impacts of weather through comparison of data sets. For example, comparing traffic on one day with acceptable weather compared to that same day with adverse weather would quantify the impact of weather and guide solutions accordingly.

Two representatives from Charlottesville EMS shared vital information on the impact of weather conditions on their operations. Harrison Brookeman (2020) is a current member of the Charlottesville-Albemarle Rescue Squad (CARS), a volunteer organization serving the community since 1960. CARS has been ranked as one of the busiest volunteer rescue squads in the country, having run over 12,000 calls in 2008 alone (Charlottesville-Albemarle Rescue Squad, 2015). Despite their call volume, Brookeman indicated they still rely on modest technological resources, including the National Weather Service (NWS) for weather forecasts and Google Maps for navigation. Doug Walker (2020), the Deputy County Executive for Albemarle County, echoed Brookeman's sentiments, stating that the local government's disaster response operations also hinge on public data from the NWS. According to Brookeman, flooding and black ice are the two biggest weather-related factors impacting their organization. Both Brookeman and D. Walker cited Charlottesville's unique geography as a contributing factor to the unpredictability of flooding. Due to CARS' reliance on Google Maps for navigation, blocked roadways, due to floods, ice, trees, and more, are not communicated clearly to EMS volunteers during call response. This can cause significant delays to their response time. Brookeman reinforced the need to integrate weather alerts into these navigation apps, both to reduce weather-related accidents and to improve routing for EMS in poor conditions. From a local government perspective, D. Walker highlighted the need for accuracy and timeliness in data collection. If they are not able to immediately react to rapidly changing weather conditions, they cannot create effective disaster response plans.

Finally, Christopher Walker (2020), a member of the Norfolk Fire Department, was able to provide a new EMS perspective. Norfolk, Virginia has over 200 miles of riverfront and bayfront property, making it easily susceptible to flooding (The City of Norfolk, 2020). Similar to CARS, C. Walker indicated a reliance on publicly available radar data as their source for forecasting. However, Norfolk first responders develop an intuition for expected flooding in any given storm, due to the prevalence of floods in the area. Even so, C. Walker believes other response teams, such as the Federal Emergency Management Agency (FEMA), would find flood mapping data invaluable. He also suggests two public safety apps, Active911 and PulsePoint, as useful tools in this area. These applications are designed to send push notifications to users about developing emergencies across the city. By integrating flood alerts into these services, C. Walker believes their call response can be improved.

Our team would like to continue to reach out to SMEs and stakeholders as the project progresses. More specifically, we are looking for insight from commercial companies already working to address our identified problem. Vaisala is a Finnish company that offers industrial weather measurement devices and data services. Their in-car software product, Vaisala Infotainment, informs drivers of hazardous conditions and formulates routes based on current weather (Vaisala, n.d.). Weather Telematics is an internet of things company that works with GPS fleet tracking services, mostly using forecasts from the NWS. Their machine learning models advise drivers about weather and calculate alternatives mid-route. The company goals are to provide a “suite of map-based media tools to help travelers choose the safest route - avoiding delays while at the same time reducing congestion, fuel consumption, operating costs and above all, avoiding high-risk accident zones" (Weather Telematics, 2019). The E-horizon road weather hazard alert service alerts both drivers and dispatchers about upcoming weather-related road hazards (Geotab Marketplace, 2020). This gives fleets the ability to reduce both the risks and costs that inclement weather brings. This service is fed directly to MyGeotab, an online portal offered by the web-based analytics group Geotab. That being said, E-Horizon is just one service provided by Geotab, which also offers a far broader suite of data information to fleet industries to maximize their efficiency (Geotab, 2020). However, efforts to contact representatives from Weather Telematics, Vaisala, and Geotab have all been met with no response. The team will continue to monitor these channels in order to provide a solution that meets the needs of many users as possible.

Literature Review and State-of-the-Art

While many factors contribute to traffic and vehicle crashes, an unsurprisingly significant number of crashes relate to inclement weather. Graduate research by Yue Liu (2013) studied fourteen-years of National Highway Traffic Safety Administration (NHTSA) data and found that 24% of vehicle crashes were weather related in the state of Maryland, which has a similar climate and geography to Virginia. Additionally, 75% of weather-related crashes occurred on wet pavement and 15% occurred during snow (Liu, 2013). Therefore, rain and snow are the biggest contributors to weather related accidents in this region.

Although a human decision is at the core of every traffic incident, there is a lack of understanding of current weather impacts on road safety for the average commuter. Researchers relied on phone surveys to determine how drivers use weather data to drive safely. In response to two winter storms in Utah, drivers looked at an average of two-to-three weather sources before commuting (Barjenbruch et al., 2016). Most of those sources came from local weather stations and personal connections rather than government websites like the National Oceanic and Atmospheric Administration (NOAA). When asked about the available weather data, almost all drivers felt satisfied with its quality. Despite feeling well-informed, the majority of drivers answered that the actual storm was more severe than expected. Additionally, only a small portion of the drivers adjusted their behaviors (Barjenbruch et. al., 2016). Consequently, any effective solution will need to account for human sentiment.

While human factors are highly important, we cannot neglect the rise of autonomous vehicles. Weather hazards may pose a particular problem for autonomous vehicles, since this adds more variables to an already huge number that control systems in these vehicles must consider when operating on the road. Furthermore, the growing presence of electric vehicles on Virginia's road systems will accelerate the fraction of autonomously driven vehicles. Currently, 2% of passenger vehicles in Virginia are electric, yet this metric is expected to balloon to 46% by 2040 (TRIP, 2020). Both electric and autonomous vehicles would benefit from a combined stream of weather and traffic data to optimize their routes and increase passenger safety.

Currently, Virginia's weather information is a synthesis of data from space and ground sources that the entire country shares. In space, the most prominently used satellites are from NOAA's Geostationary Operational Environmental Satellite (GOES) system. These satellites carry an imager that measures incoming infrared radiation from the Sun, and a sounder that observes atmospheric profiles and cloud coverages. The current generation, GOES-16, also known as GOES-R, offers greater imagery and resolution with increased frequency, providing weather updates every 30 seconds (National Weather Service [NWS], n.d.). GOES-R contains two Earth-pointing sensors, the advanced baseline imager (ABI) and the geostationary lightning mapper

(GLM) as depicted in Figure 1. The GLM is capable of detecting the location, frequency, and extent of lightning discharges, allowing it to identify intensifying thunderstorms and tropical cyclones. The ABI contains a 16-band imager capable of viewing multiple wavelengths in the visible, near-infrared, and infrared spectrum. These bands allow GOES-R to detect various elements on the surface or in the atmosphere, including cloud formation, snow, ice, rain accumulation, surface temperature, winds, fire, and many other weather-related indicators. According to the National Weather Service, GOES-R provides three times more spectral information, four times the spatial resolution, and more than five times faster temporal coverage than the previous system (NWS, n.d.).

Even though GOES detects many forms of weather, ground-based forms of data collection are still necessary to produce robust information. Several instruments, such as Doppler radar, ground stations, and weather buoys, supplement satellites by collecting data hard to obtain from space like precipitation intensity. To improve accuracy, human observations are submitted to NOAA as an additional verification method (National Oceanic and Atmospheric Administration [NOAA], n.d.). Even still, some weather measurements are collected entirely by hand. For example, snow depth is typically measured by a human at ground-based weather stations (Rasmussen et al., 2012). This leads to limited coverage since weather stations are located far apart from one another and manual measurements are infrequently updated.

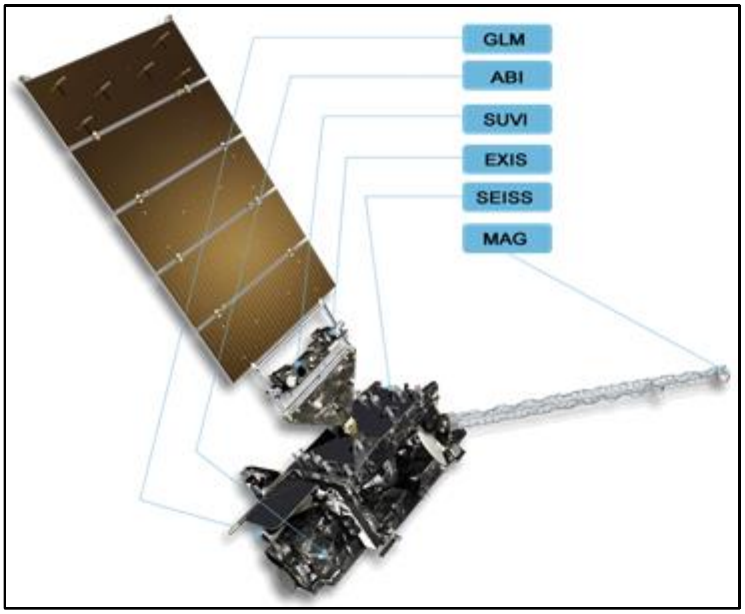

Figure 1. GOES-R satellite diagram featuring the earth-facing GLM and ABI sensors, with payload instruments labeled. (NASA, n.d.).

Overall, NOAA's weather data collection is constantly improving, with increasingly accurate and frequent data, allowing for extremely reliable short-term forecasts and improved long-term forecasts. Despite the incredible capabilities of the GOES satellites, integration of this data into preexisting, popular route planning apps is minimal, even though adverse weather conditions are a significant cause of vehicle crashes every year (Federal Highway Administration, 2020). Since GOES-R has a spatial resolution of about 2 kilometers, which is too inaccurate to distinguish features on the road (GOES-R, n.d.). Integrating real time weather data into navigational apps for drivers can improve the economy, health, and environment for Virginians.

VDOT's data comes from sensors deployed by the commercial company Vaisala as well as dispatching manual labor to observe conditions in-person. The NWS contributes to the collection of available real-time weather data streams by solving for and reporting weather conditions on the Earth's surface and different layers of the Earth's atmosphere with data from its

GOES satellite. As stated earlier, this data is not at a sufficient resolution to draw conclusions about road conditions. Private products such as Google Maps, Apple Maps, and Waze crowdsource information from drivers and relay the data to other app users. Since these applications have standards to ensure their product is consistent, weather data from individual states is often undelivered due to a lack of nationwide availability. When these navigation tools do not include real-time weather updates, local EMS encounter issues with responding to calls due to inadequate re-routing. Additionally, current weather services are not timely enough, so EMS rely on user reports to address a weather emergency such as flooding.

Solution Requirements, Data Streams, and Solution Approach

Our proposed solution must be able to detect and distinguish between, rain, snow, ice, and flooding. In addition, measurements from a remote sensing platform must be of higher resolution than an existing satellite. More specifically, the resolution must be fine enough to be able to distinguish the road from its surroundings. The standard width of a U.S. highway lane is 12 feet. Therefore, accounting for two lanes and two shoulders, we require a resolution of approximately 12 feet (Federal Highway Administration, n.d.). In order to meet the real time nature of the project, we require a high frequency data feed, refreshing every 15 minutes. This could be constrained to rush hour, when the roads are most vulnerable to congestion. Integrating and centralizing collected information allows for ease of distribution to users. Cooperation with government services, such as VDOT or EMS, as well as private services, such as Waze or Google Maps, is essential for effective data delivery. In order to fit our budget, which we aim to finalize next semester, the maximum satellite size we can consider is a 6U CubeSat. Within our CubeSat, the potential sensors that may help meet our requirements include an infrared camera, a multispectral camera, or a spectrometer, depending on cost and efficiency. Here we plan to adapt sensors that are already in use on geostationary satellites for the low resolution, Global 4 km Multisensor Automated Snow/Ice Map capability that is used by NOAA. Our challenge will be to determine the suitability and adapt these sensors as a payload for a small Low Earth Orbit satellite instead of a large geostationary satellite. (Romanov, 2016).

Robust knowledge of our transportation system comes from linking remote sensing data in space, on the ground, and/or in the water with our own new technologies. This project will incorporate existing weather and traffic data streams from VDOT, local EMS, NWS, and private services such as Google Maps, Apple Maps, etc. Weather data is frequently collected from aviation satellites, doppler radar, and remote sensors. Similarly, navigational satellites, car sensors, and traffic cameras collect traffic data. All of these sources and more can combine via a CubeSat. This small satellite will also include means to obtain additional data based on our solution requirements.

To meet our solution requirements and constraints, we plan on placing a small constellation of CubeSats into low earth orbit with a multitude of instruments to capture the status of road weather conditions at a high rate of frequency during times of heavy traffic. This constellation allows us to get the temporal resolution required. Our payload may include a visual camera, multispectral camera, or infrared sensors. By analyzing the spectral signatures of the roads, one can determine the conditions. VDOT will receive this data and notify dispatch crews and drivers, so they can reroute traffic around trouble areas. Integration with widely used apps such as Google Maps, Apple Maps, and Waze would be optimal, but we recognize their standardization may make that difficult. However, Virginia 511 is also a mobile application, so we hope to collaborate with them. We first plan to collect data on a small region of Virginia, such as Hampton Roads or

Northern Virginia, and then scale up operations to statewide levels. If successful, this could then be scaled up to national levels with minimal changes in satellite hardware.

Plan for Remaining Tasks and Schedule

The Gantt Chart for the spring semester timeline in Figure 2 identifies the current plan to continue this assignment. Future action items include developing a conceptual design of the solution's system of systems and any required new technologies. These technologies include the space mission engineering process for remote sensing instruments and spacecraft bus. Creating a prototype of the new technology and software as well as refining concepts based on key stakeholder feedback are further tasks that need to be completed. The last two tasks are identifying potential funding sources as well as forming recommendations for further development of the transportation solution.

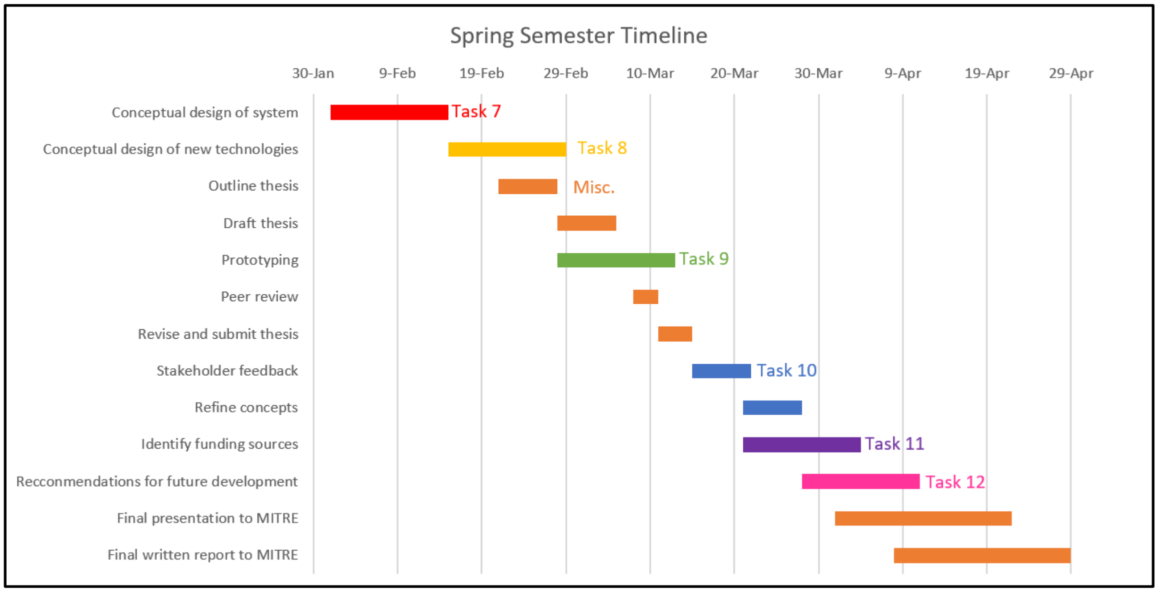

Figure 2. Spring Semester Timeline. This Gantt chart represents the predicted Spring semester schedule for the technical research. These deadlines need confirmation from our science, technology, and society advisors. The bars are color coded according to the established task numbers, and vary in length based on the time required to complete the task. The anticipated completion date is marked by the end of the bar. (Giannattasio, 2020).

Conclusion

The technical project for spacecraft design will engineer solutions to transportation issues in Virginia using data fusion and remote sensing approaches. This sub-team is working on the first area of interest, real-time weather data to enhance roadway efficiency and safety, as identified during the UIX-MITRE Space Initiative Transportation Efficiency Workshop (Kordella, 2020). The lack of platforms that combine weather and traffic data in a centralized place leads to neglecting the risks of adverse weather on the road. While roadways users typically focus on atmospheric predictions, VDOT instead relies on conditions at a driver's eye-level. These two reports tend to differ from one another, showing a lack of standardization in data delivery.

We can improve upon current methods by designing a CubeSat constellation responsible for integrating multiple data sources with weather or traffic information. Our system will also detect new data measuring conditions on the road, such as snow, ice, rain, and flooding. Furthermore, this measurement must be high resolution and low cost. A prerequisite of this new data stream is that the contrast must be sufficiently high to separate the roadway from its surroundings. We intend to deploy CubeSats with instruments such as a visual camera, multispectral camera, and infrared sensors, to satisfy our solution criteria and constraints. Upon obtaining this integrated information, VDOT and commercial partners can help distribute data to drivers. If practical, with limited improvements and enhancements, this can grow to a national scale.

STS Prospectus

Introduction

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.

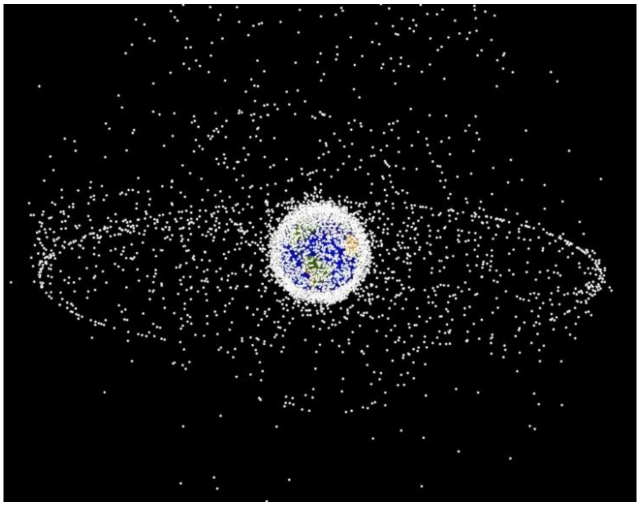

Figure 3. Rendering of Space Debris as Seen from High Earth Orbit (NASA, 2019)

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 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, none of these technologies have made it to space, but 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). The issue of space debris presents an opportunity to discuss the societal factors influencing debris production, cleanup efforts (and lack thereof), and the new technologies forming to combat this problem.

STS 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 around their preferred design and use of a technology.

The social groups I plan to investigate as part of an analysis into space debris include: scientists and researchers, the general public, private corporations, and government bodies. Each group has a unique interpretation of the space debris problem and different recommendations for which methods or technologies are best suited to clean up our skies. The scientific and research community have a large stake in developing new spacecraft for launch, but they are also likely to understand the risks posed by space debris. They are motivated to develop ways to cleanup orbital debris to minimize risk to their research projects. Private companies, such as SpaceX, and government agencies, such as NASA, are interested in reducing risk to their funding. Space missions are expensive, and there is currently little motivation for private companies to spend billions of dollars on cleanup of their own volition. In contrast, government agencies are beholden to Congress and international bodies, and thus may be compelled to assist through legislation.

An enlightening case study in this area is Starlink. Starlink is an ongoing effort by SpaceX to provide “high speed internet across the globe” through a megaconstellation of thousands of small satellites (Starlink, 2020). 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 problem will continue to get worse, as SpaceX could eventually put over 30,000 Starlink satellites into orbit, and other companies such as Amazon and OneWeb are looking to enter the market as well (Thompson, 2020).

Thus, the issue of Starlink provides an opportunity to address SCOT. The three relevant social groups, astronomers, commercial companies, and the public, all have a unique interpretation of Starlink technology. Astronomers would obviously prefer if Starlink had never come into existence, as its presence dramatically reduces their ability to examine distant celestial bodies. SpaceX clearly wants to push forward with Starlink in order to fulfill their investment into this technology. However, other commercial companies are more wary, with some 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. For many in the general public, a reliable, worldwide broadband connection could be a dream come true, especially for those in rural areas. For others, the addition of thousands of artificial objects streaking across the night sky would be a massive cultural blow. The International Dark-Sky Association (IDA) has already voiced their concerns to SpaceX over Starlink, in order to "represent the people who want to have that experience of being presented with nature in its raw beauty" (Foust, 2020).

SpaceX has responded to the mounting pressure from the scientific community by promising to solve the brightness problem associated with Starlink. Early prototypes of a so-called "DarkSat" seem promising, but it may take years to fully implement a satisfactory solution (Foust, 2020). Furthermore, SpaceX has 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, 2020). 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. 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 years to come, iterative designs will stabilize as SpaceX and others converge on a solution that satisfies all of the relevant social groups.

Research Methods

As the thesis develops, I would like to properly investigate these social groups and frame their interpretations of space debris production and cleanup around SCOT. I would also like to look at emerging technologies in the realm of debris cleanup and how they have been accepted or dismissed by various groups. I plan on targeting more research into past and present public policy efforts to address orbital debris as well. Furthermore, I would like to find more case studies like Starlink and consult with various subject matter experts on this topic. I can establish some of these contacts through my technical advisor, Professor Goyne. In these efforts, I believe I can provide an interesting view into the societal factors that have contributed to this phenomenon.

Conclusion

In addition to constructing the framework for a CubeSat that can track and transmit weather data, I hope to understand the potential ramifications of our satellite on the growing problem of space debris. At the conclusion of the technical project, our group will be able to present a detailed literature review, mission overview, design specifications, and schedule to The MITRE Corporation and the Virginia Space Grant Consortium. It is our hope that future students of the Spacecraft Design capstone course carry on our vision and eventually launch the satellite into low Earth orbit. The goal of the STS research project is to examine the societal factors influencing the production and cleanup of space debris using the Social Construction of Technology framework. The combination of these two projects will give important insight into the challenges faced by spacefaring vessels in the 21st century and beyond.

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