A SPACE-BASED SOLUTION TO IMPROVE ROADWAY SAFETY AND EFFICIENCY IN VIRGINIA: REAL-TIME WINTER WEATHER DATA FOR NAVIGATION

INVESTIGATING SOCIAL DIVIDES IN WASTE REDUCTION POLICY: HOW CONGESTION PRICING CAN INFLUENCE SPACE DEBRIS MITIGATION

A Thesis Prospectus
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By
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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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Traffic congestion is more than an inconvenience. Statewide, TRIP (2020) reported poor road conditions cost Virginians $9.5 billion each year. Congestion comprises nearly half of these losses (p. 1). Crowded roads are not only economically disadvantageous, but they also cause fatalities. Between 2014 and 2018, an average of 775 people lost their lives yearly on Virginia roads (TRIP, 2020, p. 9). The spacecraft design capstone course, advised by Christopher Goyne at the University of Virginia Department of Mechanical and Aerospace Engineering, aims to develop space mission engineering solutions that improve Virginia roadways. This project, through the University Innovation Exchange (UIX) program, is in partnership with MITRE and other Virginia colleges and universities, as well as NASA and the Virginia Space Grant Consortium (Wilkes, 2020).

As a society, we struggle with waste management in many aspects of our way of life. Some forms of waste are intangible in nature, such as greenhouse gases emitted from idle vehicles stuck in traffic. This STS thesis, advised by Catherine Baritaud at the University of Virginia Department of Engineering and Society, will focus on two types of waste: traffic congestion emissions and space debris. An exploration into social policies designed to mitigate waste generation on roads and in orbit will highlight how vulnerable social groups experience barriers from such policies.

The technical and STS theses are tightly coupled. The technical aim is to promote data-driven transportation policy decisions that will reduce traffic congestion, thereby limiting greenhouse gas emissions. Satellites gather the data needed for this project; most are less than 2,000 km above the ground in Low Earth Orbit (LEO) (Witze, 2018, para. 4). The link between the STS and technical theses is apparent, considering the heightened collision risks on these satellites due to space debris.

The deliverables for the technical and STS projects, divided between the Fall 2020 and Spring 2021 semesters, are expressed in Figures 1 and 2 on page 3. The STS project will conclude with the submission of the STS thesis at the end of March. The technical project will conclude upon completion of both the technical thesis and a final report to MITRE at the end of April.

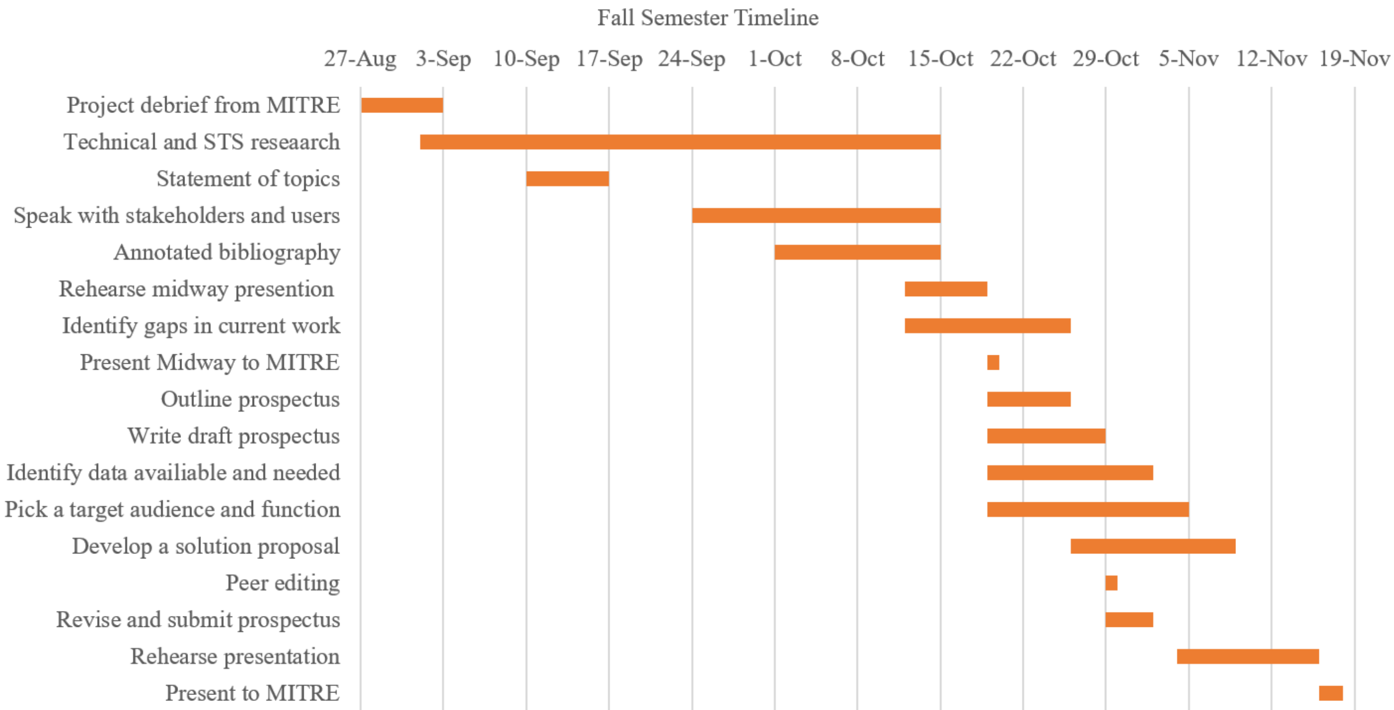


Figure 1: Fall Semester Timeline. This Gantt chart represents the predicted Fall semester schedule for both the technical and STS research. The orange bars vary in length based on the time required to complete the task. The anticipated completion date is marked by the end of the orange bar. (Giannattasio, 2020a).

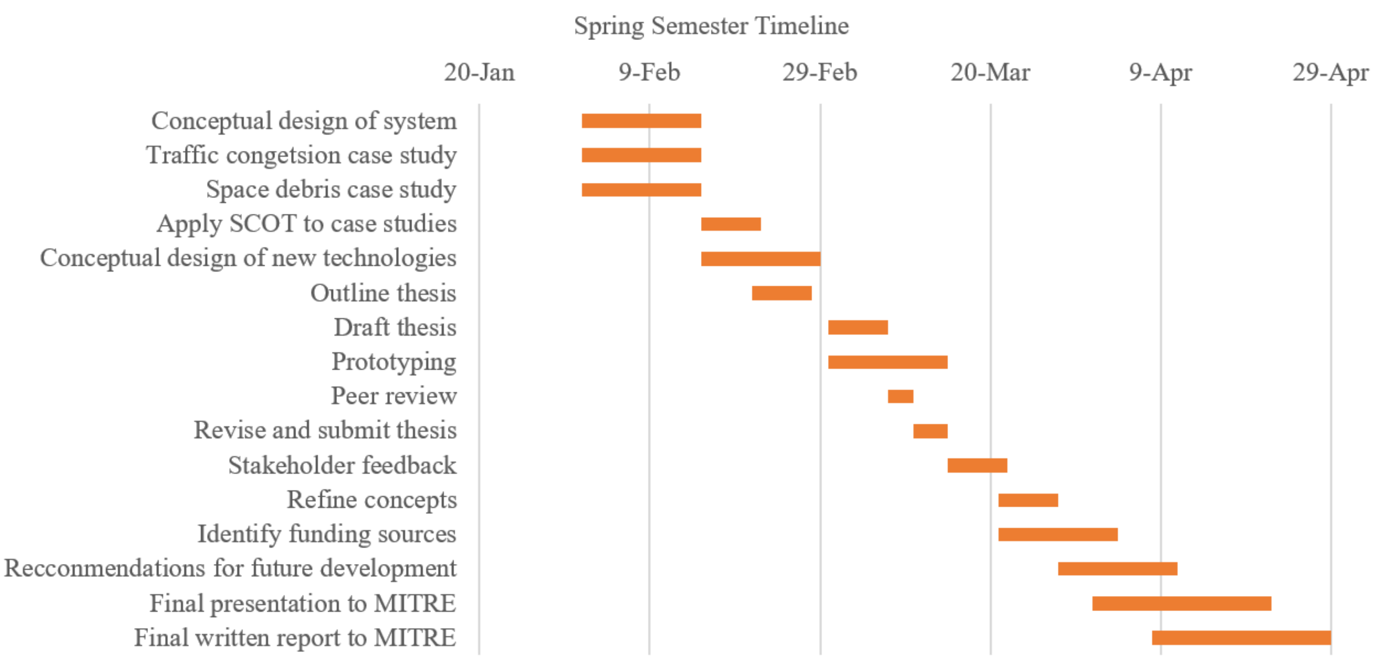


Figure 2: Spring Semester Timeline. This Gantt chart represents the predicted Spring semester schedule for both the technical and STS research. The orange bars vary in length based on the time required to complete the task. The anticipated completion date is marked by the end of the orange bar. (Giannattasio, 2020f).

SPACE-BASED SOLUTIONS TO VIRGINIA'S ROADWAY PROBLEMS

The spacecraft design technical project will develop solutions to Virginia's transportation problems using space-based methods. In August 2020, key stakeholders determined three key areas for improvement in Virginia transportation during the UIX-MITRE Space Initiative Transportation Efficiency workshop: (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, Slide 5). The students in the class divided into three sub-teams corresponding to the problems outlined above. A fourth area of interest emerged from the workshop, the effective use and interpretation of multiple data sources using open data and predictive analytics (Kordella, 2020, Slide 3). The class determined this problem applies to all three sub-teams. During the project debrief, MITRE provided us, the real time weather data team, with the above problem statement. Since then, we conducted a literature review and refined the given problem, discussed in detail below.

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. As the team leader of the real time weather data sub-team, I, Raeann Giannattasio, will work with aerospace engineers Arianna Asquini, Mici Cummings, Ian Davis, Rikia Freeman, Allen Lang, Pranav Sridhar, Elias Topp, and Ethan Vicario, as well as mechanical engineers Kyle Ebanks and Avery Walker. The goal of this sub-team, based on the first objective, is to help alleviate weather-related traffic congestion.

INSTEAD OF KNOW BEFORE YOU GO, COMPUTE WHILE YOU COMMUTE

Unsurprisingly, weather affects the safety and throughput of our roadway system. Research indicates that snow and rain pose a great threat to drivers in Virginia. Wet pavement, attributed to precipitation, is responsible for the highest proportion of weather-related accidents (Liu, 2013, p. 12). Furthermore, Tsapakis, Cheng, and Bolbol (2013) confirmed a correlation between increased rain intensity and slowed traffic (p. 208). Weather Atlas (n.d.) reports suggest that precipitation-oriented solutions must consider that snowfall in Virginia varies greatly between the coast and mountains ("The climate of Virginia"), and that thunderstorms bring excessive rainfall within a mere few hours ("Weather hazards").

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. But while many drivers check the weather before heading on the road, Barjenbruch et. al (2016) observed only 34% adjust their driving behavior to match road conditions (p. 481). That study, performed by the National Weather Service and Utah Department of Transportation, also concluded that those who check the weather favor local news sources over government ones (Table 6, p. 485). Therefore, 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. If the driver is travelling toward the 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 are stuck in weather-induced traffic, once again. This is merely one example of adverse weather contributing to road congestion. While the current method drivers use to check the weather draws misleading conclusions, including real time weather data would create a more accurate representation of the drive ahead.

Integrating weather data into existing navigation apps would allow drivers to obtain real time information about how the weather affects traffic and safety. Such a system would remove uncertainties from driving in adverse weather. Currently, some corporations offer these services. Weather Telematics (n.d.), for example, provides alternate routes that are both safe and fast based on various weather phenomenon, including hydroplaning, winds, snow, ice, visibility, and lightning (“Products”). At the time of writing, their services are offered to fleet industries, such as first aid squads, trucking companies, and snow/debris removal services, but not individual drivers (“Industries”).

PAVING THE ROAD TO WEATHER AND TRAFFIC DATA INTEGRATION

The aforementioned fourth area of interest, the use of multi-media data integration, is explained in Figure 3 on page 7; 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. Weather data is frequently collected from aviation satellites, doppler radar, and remote sensors in Low Earth Orbit (LEO). Similarly, navigational satellites, car sensors, and traffic cameras collect traffic data. The National Oceanic and Atmospheric Administration (NOAA) outlined the procedure they use to verify and distribute their data, which allows the team to build upon a recognized process (“Data processing,” n.d., para. 5). All of these sources and more can combine via a data cube, likely a small satellite such as a CubeSat. If there is a gap in current data available, this small satellite may include means to obtain additional data.

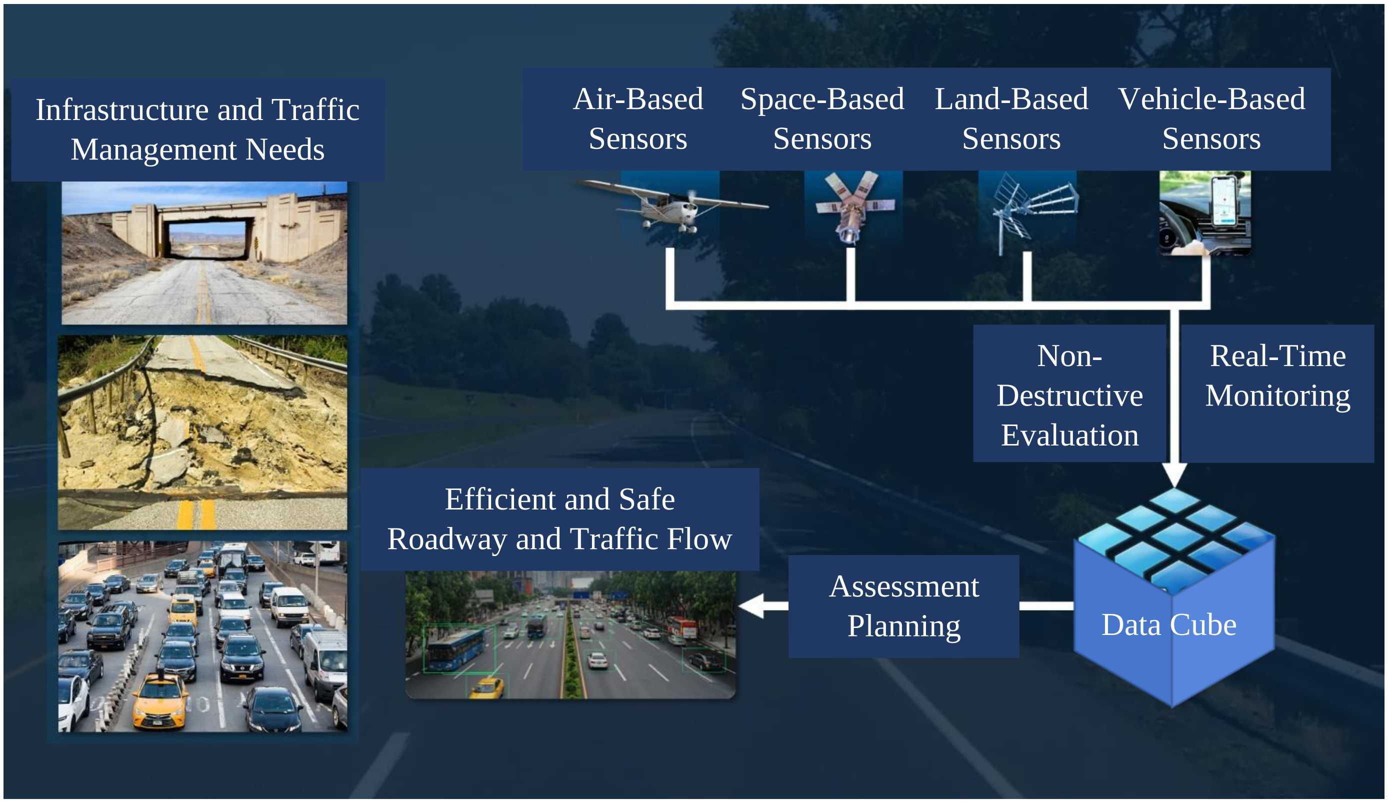


Figure 3: MITRE University Innovation Exchange Vision: Transportation. This figure visualizes the application of multi-media data integration to improve transportation. (Adapted by Raeann Giannattasio (2020b) from Scott Kordella 2020).

Ten years ago, Ezell (2010) admitted that if a project "requires a satellite and back-end payment system [,] . . . [then] it makes little sense for states to independently replicate these infrastructure investments" (p. 80). But now, universities are willing to help their state develop these capabilities. Implementing an integrated data system offers widespread availability to useful, predictive information linking weather phenomena and road conditions.

Upon completion of the entire transportation improvement project, in about 3-5 years, we hope to see real time weather data combined with real time traffic reporting and road condition information. The combined expertise of weather stations and satellites, navigation apps, as well as traffic cameras can predict driving experience in real time and better inform drivers. Maybe smartphones will even recommend a certain speed and separation distance. In order to achieve these goals. MITRE is providing mentorship and funding. Research and development at the University of Virginia will take place in the CubeSat lab in the Mechanical and Aerospace Engineering building. Subject matter experts from University of Virginia department of Engineering Systems and Environment, MITRE, and the Virginia Department of Transportation are already serving as helpful resources with this project.

Even so, the Washington Post highlighted a potential challenge with this project. At the time of writing this prospectus, the COVID-19 pandemic continues to ravage the United States. As a result, several aspects of normal life are on hold, including a sharp decrease in air travel. Meteorologists rely on commercial flights to collect the weather data used to make predictions. With fewer flights taking off, there is an average reduction of 75-80 percent in meteorological measurements from aircraft globally (Freedman, 2020, “U.N. agency sounds alarm”). It is difficult to gauge the true impact of such a massive deviation from the norm because a complete data set that could serve as a comparison tool does not exist. As we develop a mission relating weather phenomena and traffic patterns, this missing data may affect these efforts.

Analogous to past spacecraft design projects, work will continue across multiple capstone design teams. Since this year’s team is starting from the very beginning, our research objective focuses on preparing the next class to continue the project. Providing the next class with a completed prototype allows them to start the Fall semester conducting a preliminary design review. As such, the technical paper will be a cause-and-effect paper, detailing preliminary efforts towards a long-term mission and suggesting recommendations for future work.

SOCIAL DIVIDES FROM TRAFFIC AND SPACE WASTE REDUCTION POLICY

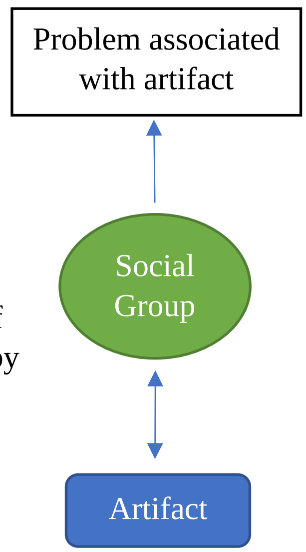
Risks to human health and safety on the road extend beyond traffic accidents. As Lindsey and Santos (2020) point out, 20% of global carbon dioxide emissions come from vehicles, so society cannot ignore that pollution from traffic congestion is somewhat responsible for many of the health issues associated with climate change (p. 1). For instance, air pollution in London in 2016 was 10 times more fatal than traffic accidents (Braizer, 2016, para. 4). Curbing traffic congestion is a worthy cause for many reasons: saving drivers' money, reducing fatalities, and lowering emissions.

While roads overflow with vehicles, Low Earth Orbit (LEO) is likewise inundated with space debris. As of 2018, LEO is home to nearly 16,000 objects (Witze, 2018, Figure 2, "Busy Skies"). But above all, inactive satellites and fragments make up around 95% of orbits (Witze, 2018, "The orbiting dead"). These objects pose a danger to future missions by increasing the likelihood of collision. Certain orbits become unavailable if more collisions occur and create more space junk (O'Callaghan, n.d., "What is Kessler"). In a similar manner to vehicle emissions, technology alone cannot resolve the problem of space debris. Both environmental issues will only get worse without immediate action.

APPLYING SOCIAL CONTRUCTION OF TECHNOLOGY

The STS portion of this paper will explore the relationship between societal perception of different types of waste and the success of mitigation efforts. Traffic congestion is seen as a local problem, but the emissions generated affect the global population, as they contribute to climate change (Lindsey & Santos, 2020, p. 7). In contrast, space debris is perceived as a global problem that has little effect on the average person's way of life. However, heightened mission risk from excessive debris impedes the launch of future missions. Missions designed to improve mapping, communication, or infrastructure may not make it to orbit if debris persists (European Space Agency, 2020). Additionally, satellites are useful tools for scientific research on many societal problems, including climate change. Delays in these missions would undoubtedly affect the well-being of a locality. Researching society's current understanding of these two waste issues could provide reasons on why existing strategies to reduce waste in Earth's atmosphere and orbit are inadequate. This is important because neglecting to enact effective policy that will lessen effects of excessive use threatens our way of life as we know it.

Figure 4: Social Construction of Technology Concept Map Legend. This figure establishes the mapping format implemented throughout the rest of the paper. (Adapted by Raeann Giannattasio (2020e) from W.B. Carlson 2007).



A case study of two social policies under consideration to reduce traffic congestion and space debris will ensue using the Social Construction of Technology (SCOT) framework. According to Johnson (2005), Bjiker & Pinch (1984) developed the SCOT method as a rejection of technological determinism (p. 1792; p. 411). Figure 4 on the left is a concept map legend that helps visualize the application of SCOT. Instead of viewing technological development as a process closed off to the outside world, Bjiker & Pinch (1984) recognized that a variety of social factors influence a technological artifact (p. 423). With this framework, we consider innovation as a two-way street. The double arrows in Figure 4 indicate that the artifact and social group influence one another. Technology shapes society upon implementation, but society also changes the technology. User interpretation of a technology affects its success, where users of a technology with a shared interpretation are defined as a social group. When social groups have differing perceptions of the artifact, this is called interpretive flexibility. Tracking all the social groups, their problems with a technology, and the resulting technical iterations is the SCOT method in practice.

Social policies are considered the artifact in this STS thesis. One policy is congestion pricing, also called road pricing, where cars pay a fee to enter a busy area during peak hours. The funds generated promote efforts to switch away from fuel-burning vehicles (Tirone, 2020, para. 2). The other policy, Orbital Use Fees (OUFs), addresses the space debris issue by putting a price on orbits themselves (Rao, Burgess, & Kaffine, 2020, p. 12756). A SCOT analysis can identify populations these policies neglect. Recognizing inequity in the policies helps steer implementation and regulation in a direction that will alleviate these burdens. In this way, the perspectives of the social groups further refine the artifact.

NAVIGATING CONGESTION PRICING: ARE WE MISSING A STOP?

Scholars have debated whether congestion pricing bolsters or minimizes social justice since before implementation of the policy in the real world. Congestion pricing promotes social justice if the benefits outweigh the consequences for all social groups in society. Foster (1972) published a paper in the *International Journal of Transport Economics* claiming that road pricing benefits low-income residents (p. 135). In response, Richardson (1974) expanded upon the social complexities surrounding congestion pricing (p. 83). Their conflicting papers offer differing perspectives on the relationship between congestion pricing and social justice. In the time since their written deliberations occurred, many cities all over the world have instituted this economic model. Present-day case studies can either confirm or deny the two authors' claims.

Currently, five places use congestion pricing to address their crowded roadways: Singapore, London, Stockholm, Milan, and Gothenburg (Linsey & Santos, 2020, p. 4). After one year of fees to enter 8 square miles of London, congestion reduced by 30% and pollution by 25% (Tirone, 2020, para. 3). This is different from other tolls where most of the money collected is for local road fixes (Lindsey & Santos, 2020, p. 4). This policy has the potential to hinder many social groups. Such groups include, but are not limited to, the middle class, low-income drivers, and non-drivers, as rendered in Figure 5 below.

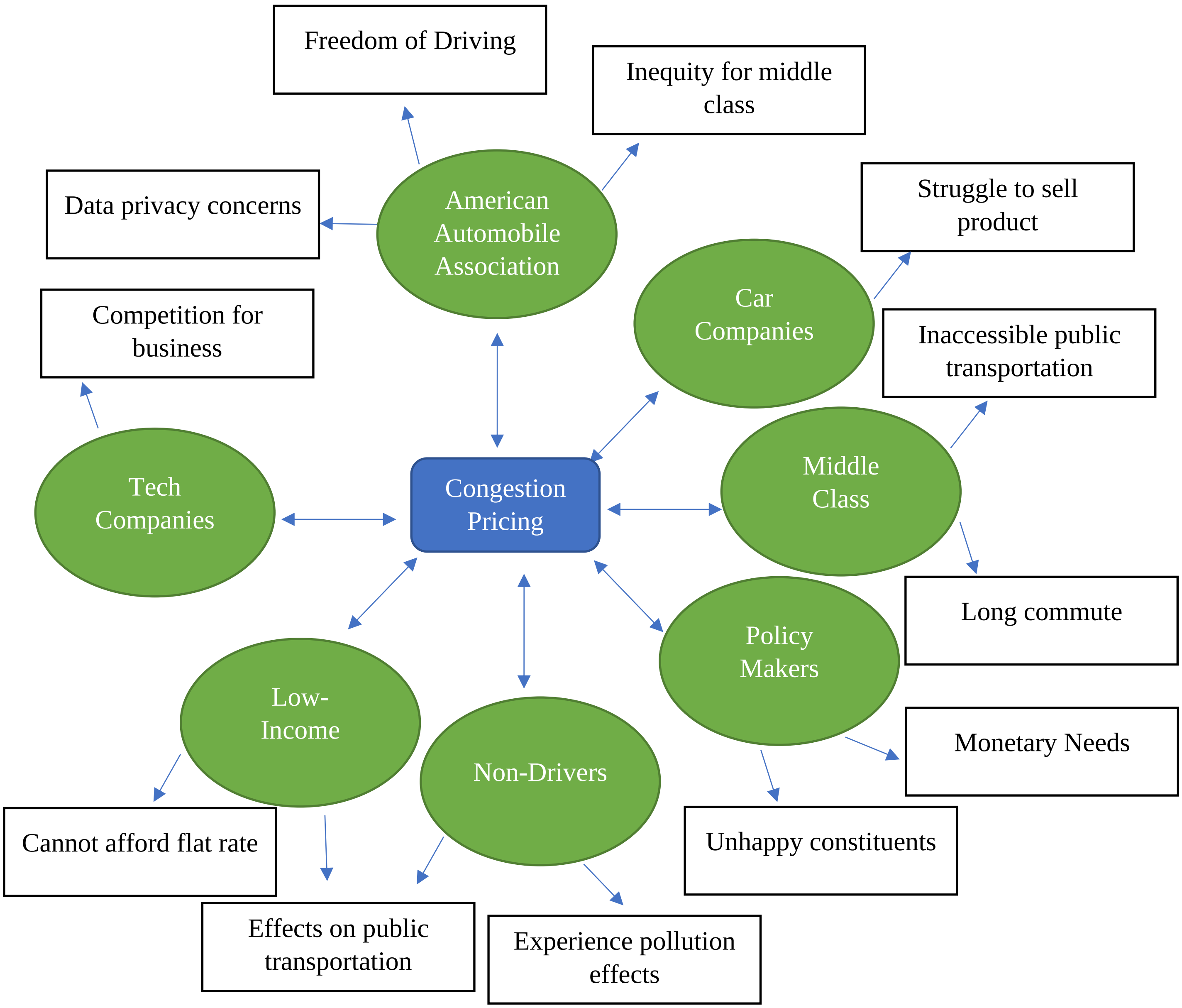


Figure 5: Social Construction of Congestion Pricing. This concept map depicts the different social groups, in green, affected by the artifact, congestion pricing, in blue. Each group's perceptions of the issue are documented in white squares. (Adapted by Raeann Giannattasio (2020c) from W.B. Carlson 2007).

The American Automobile Association (AAA) advocates for social justice on the road. They view driving as a personal freedom that should not require fees. Most tolls are charged by reading license plates, which raises privacy concerns (Tirone, 2020, para. 4). Tirone (2020) shares that the organization claims that the middle class faces unfair financial burden from this policy, since those living in suburbs must drive to the city for work without access to public transportation (para. 6).

While the low-income social group cannot always afford the flat-rate congestion pricing charges, many do not own a car and instead rely on public transportation. Some argue that congestion pricing will improve public transportation, and thus provide help to this group (Cain & Jones, 2008, p. 55). Less obviously, non-drivers are another social group that influence congestion pricing policy. Despite not contributing to vehicle emissions, the global nature of climate change means many non-drivers experience the environmental, economic, and health effects of this waste (Manville & Goldman, 2018, p. 330).

ORBITAL USE FEES: A COVER CHARGE FOR SPACE

Unlike congestion pricing, Orbital Use Fees (OUFs) are a new concept, so there is no current implementation. The economic benefits resulting from a study performed by Rao et. al (2020) are hard to ignore. Compared to Business as Usual (BAU) simulations, OUF models show a potential increase in industry value from $600B to $3T. In 95% of randomly drawn results, satellite industry value under OUF simulations was over four times greater than BAU by 2040 (p. 12757). These staggering numbers simulate starting OUF regulation in 2020. Unsurprisingly, the benefits of OUF diminish as the period of latency increases; inaction until 2025 costs the industry $300B. (Rao et. al, 2020, p. 12757). If such a policy were enacted, the most important consideration is proper regulation. International regulators must maintain orbit pricing, since space is a shared resource. For example, treaties from the United Nations Office of Outer Space Affairs (n.d.) could include this policy (“Treaties and principals”).

However, pricing space in an orbit may harm certain social groups more than others. These social groups and their perspectives on this policy are mapped out in Figure 6. Amateur space enthusiasts and students gain valuable experience form launching small satellite missions known as CubeSats (Larsen & Nielsen, 2011, p. 782). An orbital use fee incurs an additional cost that may be insurmountable to many low-cost CubeSat programs. Similarly, this policy could be a barrier to participation in third world countries with budding space programs (Tuvayanond, 2004, p. 197).

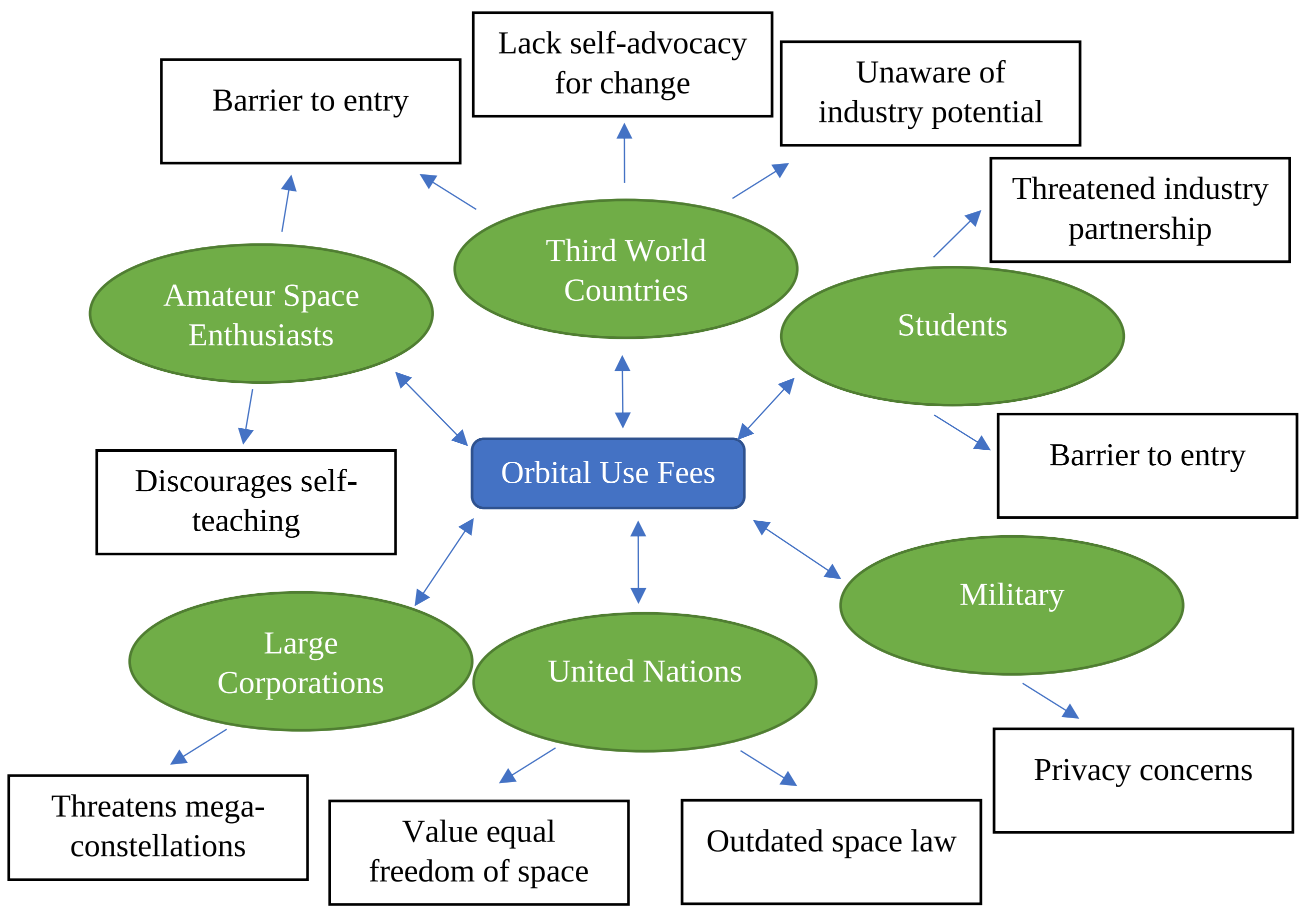


Figure 6: Social Construction of Orbital Use Fees. This concept map depicts the different social groups, in green, affected by the artifact, Orbital Use Fees, in blue. Each group's perceptions of the issue are documented in white squares. (Adapted by Raeann Giannattasio (2020d) from W.B. Carlson 2007).

Yet not all social groups are worried about money. For example, military branches all over the world are concerned about privacy risks stemming from controlling orbit use. This is similar to the American Automobile Association's position on congestion pricing. Governments want to keep certain operations in Low Earth Orbit (LEO) a secret, but it's possible cleaning up space debris would help with that as well. In 2007, China was testing an antisatellite rocket that inadvertently created a massive collision because of the excessive amount of space debris in its path, as reported by the New York Times (Broad, 2007). This one test produced over 800 pieces of space debris, which puts all satellites in danger of collision, including China's own (para. 5). Bridging the gap between satellite technology and space debris policy could help prevent destruction of this scale in the future.

USING DATA INTEGRATION AND SOCIAL POLICY TO REDUCE WASTE

Greenhouse gas emissions and space mission fragments are examples of waste that have detrimental effects on the environment, economy, and health of both a locality and the global population. The real time weather data team is working on a technical solution to mitigate pollution caused by traffic congestion. Through a combination of weather and traffic data, stemming from multiple sources, we hope to decrease weather-induced slowdowns.

Reducing waste is a worthy cause both on the road and in an orbit. Naturally, economists and policymakers propose social policies to combat these two intangible forms of waste. If harmful effects of these policies are identified and corrected before enactment, then society can reduce waste in a way that benefits all. Examining the impact of such policies on various social groups will help establish a more equitable solution by promoting proactive interference.

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