Introduction

Why are bicycle crashes so prevalent in the United States?

When considering the statistic that 846 bicyclists were killed in car crashes in 2019 in the United States alone, it is unsurprising that more people do not become cyclists (National Highway Traffic Safety Administration, 2019). A survey of potential cyclists showed that risk of crash is the highest deterrent from using cycling as a means of transportation (Useche, 2019). The number of bicycle-car collisions in the United States is a pressing issue with several compounding causes. On the individual level, there is a lack of preventative safety technology to provide cyclists with advanced notice of collision risks. On the societal level, cities in the U.S. are designed for cars (Norton, 2008), meaning that bicycles are systemically overlooked when engineering traffic flow for safety. The technical capstone submitted with this prospectus will address the lack of bicycle collision notification systems in the market by designing and prototyping a device to alert cyclists of cars approaching from the rear. The Science, Technology, and Society (STS) portion of this capstone examines roundabouts as a specific infrastructural technology which—despite being designed for traffic safety—adversely impacts bicycle safety. Taken together, the technical and STS portions of this capstone reflect a larger systemic problem: U.S. traffic infrastructure, because of its overwhelming focus on automobiles, creates an ecosystem that harms and even kills cyclists.

Sentinel: A solar-powered device to alert cyclists of cars approaching from the rear

How can technology impact bicycle safety at an individual level?

The technical deliverable for this capstone is developed in collaboration with Brandon Brnich, Julia Graham, Julia Rudy, and Rex Serpe and will be submitted to Professor Harry Powell of the Electrical and Computer Engineering Department.

If one were to google “bike safety technology” one would find numerous articles talking about ways to keep cyclists safer but existing technology is largely reactive rather than proactive. Existing bike safety technology can be divided into three categories: prevention of injury from bodily strain (goggles, heart rate monitors, etc.), reaction to crashes (better helmets, tracking devices), and prevention of automobile user error. While the last of these categories is an important factor in preventing crashes, there is a lack of technology that allows bicyclists to avoid crashes by providing advanced notification of collision risk. The finished product, *Sentinel*, enables cyclists to proactively protect themselves by notifying them of cars approaching from the rear as they navigate an ecosystem that was not built for them.

At the time this paper was authored, The Garmin Varia™ (Garmin, 2020) was the only device readily available to notify cyclists approaching from the rear. The Varia™ pairs with a trip computer, smartphone, or smartwatch to provide cyclists a visual depiction of cars behind the bike (Norman, 2020). The Varia™ has two noteworthy areas for improvement. First, the display provides more information than necessary to react to a possible collision. Extraneous information only increases processing time before reacting to a potential collision and decreases the overall effectiveness of a collision prevention system. Second, the Varia™ is powered by a wall charger. Given that a major encouraging factor for cyclists is environmental sustainability (Useche et al., 2019), they would likely prefer a bicycle safety device powered by renewable energy.

Sentinel will address the issues with the Varia™ by using a solar-powered, intuitive light display to notify cyclists of cars approaching from the rear. Feedback from end-users will inform the development of notification signals consistent with human intuition and providing no more information than necessary to act to avoid a collision. The system will be able to generate enough solar energy to power the system for nearly all commuting use cases. Sentinel utilizes several distinct technical components whose configuration and key interfaces are summarized in Figure 1.

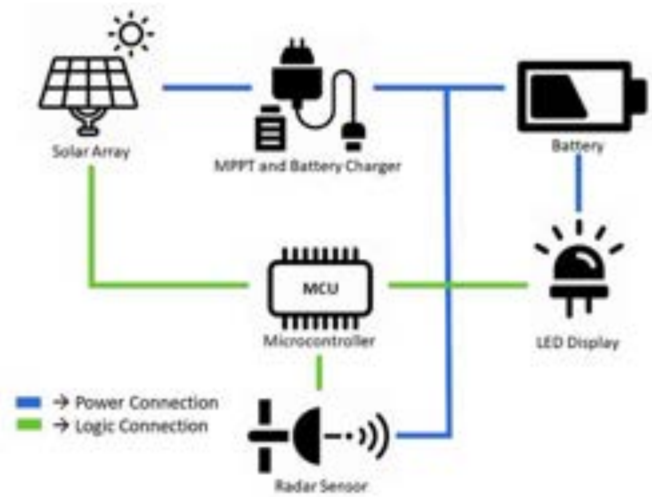

Figure 1. System Block Diagram showing its major technical features and their interfaces

To detect approaching cars, an OmniPreSense OPS243-C-FC-RP radar sensor (OmniPreSense, 2019) is mounted behind the bike. An MSP430F5529 microcontroller (Texas Instruments, 2020) reads data from the radar sensor via UART interface to gather information on vehicle speed and direction (inbound/outbound). As a car approaches a cyclist from behind, a series of LEDs mounted on the handlebars of the bike alerts the rider.

A ~2 m wiring cable is routed from the back of the bike to the handlebars to provide power and control signals to the LEDs. All mounts for the electronics are 3D printed. As the radar sensor uses a 24 GHz transmitter, it can be placed behind plastic for weatherproofing and still function as expected. The placement of the display is shown in Figure 2.

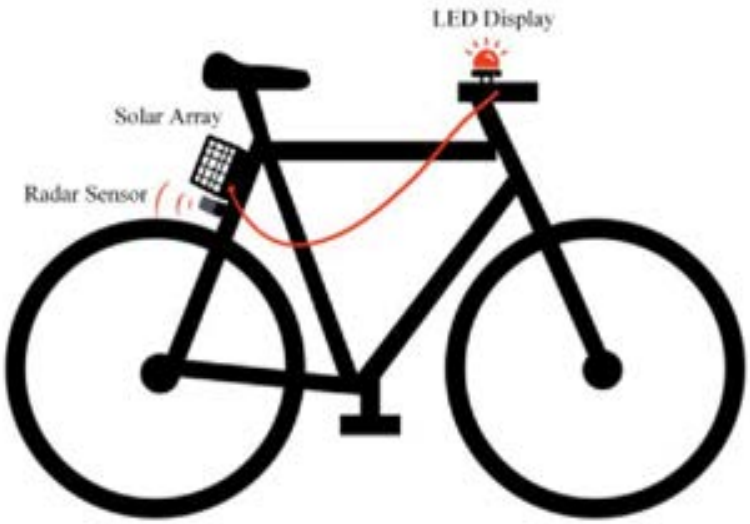

Figure 2. System Placement on Bicycle

A maximum power point tracker (MPPT) control system is used to efficiently charge a battery using a 10W Renology solar panel (Renology, 2015). The battery is composed of 2 lithium-ion 18650 cells (Great Power, 2018) combined to produce a final nominal voltage of 7.4V. The battery, in turn, powers the LED display, microcontroller, and radar sensor. The worst-case power draw for these three components was measured to be 2.3W. Power budget calculations show that under worst-case (midwinter) solar irradiance conditions in Charlottesville our system will collect over an hour's worth of energy from our solar panel. Based on an ~20 minute average bike-commute length (McLeod, 2014), this solar panel will generate enough energy to power nearly all commuting use cases.

Sentinel empowers cyclists to react to potential collisions before they take place but, admittedly, does not address the deeper societal issue that traffic infrastructure is designed to disadvantage cyclists. Given that traffic infrastructure in the U.S. is designed for cars (Norton, 2008), promoting bicycle safety on a systemic level will require looking examining how individual traffic control technologies impact bicycles in-practice. Only after traffic is analyzed with bicyclists as essential actors can cycling be made safer at a structural level. Before the time comes when cycling is systemically embedded in infrastructure design, Sentinel will provide functionality essential to improving bicycle safety in a car-centered society.

Invisible and Broken: Roundabout Impact on Bicycle Safety in the U.S.

How can technology impact bicycle safety at a societal level?

Roundabouts in the U.S. are marketed by government agencies as a safer traffic intersection for cars, bicycles, and pedestrians (Federal Highway Administration, 2020). The safety features they cite, however, are the same safety features found in a cross-cultural literature review of roundabouts to correlate to an increase rather than a decrease in bicycle crashes (Poudel & Singleton, 2021). Enacting structural change to protect bicyclists depends on fully understanding the factors that negatively impact their safety. This STS thesis will explore the impact of roundabouts on bicycle safety by uncovering the overarching principles governing U.S. traffic networks, detailing the specific role of roundabouts within those networks, and empirically examining the link between roundabout prevalence and bicycle safety.

Description of foundational STS frameworks

This STS thesis uses two frameworks to examine the effects of roundabouts on bicycle safety. Actor Network Theory (ANT) (Latour, 1992) is used to understand traffic in the U.S. as a network of human and non-human actors that can discriminate against bicyclists. The Ethnography of Infrastructure framework (Star, 1999) is used to understand the essence and impact of roundabouts as infrastructural artifacts. The combination of these two frameworks allows us to characterize roundabouts as non-human actors and evaluate their interactions with other actors in the larger traffic network.

ANT Analysis of traffic history

Latour's (1992) definition of Actor Network Theory provides an analytical framework that can be used to describe how traffic infrastructure in the U.S. evolved to prioritize cars. ANT places human and non-human actors on the same plane of morality wherein non-human actors can hold moral values and prescribe human behavior much in the same way that humans are assumed to do. ANT breaks apart interaction between human and nonhuman actors into several distinct categories including programs of action, prescription, and discrimination. In ANT, a *program of action* is an installation of values within technology through delegation of process or function. *Prescription* describes the way in which non-human actors push human actors to behave within a sociotechnical system. *Discrimination* is the result of a translation of values which rigidly prescribe human action which consistently and adversely affects specific groups of people. Programs of action, prescription, and discrimination can all be identified in a historical examination of U.S. traffic infrastructure.

Peter Norton's (2008) book *Fighting Traffic* provides a historical analysis of U.S. cities as they evolved to place cars at the forefront of traffic design decisions in a process consistent with Actor Network Theory. The relationship between Norton's narrative of traffic evolution and ANT is summarized in Figure 3. Norton writes that, prior to the advent of the "automotive city" (Norton, 2008, p. 1), streets were public utilities wherein children played, horses rode, and only the occasional car passed. In the 1920s, however, traffic engineers shifted from believing in public interest to holding "efficiency" as their guiding principle, placing a monetary rather than human-benefit value of the efficacy of the system of city streets (Norton, 2008, p. 105). This shift in cultural values necessitated a *program of action* that centered cars in roadway design through delegating the responsibility of efficient commercial development to car mobility. The inherent danger of cars to pedestrians based on physical size meant that—even before the responsibility of avoiding crashes was delegated to pedestrians by law—traffic systems *prescribed* pedestrians give way to cars for their own safety (Norton, 2008).

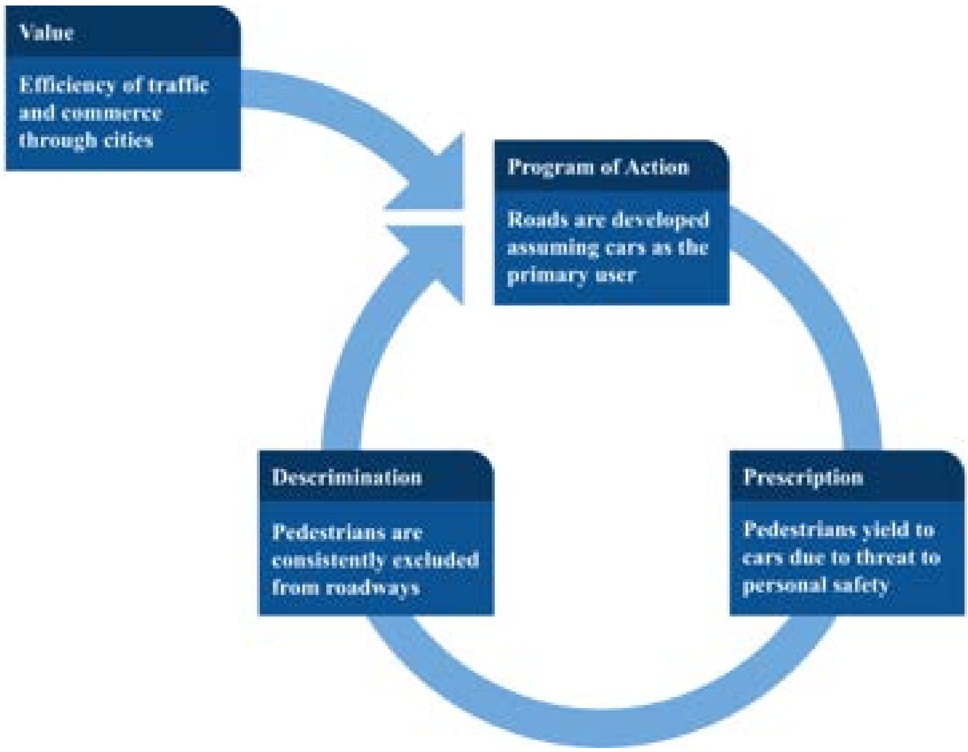

Figure 3. ANT characteristics of the evolution of U.S. traffic infrastructure

The programming of values which dictated that cars should have free movement through cities and the safety necessity prescribing pedestrians give way to cars eventually culminated in Jaywalking laws that codify the *discrimination* against pedestrians in traffic (Norton, 2008) which, in turn, cements the belief that roads are meant for cars.

Ethnography of infrastructure analysis of roundabouts

Roundabouts, as non-human actors in the U.S. traffic network, have the capacity to both embody design values through *programs of action* and prescribe behavior that can discriminate against human actors. When roundabouts are designed within U.S. traffic infrastructure, they carry the same values as the rest of the system (Figure 4) and can be characterized through Star's (2009) Ethnography of Infrastructure framework.

Figure 4. Relationship between roundabouts, U.S. traffic infrastructure, and the scope of this STS thesis

Embodiment of standards, links to practice, and *visible when broken* are all facets of infrastructure that Star identifies as describing the mechanisms by which infrastructural actors interact with the rest of their network. In Star's framework, *embodiment of standards* describes the way that infrastructural artifacts—e.g., roundabouts—reflect the values of the society in which they function. *Links to practice* is Star's way of saying that the function of a piece of infrastructure is defined by how it is used in practice. In the scope of this paper, *links to practice* means that the contribution of roundabouts to traffic safety should be judged by their real-world impact rather than the intention driving their construction. This evaluation of a piece of infrastructure is often forgotten until it does not perform as designed because, as Star puts it, infrastructure is only *visible when broken*. When considering roundabouts, it is important to consider that their brokenness is defined with respect to the value of car-centered design so, when interacting with bicycles, they may be both invisible and broken.

Can roundabouts be empirically linked to higher rates of bicycle crashes across the U.S.?

Poudel and Singleton's (2021) study only includes two roundabouts from the U.S. so, because infrastructural artifacts are linked to practice and an embodiment of the standards held by their environment, it is not safe to say that the results from their study will necessarily translate to the United States (Figure 5). Addressing the impact of roundabouts on bicycle safety begins by making visible the fact that they are broken so this research will answer the question: can roundabouts be empirically linked to higher rates of bicycle crashes across the U.S.?

Figure 5. Relationship between U.S. traffic infrastructure and STS research question

How will the link between roundabouts and bicycle crashes be examined?

I will examine the link between roundabout prevalence and bicycle crashes in the U.S. by measuring the statistical correlation between them. I will aggregate publicly available data to measure the number of roundabouts per intersection and bicycle crash rates in each state. Once the data is collected, I will use computational data science and visualization methods to measure the correlation between the two variables.

For this research I will collect three types of data: roundabout prevalence, car-bicycle crash counts, and bicycling prevalence. Erin Davis (2020) has already demonstrated that it is possible to enumerate the number of roundabouts per intersection for any given city in the United States using the R programming language (R core team, 2020) and open-source data. The National Highway Traffic Safety Administration (2019) has publicly available data on both fatal and non-fatal car-bicycle crash statistics that includes information on whether or not the collisions took place in intersections, and where the car made contact with the bicycle. The United States Census Bureau (2020) provides data on bicycling rates through its measurement of transportation method prevalence. These data will allow me to conduct meaningful analysis between states by normalizing crash statistics by bicyclist prevalence.

I will analyze the data I aggregate using Python and its associated packages (Python Core Team, 2021). I have chosen Python both because I have enough experience with the language to feel comfortable using it for multivariate analysis and because I have identified several packages to aid in extracting, interpreting, and visualizing data. The numpy (Harris et al., 2020) and pandas (The pandas development team, 2020) (McKinney, 2010) packages will be used to extract data from excel and csv file formats and perform statistical correlation. The census package (Gregg & Carbaugh) will be used to query the United States Census Bureau's (2021) data API to gather data from its publicly available databases. The matplotlib (Hunter, 2007) GeoPandas (GeoPandas Developers, 2021) packages will be used to visualize analyses of the data.

This research will be split into three phases: data aggregation, data analysis, and interpretation of results. Data aggregation will include querying datasets for bicycle crash statistics and replicating Erin Davis's (2020) work of counting roundabouts per intersection using Python. Data analysis will include creating composite variables such as "bike crashes per regular bike commuter" for each state and correlating bike crash variables with roundabout prevalence. Interpretation of results will include determining which states provide statistically significant information, visualizing the data to summarize key finding, and documenting findings and recommendations for future research in my STS thesis. I estimate that each of these stages will take three weeks to complete, allowing for the submission of my thesis by the beginning of Spring Recess on March 5th, 2022.

What can be learned from the link between roundabouts and bicycle deaths?

The car-centric design philosophy of U.S. traffic systems harms cyclists by failing to explicitly consider their safety when building infrastructure. Protecting the lives of cyclists depends on identifying major infrastructural contributors to bicyclist injury and death so traffic systems can be re-designed with bicycle safety at the forefront. My research will show, at the very least, that roundabouts must be examined more closely as potential threats to bicycle safety. Until roundabouts can be definitively linked to bicycle injury and fatality in the U.S., the human actors that build cities will sit complacent in the values that have dictated their work for the past century. My research will provide essential information for beginning to reconsider roundabouts for the protection of cyclists' lives by making their brokenness visible.

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Sentinel: A Solar-Powered Device to Alert Cyclists of Cars Approaching from the Rear
(Technical research project in Electrical and Computer Engineering)

Invisible and Broken: Roundabout Impact on Bicycle Safety in the U.S.
(STS research project)

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Electrical Engineering

By
AJ Cuddeback

November 1, 2021

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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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