Project description; Collaboration of faculty, students, and licensed professional engineers; Protection of health, safety, and/or welfare of the public; Multidiscipline and/or allied profession participation; Knowledge or skills gained.

Project Description:
While many cities outside the United States have seen improvements in reduced traffic deaths in the last five decades, most American cities have been regressing in the past several years (Zipper). This is in large part because American cities have failed to widely adopt infrastructure such as protected bike lanes and traffic calming, which are the norm in many European cities and are proven to be associated with a significant reduction in vulnerable road user death. Data on cars and people using the same space as cars, like pedestrians or people using bicycles or scooters, can be difficult to obtain.

Our design project, called the Bike Walk Census Tool, addresses the lack of data on non-vehicle road uses by automating the data gathering and processing. The Bike Walk Census Tool is a machine-learning (ML) based solution that consists of two parts: a video recording device, which can be installed anywhere and is powered by a solar panel and battery pack to enhance recording longevity, and a separate device running an ML model for automatically counting traffic in recorded video. It is temperature- and weather-resistant, modular, and can record video at all times of day with minimal to no user input. All processing is done on a separate computer supplied by us (or a user's personal computer) to reduce our cost of production to just over $500 per recording device.

Project Background:
Our state's engineering metrics for intersection and road design place significant emphasis on annual average daily car traffic, or AADT ("Traffic"). In the Town where our college is located ("the Town"), cars are counted every 1-3 years depending on the street for up to two weeks at a time, while no universal or regular count for bicyclists and pedestrians exists (Chamberlain). The Town has completed sporadic manual counts of these groups before, which involves recruiting either a volunteer or a paid worker to spend hours counting the number of people or bikes crossing a specific line through a path. Unfortunately, the amount of time this method takes makes it difficult to complete regularly, and the data is subject to errors inherent with human inspection methods (Kulbacki). Due to this lack of high quality data, traffic engineers in the Town prioritize vehicle throughput over the pedestrian and biking experience. This leads to a negative cycle in which fewer vulnerable road users (i.e., pedestrians and those using non-powered wheeled transportation modes) opt for these methods of transportation, resulting in more drivers, and ultimately justifying more car infrastructure at the expense of safe design for other transport modes.

The members of the Town Bike Walk committee (TBW) are attempting to reverse this trend at a local level. The purpose of the TBW is to inform the Town Planning Commission and the public on walking and biking related issues and advocate for the construction of safe and equitable pedestrian and bicycle infrastructure. Gathering pedestrian and cycling data is an area of interest for the town because it has been proven to be effective in the implementation of infrastructure. In places from Delaware to D.C., counts of users from before and after pedestrian and bike infrastructure installation, such as a buffered bike lane, facilitated the project's approval, proved the success of the project, and spurred further development (Ryus). Furthermore, these infrastructure changes do make a tangible difference in modal shift: studies replicated nationwide show that an estimated 66% of the urban U.S. population would bike regularly if they felt it was safer, easier, and more accessible to do so (Acker). The TBW tasked our senior design capstone team with creating a method that would automate the collection of data to improve the Town's planning efforts for non-car road users.

Project Approach and Collaboration of Faculty, Students, and Licensed PEs:
To begin our design, we first developed specifications with the help of the TBW, the Town's zoning and code director who is a primary user of our device, our capstone project advisor and course directors (both of whom are PEs) and two consulting engineers who are passionate about the concept of "complete streets" as a framework for designing safer, more inclusive environments. To ensure progress toward meeting these specifications, we established certain collaborative norms: We met weekly with our engineering technical adviser who is a licensed PE and is a faculty member at our college's school of engineering. We also met weekly with our sponsor. We met monthly in a mix of zoom and in-person meetings with various Town employees, members of the regional planning commission, and transportation planners. Finally, we gave a presentation of our design and test results, including a tutorial on how to set up our device, to the TBW and other Town staff engineers (including PE's). Our specifications are summarized below.

Number	Specification
1	The ability to count at night as well as during the day. Human counters typically prefer counts during commute and work hours from 6 AM to 6 PM (Josephson), which leaves out a dangerous time period (twilight hours from 6 PM to 9 PM) for vulnerable road users. This is when the most vehicle and bicycle/pedestrian collisions occur (United States).
2	Ease of use and convenience. Count data should automatically be recorded in an electronic format that is easily accessible through common data analysis software, with setup of any data collection methods as easy as hiring a manual counter and setting up a chair. We quantified this specification by allotting 15 minutes each for study setup, study teardown, and analysis setup.
Longevity and durability in the outdoors. Any counting method must be able to count continuously for up to 72 hours at a time. Current annual motor vehicle volume counts use pneumatic tubes for 3-4 day stretches by the Regional Planning Commission for the state Department of Transportation, but walk and bike studies are typically under 24 continuous hours (Chamberlain). We aim to match or outperform this continuous timespan of counts to level the playing field across modes. This, of course, brings related sub-objectives including:	
3A	Counting within commonly expected weather (excluding extreme weather scenarios).
3B	Counting at all times of day, as stated in secondary objective (1).
3C	Ease of maintenance in any solution produced by us, necessitating less than one day's worth of maintenance per year, and more than 24 hours required between checkups while a study is running.
4	Accuracy that is within a ±10% margin of error of manual counts, especially in categorization of road users and in heavy traffic scenarios. Accuracy is paramount to collecting good data, as the data may then be compared to motor vehicle counts and prior pedestrian and bike counts done by the same method.
5	Flexibility in where counts are able to be conducted. Any counting solution should be able to count at nearly all locations, regardless of the lack of attachment sites, terrain, and availability of grid power.
6	Low cost compared to manual counts and current market solutions. One prototype solution should be within our project budget of $1,500.
7	Documentation of the design, operation, and maintenance of the counting solution.
We have additionally identified tertiary objectives for our users that we classified as stretch goals, in order of priority and usefulness to our users:	
8	Fine-grain road user classifications, including distinctions between bicycles and scooters as a high priority.
9	Place use patterns, including heatmaps of person-minutes spent in locations and street travel direction.
10	An intuitive and easy to use front-end interface for analyzing and presenting data.
11	Make more than one counting device with the allotted $1,500 budget.
12	Speed measurements for non-pedestrian road users, including bicycles.
13	On-device real time count processing.

Table 1: Specifications for our device design

Numerous solutions have been developed for counting automotive traffic, so we explored existing methods to understand their strengths and limitations with regard to our specifications. Examples we did not ultimately pursue include:

1. Manual Counting
    a. Manual counting involves a person watching an area and recording how many of a given type of road user pass through. It can also be done via video recording. Manual counts are widely considered to be the standard for accuracy in short-term studies and the specificity of data that can be collected (Ryus 77). The main drawback of this method is that it is very time consuming and labor-intensive, and that people can make mistakes when tired, which we have found to be the case when doing ground truth counts on our own.
2. Pneumatic Tubes
    a. Pneumatic tubes are the most common method for counting cars in the street. This method is limited for our use case in that it could only be used to count cyclists since a significant number of pedestrians would likely step over the tubes (Ryus 86, Nordback).
3. Passive Infrared
    a. Passive infrared devices compare the infrared signatures of a person passing by to the background infrared radiation to count pedestrians and cyclists. This technology cannot differentiate between pedestrians and cyclists and it is limited to narrow, defined paths for only pedestrians and cyclists (Eco-Counter Mobile-MULTI).
4. Inductive Loop Detectors
    a. A permanent solution for counting bicyclists are loops of wires that are either embedded in or laid on top of the pavement. Their drawbacks include challenging installations, lack of pedestrian counting ability, limited coverage area, and accuracy issues on mixed-use roadways.
5. Location Services Data Collection
    a. Companies like Streetlight Data use massive repositories of app-based location data to create heat maps of certain roads and trails. This introduces ethical and privacy concerns, and makes the data very expensive, costing upward of $50,000 per year (City).

Then, we turned toward the only implementation which appeared to possibly fulfill all of our specifications simultaneously, which were camera-based systems. Two current competitors in this space are:

1. GridSmart
    a. The Town of Hanover owns a few GridSmart camera units (see Appendix (13), (14)). It is primarily designed to control traffic lights and count traffic volumes. It can only be installed at traffic light intersections, is not portable, and costs $25,000 per unit. This recently manifested a $40,000 repair bill when two of the town’s units broke because they lacked surge protectors.
2. Miovision
    a. The next solution we looked at was Miovision, a portable system. Although a bit cheaper at $6,121.25 (see Appendix (15)-(17)), this price is still too high for the

Hanover Bike Walk Committee to spend. It also costs $27.26 per hour to manually verify bike/pedestrian accuracy, which means more than $3000 for a week-long study.

Observing the limitations of the potential alternatives, and determining where our competitors using machine-learning based solutions came up short, we built our own machine-learning based solution that consists of three parts:

(1) A portable camera-based recording device, which will be installed near the area the user would like to count traffic in, powered by a solar-based power supply provided by the Town of Hanover.
(2) A device running software with an ML model for automatically counting traffic in recorded video.
(3) Documentation including build instructions, a user manual, and a QuickStart guide.

Project Design, Testing and Results

The Bike Walk Census Tool solution was able to meet all of our specifications with some minor modifications that we clarified with our sponsor throughout the process, in addition to some stretch goals. Power for the device is provided either by an internal portable battery pack or by a 12V power supply (PSU) and solar panel. This solar PSU setup is the type used for crosswalk lighting and is able to withstand any weather conditions while providing adequate power for our device. We initially considered performing on-device processing of camera data, but found that off-device processing would be a more flexible approach due to the decreased power draw required, as well as reducing the cost and complexity of the recording device. Instead of doing on-device counts, the Raspberry Pi runs the recording script and web application and determines lighting changes throughout the day to swap between cameras in order to keep the video recording as clear as possible.

Figure 1: Two team members performing field testing with Prototype 1 of our recording device

We built and tested three prototypes of our recording device. The first prototype was assembled January 19th, the second prototype February 15th, and the third prototype at the very end of the term on March 11th for handoff to our sponsor.

Raspberry Pi 4 Model B (4 GB RAM)	HangTon HE21 2-Pin Circular IP68 500V 30A Plug

USB A to SD Card Adapter	¼ inch x 20 tpi Tripod Pan Tilt Adapter
6.1 x 5.3 inch IP67 Boxco ABS Clear Front Enclosure	8 ft. Camera Tripod
2 x 64 GB Industrial SD Card (Kingston SDIT)	VEEKTOMX 10,000 mAh USB-C Battery Bank
1080p 5MP OV5647 Sensor Infrared Fisheye RPi Camera	Generation 1 PCB w/ PCB components
Apple AirTag	First-generation custom 3D-printed camera mount

Table 2: Prototype 1 Primary Components

11 x 7.5 inch IP67 Boxco ABS Clear Front Enclosure	VEEKTOMX **30,000** mAh USB-C Battery Bank
ELP 5MP OV5640 USB 2.0 Daytime Camera	**Generation 2** PCB with upgraded component**s**
¼ inch x 20 tpi Tripod **Ball Joint Adapter**	**Second-generation** custom 3D-printed camera mount
13 ft. Light Stand Tripod	**6W 12V Infrared Spotlight**

Table 3: Prototype 2 Components (Changes only)

Prototype 2 was designed to run longer outdoor tests, achieve better counting accuracy, and provide us with the ability to implement nighttime counts.

Raspberry **Pi 5**	**Generation 3** PCB with upgraded components
USB-C Dual Right Angle Power Cable	**Third-generation** interior 3D-printed component mounting system and exterior tripod-enclosure mount
1080p 5MP OV5647 **Sensor Fisheye RPi Camera G**	

Table 3: Prototype 3 Components (Changes only)

Prototype 3 builds on Prototype 2 by replacing the Raspberry Pi 4B with a Raspberry Pi 5, allowing us to use two native CSI-2 cameras rather than mixing CSI-2 and USB video feeds. This greatly simplifies the recording process, and allows us to take advantage of the Raspberry Pi's ability to encode H.264 video. These improvements ultimately result in reduced power consumption and smaller video sizes, as well as finer control over each camera's behavior. The revised circuit board for this prototype fixes an issue we had with the real time clock, and also solves the problem of powering the Raspberry Pi 5 as it is capable of drawing a significantly higher peak power than our previous Pi 4. This circuit board moves from using DC/DC converters for stepping down the external battery's 12V to the 5.1V that the Raspberry Pi uses to a custom switching power supply, allowing us to reach 95% efficiency when supplying the 6 amps that the device can draw. At the time of building this device, Raspberry Pi 5 availability is not always guaranteed, so all of our components and software are still compatible with the previous Raspberry Pi 4B, giving users flexibility in terms of component choices.

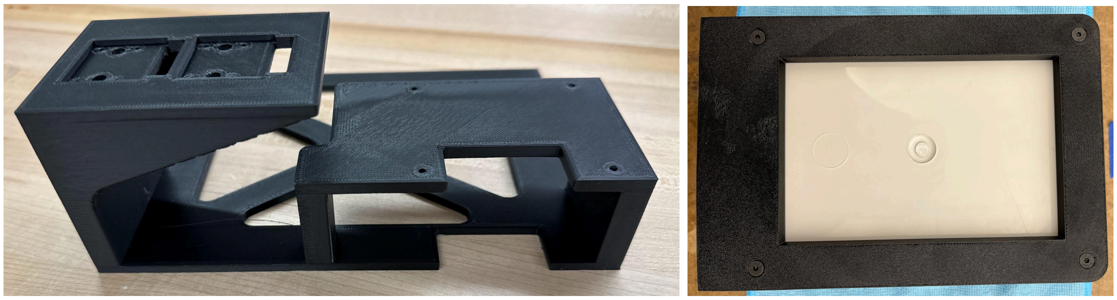

Figure 2: Final iterations of interior (left) and exterior (right) mounting system

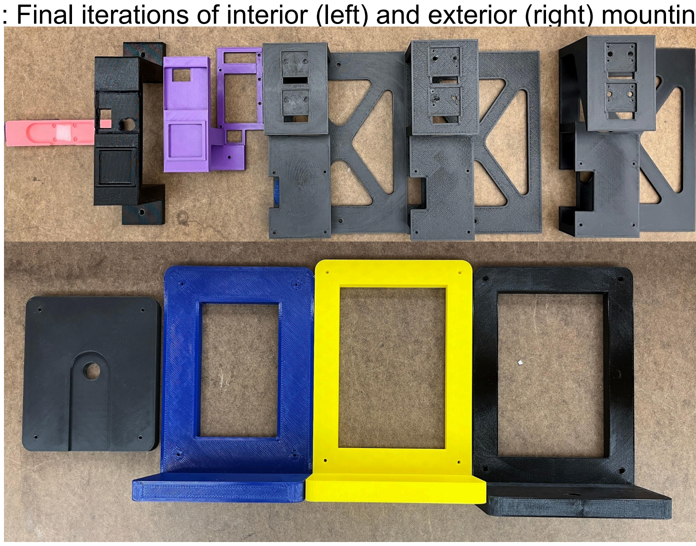

Figure 3: Iterative progression of internal (above) and exterior (below) mounts

Both the external mount to attach the enclosure to the tripod and the internal mounting system for arranging the components as neatly as possible within the waterproof enclosure have gone through several iterations, as shown in Figure 3. The internal mount for Prototypes 1 and 2 was simply a basic rectangular slab that rested the camera(s) on top of it and used friction fitting to ensure minimal motion. However, most of the other components were loose within the device, which was not ideal for long-term system stability. To solve this problem, we iteratively designed a comprehensive internal mounting system, where the components are well-organized, secure, and easily accessible for repairs. The external mounting system similarly went through a few iterations as we increased our enclosure size. The tripod attachment screw initially threaded directly into the plastic of the mount, but this was unsuitable for our larger, heavier enclosure, so we added a heat-set threaded insert to increase the durability of the mount. We designed each iteration in common industry tool SolidWorks and used 3D printers in our engineering school's machine shop to create the part.

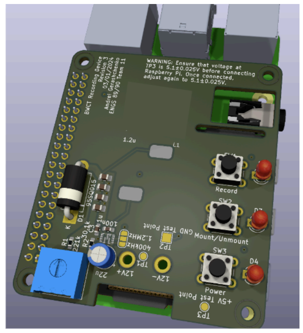

Figure 4: CAD model of Prototype 3 Recording Device PCB and Raspberry Pi.

Through testing, we evaluated the performance of both cameras, both portable batteries, video storage, the solar panel power supply, and nighttime camera. We found that the portable battery enabled an average runtime of 6.5 hours, thereby providing us an estimated minimum of 15 hours of runtime with our new 30,000 mAh prototype battery, which we confirmed in our 21st recording shown above. With the solar panel power supply, we lasted an entire night, allowing for perpetual recordings up to our storage capacity since the solar panel is able to fully charge the 12V battery over the course of a day at 30W. These tests confirm that our device meets specifications (1) and (3), night counts and longevity/durability outdoors. In addition, the wide variety of locations we were able to record to show our device meets specification (5), portability. Two key target users were able to set up and teardown the recording device in less than 15 minutes after only reading the instructions once. This feedback showed that the recording device meets specification (2), ease of use and convenience, and additionally gives us valuable information on what aspects of the device to prioritize in order to continue to have a positive user experience.

If the user has a phone available, they can connect to the recording device's WiFi network and open http://bwct.local to bring up the web app. When using this feature, the internal buttons continue to work normally, giving users the ability to interact with the device in any way they choose at any time. Once this is done, users are presented with a camera preview to frame their shot and start/stop the recording from a distance. They can also use the web app to see how long their current recording is, and can use it from a distance of up to 50 feet from the device.

Ethical Considerations

With a device as multifaceted as ours, there are numerous societal contexts in which we must consider the way the device impacts people. State law does not criminalize the use of recording devices in areas where there is no feasible expectation of privacy, so our device is legal. However, what we decide to do with the footage of crimes, accidents, and emergencies has the potential to significantly impact individual privacy, legal proceedings, and public trust in our device. Considering that the device is just like any other commercially available video recording device like a security camera, the user of the device is to be the sole decision maker of footage distribution and should promptly dispose of it after processing if there are no other uses for it. Exceptions could be made for cases where the footage is needed for further analysis, such as before and after comparisons of place use activity, and in the aforementioned cases where it is to be used for law enforcement and judicial purposes (Chamberlain). We created a brief set of written circumstances in our product documentation as to what footage can be shared.

We also have ensured our identification models have no harmful biases against particular users. During the training of our ML model, we have incorporated diverse dataset annotations to ensure all groups are fully represented and accurately classified. Although pedestrians outnumber other classes including wheelchairs, our ground truth counts show that within the Town, the other data classes are still greatly overrepresented by our dataset, making our model inclusive and unbiased. Given the difficulty of detection in low-light conditions, we chose YOLO-v8 as our model to emphasize shape recognition as compared to color-based feature recognition as implemented in other state of the art detection models.

Lastly, we have kept sustainability in mind as we designed our device, most directly by extending the life cycle of our product by reducing material consumption and disposal. To do this, the device can easily be assembled and disassembled, providing upgradable replacement parts as needed.

Multidiscipline and/or Allied Profession Participation

This project succeeded with the help of professional engineers; faculty in our engineering school across the disciplines of mechanical engineering, computer engineering, and electrical engineering; consulting engineers who plan transportation projects professionally; regional planning board members; Town staff who manage and implement transportation design projects locally; and the Town Bike Walk committee members who comprise a diverse group of individuals in our Town’s community.

Knowledge or skills gained

Our project helped us to improve our knowledge and skills in the following areas:

- Machine learning and artificial intelligence methodologies,
- Transportation planning,
- PV design,
- Ethical considerations in design and technical communication,
- Prototyping,
- Statistical analysis,
- Design for usability and accessibility,
- Additive manufacturing,
- Technical communication,
- Civic engagement, especially as engineers.