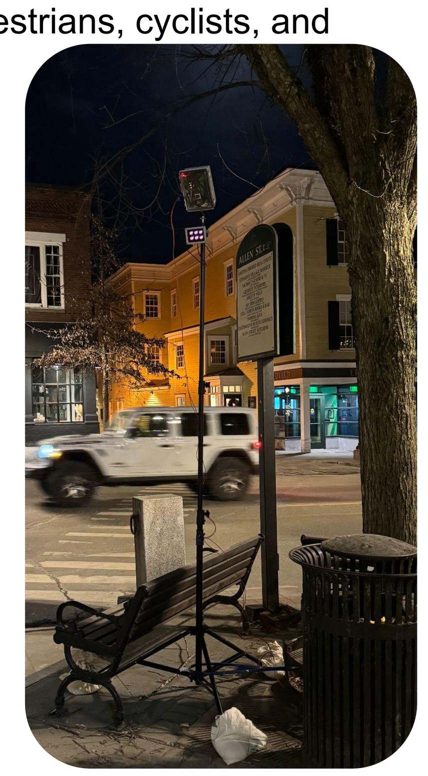
Bike Walk Census Tool Designed for More Inclusive Transportation Planning in College Downtown

INTRODUCTION AND DESIGN SUMMARY

Anyone who has spent time as a pedestrian in the United States knows the feeling of being on an unsafe and unpleasant street with cars whizzing by. In the town in which our college is located (“the Town”), this unease is a result of a deliberate planning choice resulting from a century of traffic engineers changing the physical landscape to favor cars over people. While cars are counted to gauge road usage patterns automatically every three years (or more frequently) for up to two-week periods, pedestrians and cyclists are only counted sporadically under a tedious manual counting process that can be subject to errors. Shifting the focus from cars by automating counts for vulnerable road users (i.e., pedestrians, cyclists, and those who cannot drive due to ability or economic status) will help the Town and planning engineers create more pedestrian and cycling friendly spaces that are safe and welcoming to those of all income and ability levels.



Our device is called the **Bike Walk Census Tool.** It 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 device.

CONTEXT AND ETHICS CONSIDERATIONS

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). While the Town has completed sporadic manual counts of these groups, 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). 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.

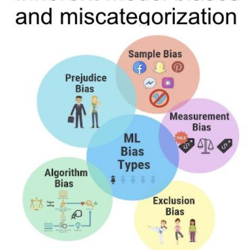
Our device requires ethical considerations related to privacy and bias. State law does not criminalize the use of recording devices in areas where there is no feasible expectation of privacy, so our device is legal. Considering that the device is just like any other commercially available video recording 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 cases where it is to be used for law enforcement and judicial purposes. We created a brief set of written circumstances in our product documentation as to what footage can be shared.

ML Model Bias

Concern: Inherent model biases and miscategorization

Solution: Custom model with inclusive datasets



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.

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.

Counting → Planning→ Including

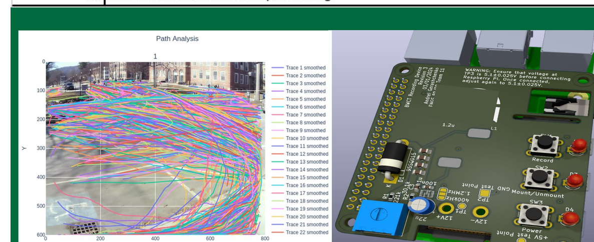
DESIGN SPECIFICATIONS & PROTOTYPE DEVELOPMENT

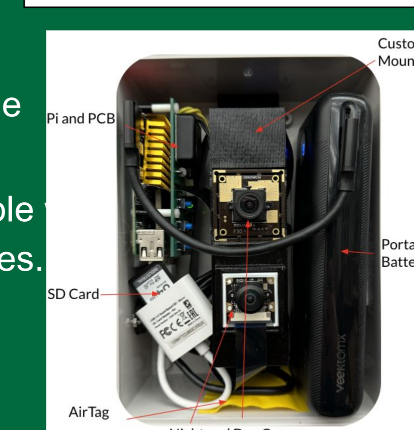
Number	Specification
1	The ability to count at night as well as during the day. Human counters typically prefer counts during commute and work hours from 6 AM to 6 PM (Josephson), which leaves out a dangerous time period (twilight hours from 6 PM to 9 PM) for vulnerable road users. This is when the most 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.

Specifications were developed 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.

Our final prototype was achieved 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 new circuit board for this prototype fixes an issue 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 previous. 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 Raspberry Pi 4B, giving users flexibility in terms of component choices.

Prototype 3 Parts
Raspberry Pi 5
USB A to SD Card Adapter
11 x 7.5 inch IP66 Boxco ABS Clear Front Enclosure
2x 64 GB Industrial/High Endurance SD Card
1080p 5MP OV5647 Sensor Fisheye RPi Camera G
1080p 5MP OV5647 Sensor Infrared Fisheye RPi Camera H w/ IR LEDs
Apple AirTag
HangTon HE21 2-Pin Circular IP68 500V 30A Plug
¼ inch x 20 tpi Tripod Ball Joint Adapter
13 ft. Light Stand Tripod
VEEKTOMX 30,000 mAh USB-C Battery Bank
USB-C Dual Right Angle Power Cable
Generation 3 PCB with upgraded components
Third-generation interior 3D-printed component mounting system





TESTING AND RESULTS

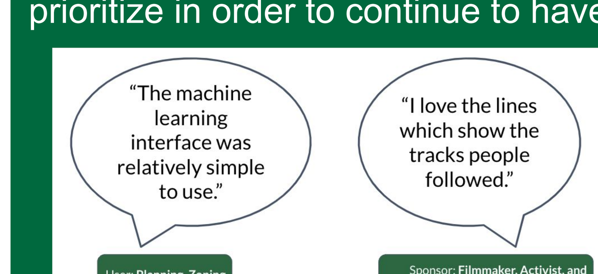
Through these tests, we evaluated the performance of both cameras, both portable batteries, video storage, the solar panel power supply, and nighttime camera. We found that the portable battery enabled an average runtime of 6.5 hours, thereby providing us an estimated minimum of 15 hours of runtime with 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. Prototype 1 generally used about 1 GB of storage per hour of video. Prototype 2 saw an increase in storage requirements for the video to 3.4 GB/hour due to the addition of the USB camera, but Prototype 3 reduced storage requirements back down to 1 GB/hour of video. 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.

We also conducted user tests of the recording device, and received generally positive feedback. User comments from our key stakeholders, including our Bike Walk Committee sponsor and the Town Director of Planning and Zoning, included statements about the importance of being able to carefully frame camera angles through the web application, and that the device was intuitive and easy to use. In addition, both 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.

Video	Temp. (C)	Duration (min)	Start %	End %	Drop %	Runtime (hr)	Date	Location
Recording tests using VEEKTOMX 10,000 mAh battery								
10	0	180	100	54	46	6.52	1/29	Thayer Walkway looking south
11	0	90	54	25	29	5.17	1/30	Fahey Design Center looking east
12	-1	45	100	87	13	5.77	1/31	North Main St. looking west
13	3	135	100	68	32	7.03	2/1	Fahey-McLane Hall looking south
15	0	120	99	74	25	6.52	2/5	Thayer Walkway looking west
16	1	240	100	53	47	5.17	2/6	Allen St. looking west
Recording tests using solar PSU								
19	0	930	Lasted overnight				2/25	Allen St. looking west
Recording tests using VEEKTOMX 30,000 mAh battery								
21	6	495	100	54	46	17.93	3/7	Collis Patio looking east

	Line	Direction	Class	Ground Truths	ConfTrack yolov8s-2024-02-14 no
VIDEO: 16 (intersection of allen and main looking down allen street)	Center Line	Left	Pedestrian	653	597
			Bike	6	3
			Scooter	0	0
			Wheelchair	3	2
		Right	Pedestrian	687	592
			Bike	7	5
			Scooter	0	1
			Wheelchair	4	1
					88.73%
					61.54%
					50.00%
					42.86%
					86.19%
					88.31%

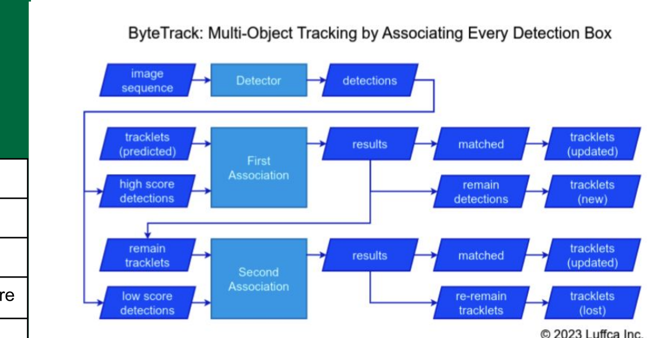
Copy data from device to computer with analysis software → Draw boundary lines in the target area and click start → Download the graphs and tables, ready to be used for documents and presentations

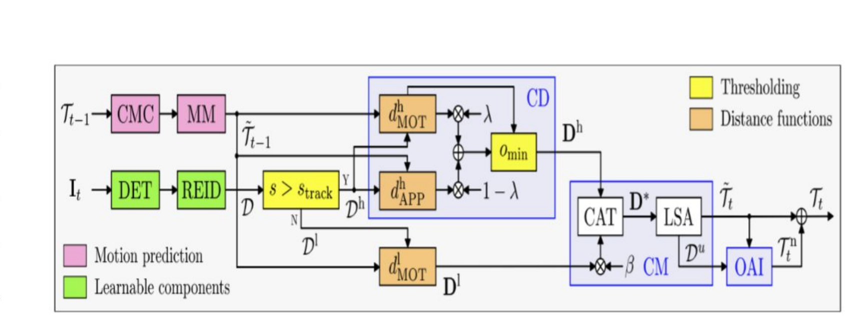


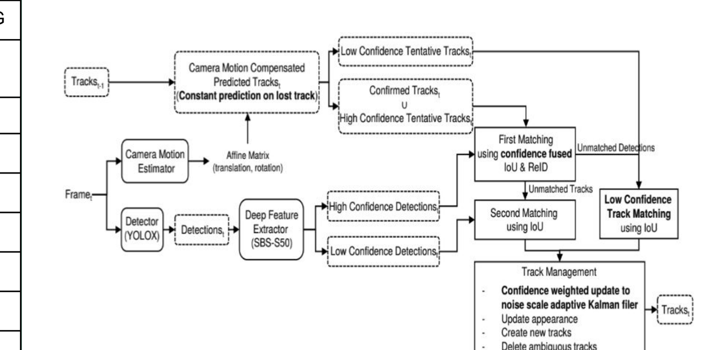
Model	YOLO v8s 14th Feb, 2024	YOLO v8s 14th Feb, 2024	YOLO v8s 14th Feb, 2024	YOLO v8s 14th Feb, 2024	YOLO v8s 16th Feb, 2024	YOLO v8s 16th Feb, 2024	YOLO v8s 16th Feb, 2024	YOLO v8s 16th Feb, 2024	YOLO v8n 3rd Nov, 2023	YOLO v8n 3rd Nov, 2023	YOLO v8n 3rd Nov, 2023
Tracker	Improved Association	Conf Track	Byte Track	LSTM Track	Improved Association	Conf Track	Byte Track	LSTM Track	Improved Association	Conf Track	Byte Track
Average Tracker+ Model Accuracy	82.61%	84.67%	81.67%	21.73%	84.30%	85.08%	82.79%	26.65%	34.18%	24.63%	5.98%

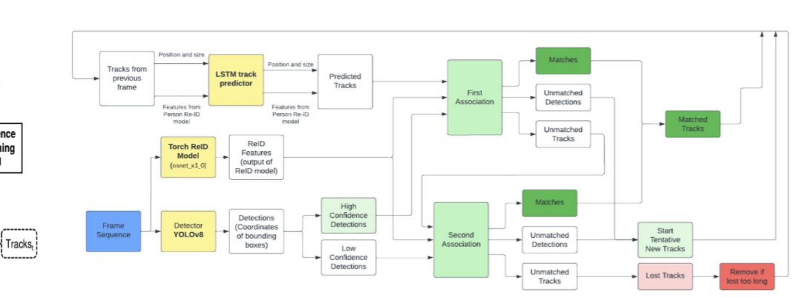
METHODS IN MACHINE LEARNING

The second part of counting road users is tracking each object through the video. This is a fast-moving sector of computer vision right now, with new state-of-the-art algorithms and models coming out every month. There are many different solutions to this problem, but most of them rely on the aforementioned object detector model to detect objects in every frame with an algorithm to match all of the objects between pairs of frames. After matching the objects, the position of the object in the new frame is added to the track. We implemented four state-of-the-art-trackers: ByteTrack, Improved Association, ConfTrack, and LSTMTrack.





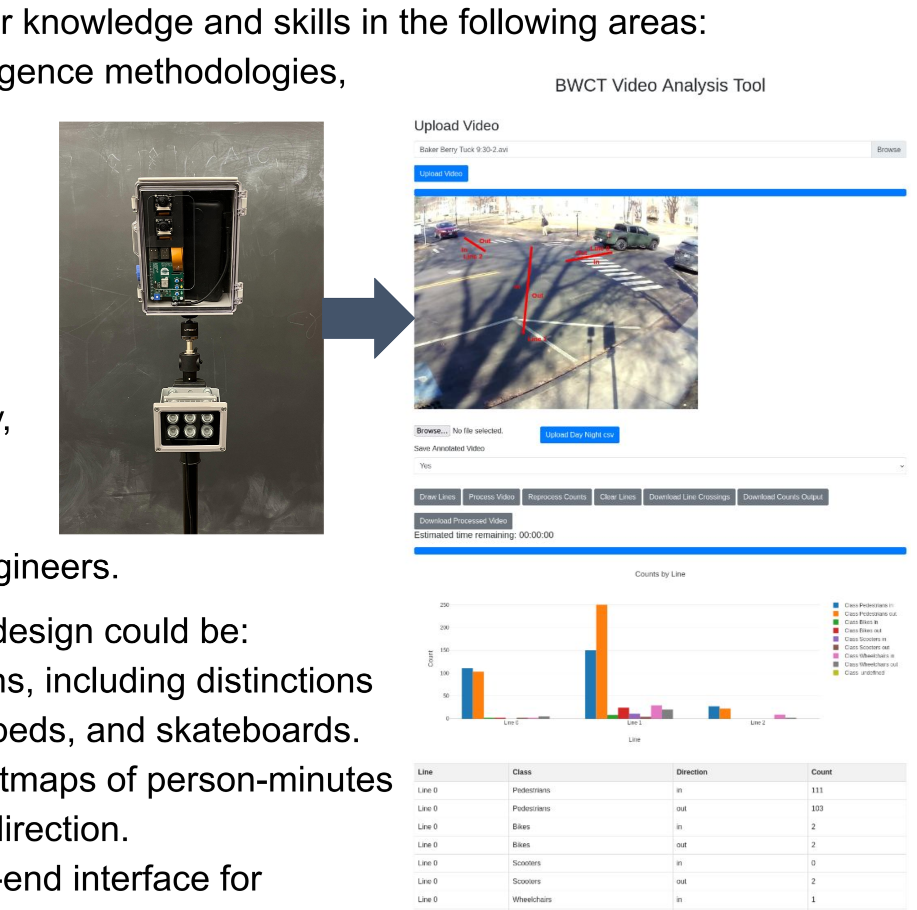




In total, our dataset has 25,000 source images with 45,000 annotations. These annotations include 25,576 pedestrians, 8,544 bikes, 6,036 scooter riders, and 5,426 wheelchair users. analyze the average performance of each combination of detector and model. We found that a majority of missed counts are a result of occlusion at the moment a user crossed the count line, and that these can be minimized, but not eliminated, by ensuring videos are taken at a 45 degree angle offset from the path of interest. As a result, the best average performance we reached on any single video, detector, and tracker combination was 85% with our most recently trained detector and ConfTrack.

SKILLSET AND POSSIBLE FUTURE WORK

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,
-Technical communication,
-Prototyping,
-Statistical analysis,
-Design for usability and accessibility,
-Additive manufacturing,
-Technical communication,
-Civic engagement, especially as engineers.



Some possible future work on this design could be:
(1) Fine-grain road user classifications, including distinctions between bicycles and scooters, mopeds, and skateboards.
(2) Place use patterns, including heatmaps of person-minutes spent in locations and street travel direction.
(3) An intuitive and easy to use front-end interface for analyzing and presenting data.

COLLABORATION ACROSS INDUSTRIES

We worked closely with several advisors, citizens, consultants and planners:

- our engineering technical adviser who is a licensed PE and engineering faculty member
- multiple computer and electrical engineering faculty members who provided guidance on machine learning and electronics design for usability and safety
- our project sponsor, a filmmaker and activist who sits on our town’s selectboard
- our capstone course directors who helped us plan our project and prioritize our time
- two PEs who work at an engineering consulting and planning firm who are passionate about designing transportation systems for inclusion and accessibility
- our town’s engineer, selectboard, and the Bike Walk advisory committee
- our regional planning commission staff