User Trust and AV Interaction with Vulnerable Road Users - Field Test with the Badger

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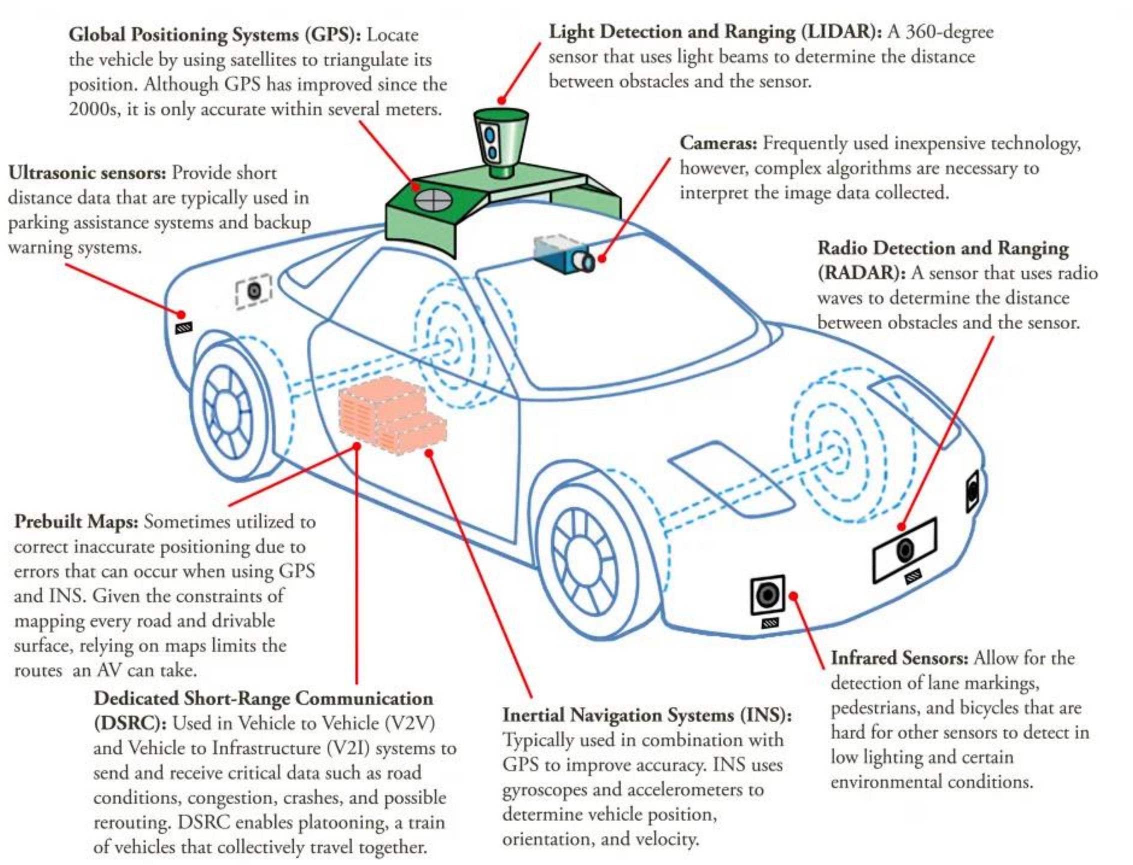
Introduction

- Automated Vehicles (AV)

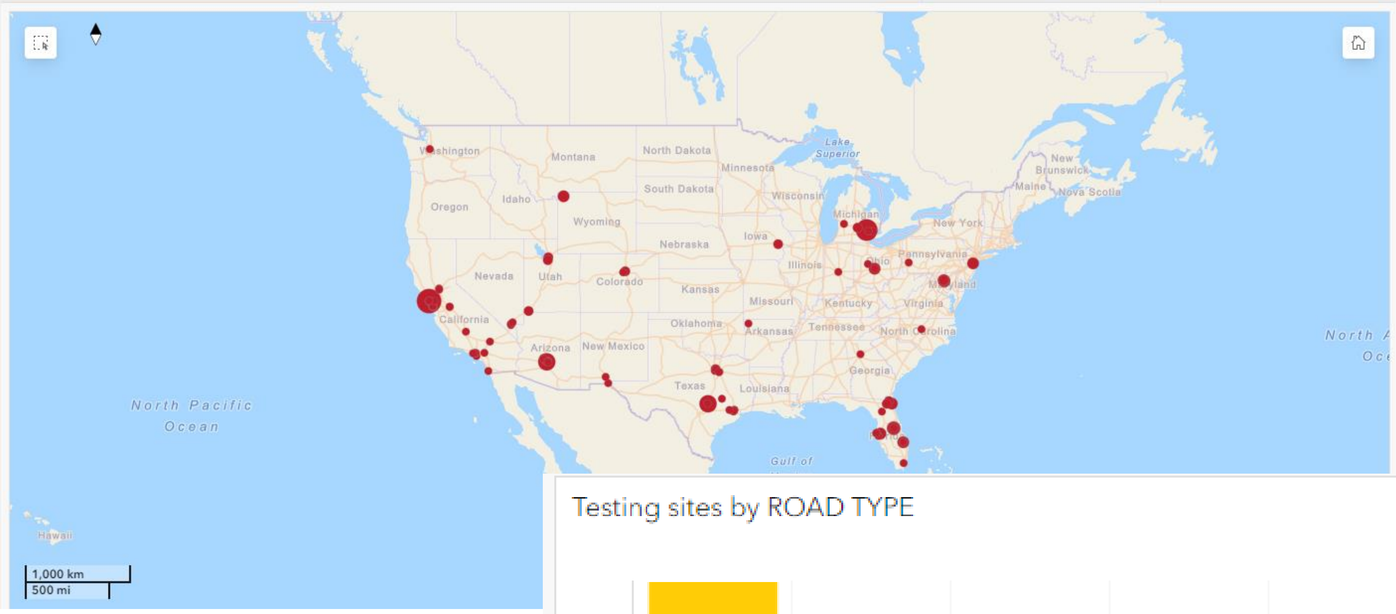


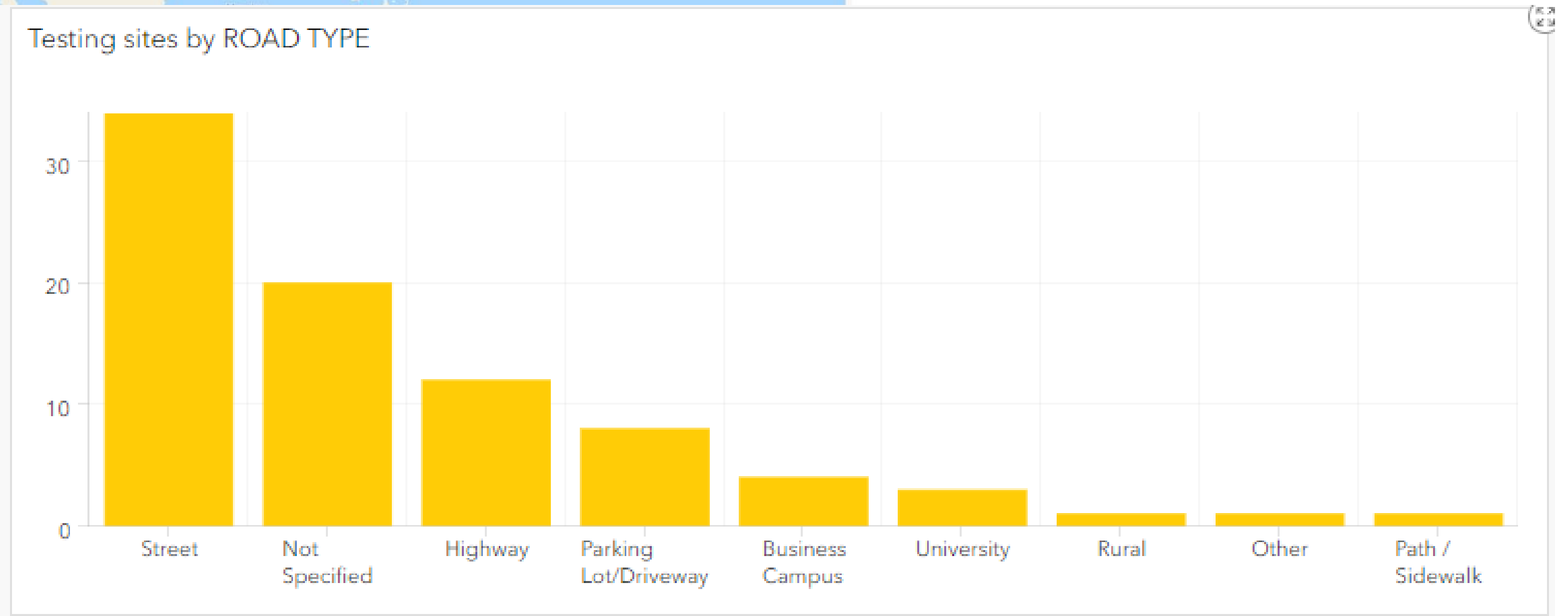
Source: University of Michigan

Source: Waymo

Motivation

- AV Test in the US





Source: NHTSA

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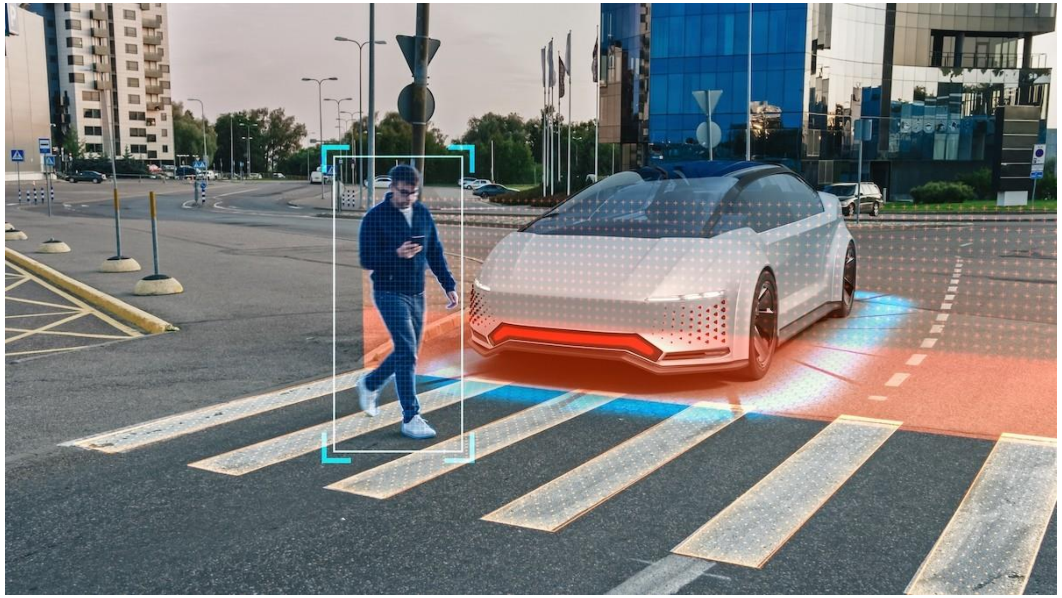
Objectives

1. How does user trust in AVs evolve?
2. How do AVs interact with vulnerable road users?



The Badger

GPS UNIT

One GPS unit, providing location and speed of the vehicle.

RADAR UNITS

Two SMS UMRR and one Aptiv ESR2.5 radars, detecting objects around the vehicle's path.

CAMERA UNITS

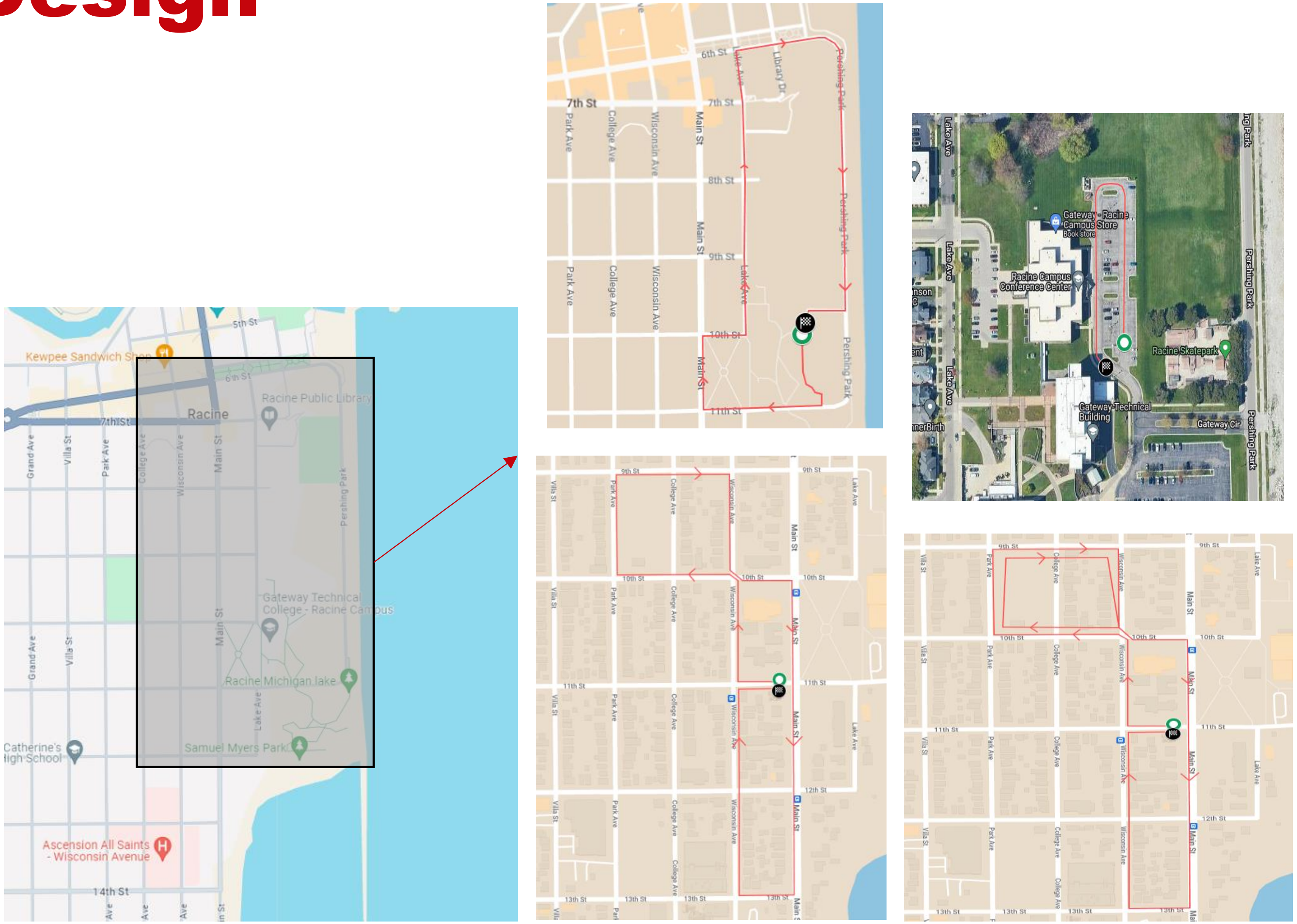
Providing videos of the vehicle's front-view.

LIDAR UNITS

Two Velodyne VLP-16 LiDARs, using laser beams to generate a 360-degree image of the vehicle's surroundings, as well as detecting objects around the vehicle.

Experimental Design

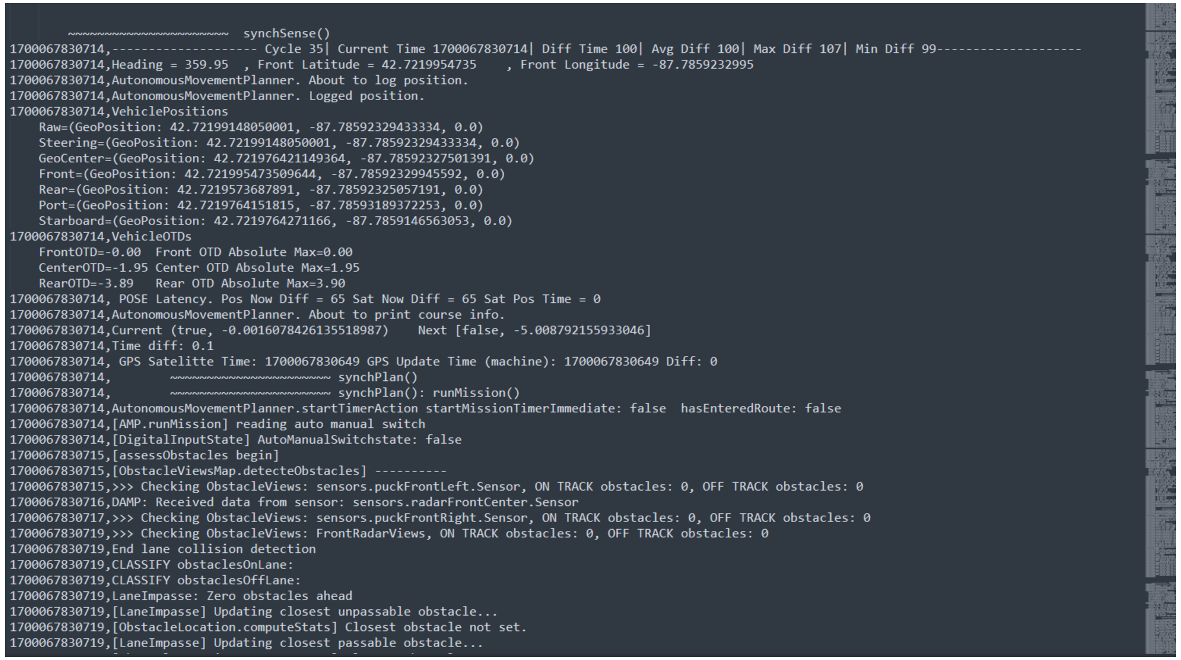
- Four testing routes
- Four days of experiments
  - March 17, October 22, November 10, and November 15 in 2023
- Four drivers
  - Valid US driver's license
  - Normal or corrected-to-normal vision
- Two riders



The map of routes in Racine, WI

Data Collection

- Vehicle log
  - Unstructured text data
- Front and inside view cameras
  - Video data



```
        ~~~~~~~~~~~~~~~~~~~~~~  synchSense()
1700067830714,------------------- Cycle 35| Current Time 1700067830714| Diff Time 100| Avg Diff 100| Max Diff 107| Min Diff 99-------------------
1700067830714,Heading = 359.95  , Front Latitude = 42.7219954735    , Front Longitude = -87.7859232995
1700067830714,AutonomousMovementPlanner. About to log position.
1700067830714,AutonomousMovementPlanner. Logged position.
1700067830714,VehiclePositions
    Raw=(GeoPosition: 42.72199148050001, -87.78592329433334, 0.0)
    Steering=(GeoPosition: 42.72199148050001, -87.78592329433334, 0.0)
    GeoCenter=(GeoPosition: 42.721976421149364, -87.78592327501391, 0.0)
    Front=(GeoPosition: 42.721995473509644, -87.78592329945592, 0.0)
    Rear=(GeoPosition: 42.7219573687891, -87.78592325057191, 0.0)
    Port=(GeoPosition: 42.7219764151815, -87.78593189372253, 0.0)
    Starboard=(GeoPosition: 42.7219764271166, -87.7859146563053, 0.0)
1700067830714,VehicleOTDs
    FrontOTD=-0.00  Front OTD Absolute Max=0.00
    CenterOTD=-1.95 Center OTD Absolute Max=1.95
    RearOTD=-3.89   Rear OTD Absolute Max=3.90
1700067830714, POSE Latency. Pos Now Diff = 65 Sat Now Diff = 65 Sat Pos Time = 0
1700067830714,AutonomousMovementPlanner. About to print course info.
1700067830714,Current (true, -0.0016078426135518987)    Next [false, -5.008792155933046]
1700067830714,Time diff: 0.1
1700067830714, GPS Satelitte Time: 1700067830649 GPS Update Time (machine): 1700067830649 Diff: 0
1700067830714,        ~~~~~~~~~~~~~~~~~~~~~~ synchPlan()
1700067830714,        ~~~~~~~~~~~~~~~~~~~~~~ synchPlan(): runMission()
1700067830714,AutonomousMovementPlanner.startTimerAction startMissionTimerImmediate: false  hasEnteredRoute: false
1700067830714,[AMP.runMission] reading auto manual switch
1700067830714,[DigitalInputState] AutoManualSwitchstate: false
1700067830715,[assessObstacles begin]
1700067830715,[ObstacleViewsMap.detecteObstacles] ----------
1700067830715,>>> Checking ObstacleViews: sensors.puckFrontLeft.Sensor, ON TRACK obstacles: 0, OFF TRACK obstacles: 0
1700067830716,DAMP: Received data from sensor: sensors.radarFrontCenter.Sensor
1700067830717,>>> Checking ObstacleViews: sensors.puckFrontRight.Sensor, ON TRACK obstacles: 0, OFF TRACK obstacles: 0
1700067830719,>>> Checking ObstacleViews: FrontRadarViews, ON TRACK obstacles: 0, OFF TRACK obstacles: 0
1700067830719,End lane collision detection
1700067830719,CLASSIFY obstaclesOnLane:
1700067830719,CLASSIFY obstaclesOffLane:
1700067830719,LaneImpasse: Zero obstacles ahead
1700067830719,[LaneImpasse] Updating closest unpassable obstacle...
1700067830719,[ObstacleLocation.computeStats] Closest obstacle not set.
1700067830719,[LaneImpasse] Updating closest passable obstacle...
```

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Data Collection

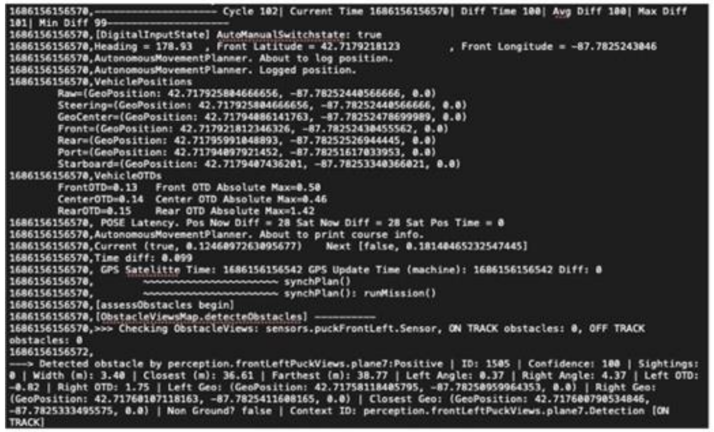
- Rider responses collected:
  - two weeks before riding
  - immediately before riding
  - one week after riding
- Rider attitude about:
  - familiarity with AV technology
  - expectation of comfort, AV ability, and drivers' ability
  - general observations

How comfortable do you think you would be...

	Not at all	A little	Somewhat	Very	Extremely
...riding in the automated vehicle described in this study?	○	○	○	○	○
...sharing a city street with automated vehicles as a driver or passenger in another vehicle?	○	○	○	○	○

Data Preparation

- A Python-based script for automated log data preparation
- The unstructured log data are converted into structured data
  - Location
  - Speed
  - Detection



```
1686156156570,--------------------- Cycle 102| Current Time 1686156156570| Diff Time 100| Avg Diff 100| Max Diff
101| Min Diff 99---------------------
1686156156570,[DigitalInputState] AutoManualSwitchstate: true
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1686156156570,AutonomousMovementPlanner. About to log position.
1686156156570,AutonomousMovementPlanner. Logged position.
1686156156570,VehiclePositions
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        Steering=(GeoPosition: 42.717925804666656, -87.78252440566666, 0.0)
        GeoCenter=(GeoPosition: 42.71794086141763, -87.78252478699989, 0.0)
        Front=(GeoPosition: 42.717921812346326, -87.78252430455562, 0.0)
        Rear=(GeoPosition: 42.71795991048893, -87.78252526944445, 0.0)
        Port=(GeoPosition: 42.71794097921452, -87.78251617033953, 0.0)
        Starboard=(GeoPosition: 42.7179407436201, -87.78253340366021, 0.0)
1686156156570,VehicleOTDs
        FrontOTD=0.13   Front OTD Absolute Max=0.50
        CenterOTD=0.14  Center OTD Absolute Max=0.46
        RearOTD=0.15    Rear OTD Absolute Max=1.42
1686156156570, POSE Latency. Pos Now Diff = 28 Sat Now Diff = 28 Sat Pos Time = 0
1686156156570,AutonomousMovementPlanner. About to print course info.
1686156156570,Current (true, 0.1246097263095677)    Next [false, 0.18140465232547445]
1686156156570,Time diff: 0.099
1686156156570, GPS Satelitte Time: 1686156156542 GPS Update Time (machine): 1686156156542 Diff: 0
1686156156570,        ~~~~~~~~~~~~~~~~~~~~~~ synchPlan()
1686156156570,        ~~~~~~~~~~~~~~~~~~~~~~ synchPlan(): runMission()
1686156156570,[assessObstacles begin]
1686156156570,[ObstacleViewsMap.detecteObstacles] ----------
1686156156570,>>> Checking ObstacleViews: sensors.puckFrontLeft.Sensor, ON TRACK obstacles: 0, OFF TRACK
obstacles: 0
1686156156572,
---> Detected obstacle by perception.frontLeftPuckViews.plane7:Positive | ID: 1505 | Confidence: 100 | Sightings:
0 | Width (m): 3.40 | Closest (m): 36.61 | Farthest (m): 38.77 | Left Angle: 0.37 | Right Angle: 4.37 | Left OTD:
-0.82 | Right OTD: 1.75 | Left Geo: (GeoPosition: 42.71758118405795, -87.78250959964353, 0.0) | Right Geo:
(GeoPosition: 42.71760107118163, -87.7825411608165, 0.0) | Closest Geo: (GeoPosition: 42.717600790534846,
-87.7825333495575, 0.0) | Non Ground? false | Context ID: perception.frontLeftPuckViews.plane7.Detection [ON
TRACK]
```
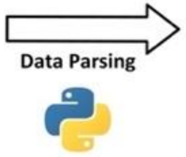
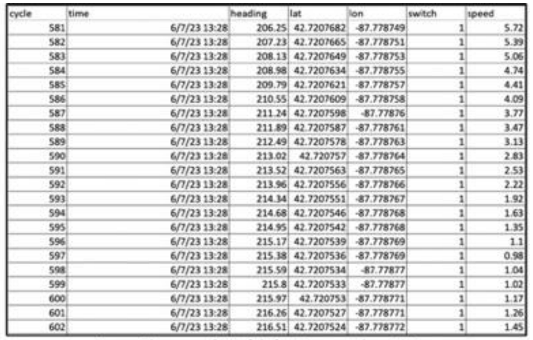
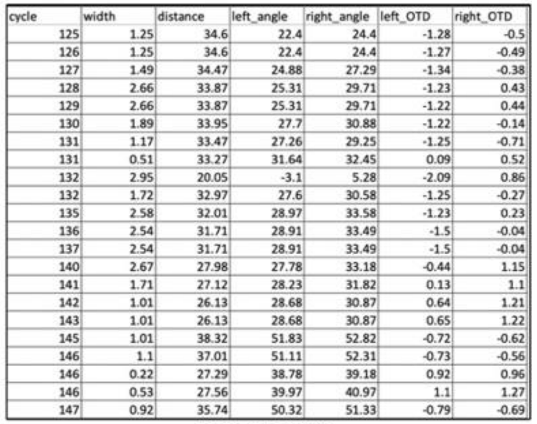

Unstructured Log Data





cycle	time	heading	lat	lon	switch	speed
581	6/7/23 13:28	206.25	42.7207682	-87.778749	1	5.72
582	6/7/23 13:28	207.23	42.7207665	-87.778751	1	5.39
583	6/7/23 13:28	208.13	42.7207649	-87.778753	1	5.06
584	6/7/23 13:28	208.98	42.7207634	-87.778755	1	4.74
585	6/7/23 13:28	209.79	42.7207621	-87.778757	1	4.41
586	6/7/23 13:28	210.55	42.7207609	-87.778758	1	4.09
587	6/7/23 13:28	211.24	42.7207598	-87.77876	1	3.77
588	6/7/23 13:28	211.89	42.7207587	-87.778761	1	3.47
589	6/7/23 13:28	212.49	42.7207578	-87.778763	1	3.13
590	6/7/23 13:28	213.02	42.720757	-87.778764	1	2.83
591	6/7/23 13:28	213.52	42.7207563	-87.778765	1	2.53
592	6/7/23 13:28	213.96	42.7207556	-87.778766	1	2.22
593	6/7/23 13:28	214.34	42.7207551	-87.778767	1	1.92
594	6/7/23 13:28	214.68	42.7207546	-87.778768	1	1.63
595	6/7/23 13:28	214.95	42.7207542	-87.778768	1	1.35
596	6/7/23 13:28	215.17	42.7207539	-87.778769	1	1.1
597	6/7/23 13:28	215.38	42.7207536	-87.778769	1	0.98
598	6/7/23 13:28	215.59	42.7207534	-87.77877	1	1.04
599	6/7/23 13:28	215.8	42.7207533	-87.77877	1	1.02
600	6/7/23 13:28	215.97	42.720753	-87.778771	1	1.17
601	6/7/23 13:28	216.26	42.7207527	-87.778771	1	1.26
602	6/7/23 13:28	216.51	42.7207524	-87.778772	1	1.45

Location and Vehicle Dynamics Data



cycle	width	distance	left_angle	right_angle	left_OTD	right_OTD
125	1.25	34.6	22.4	24.4	-1.28	-0.5
126	1.25	34.6	22.4	24.4	-1.27	-0.49
127	1.49	34.47	24.88	27.29	-1.34	-0.38
128	2.66	33.87	25.31	29.71	-1.23	0.43
129	2.66	33.87	25.31	29.71	-1.22	0.44
130	1.89	33.95	27.7	30.88	-1.22	-0.14
131	1.17	33.47	27.26	29.25	-1.25	-0.71
131	0.51	33.27	31.64	32.45	0.09	0.52
132	2.95	20.05	-3.1	5.28	-2.09	0.86
132	1.72	32.97	27.6	30.58	-1.25	-0.27
135	2.58	32.01	28.97	33.58	-1.23	0.23
136	2.54	31.71	28.91	33.49	-1.5	-0.04
137	2.54	31.71	28.91	33.49	-1.5	-0.04
140	2.67	27.98	27.78	33.18	-0.44	1.15
141	1.71	27.12	28.23	31.82	0.13	1.1
142	1.01	26.13	28.68	30.87	0.64	1.21
143	1.01	26.13	28.68	30.87	0.65	1.22
145	1.01	38.32	51.83	52.82	-0.72	-0.62
146	1.1	37.01	51.11	52.31	-0.73	-0.56
146	0.22	27.29	38.78	39.18	0.92	0.96
146	0.53	27.56	39.97	40.97	1.1	1.27
147	0.92	35.74	50.32	51.33	-0.79	-0.69

Detection Data

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Data Preparation

Data Description

Type	Name	Description
	Cycle	The number of the cycle
General	Mode	The driving mode of the vehicle, which is either automated or manual
	Time	The timestamp of the cycle
	Latitude & Longitude	The latitude and longitude of the vehicle in world geodetic system 1984 coordinate
Vehicle	Speed	The speed of the vehicle in mph
	Heading	The angle from the true north to the forward heading of the vehicle in degrees
Detection	Width	The detected width of the object in meters
	Distance	The distance between the closest point of the object and the associated sensor in meters

Data Preparation

Parking Lot

Public Street

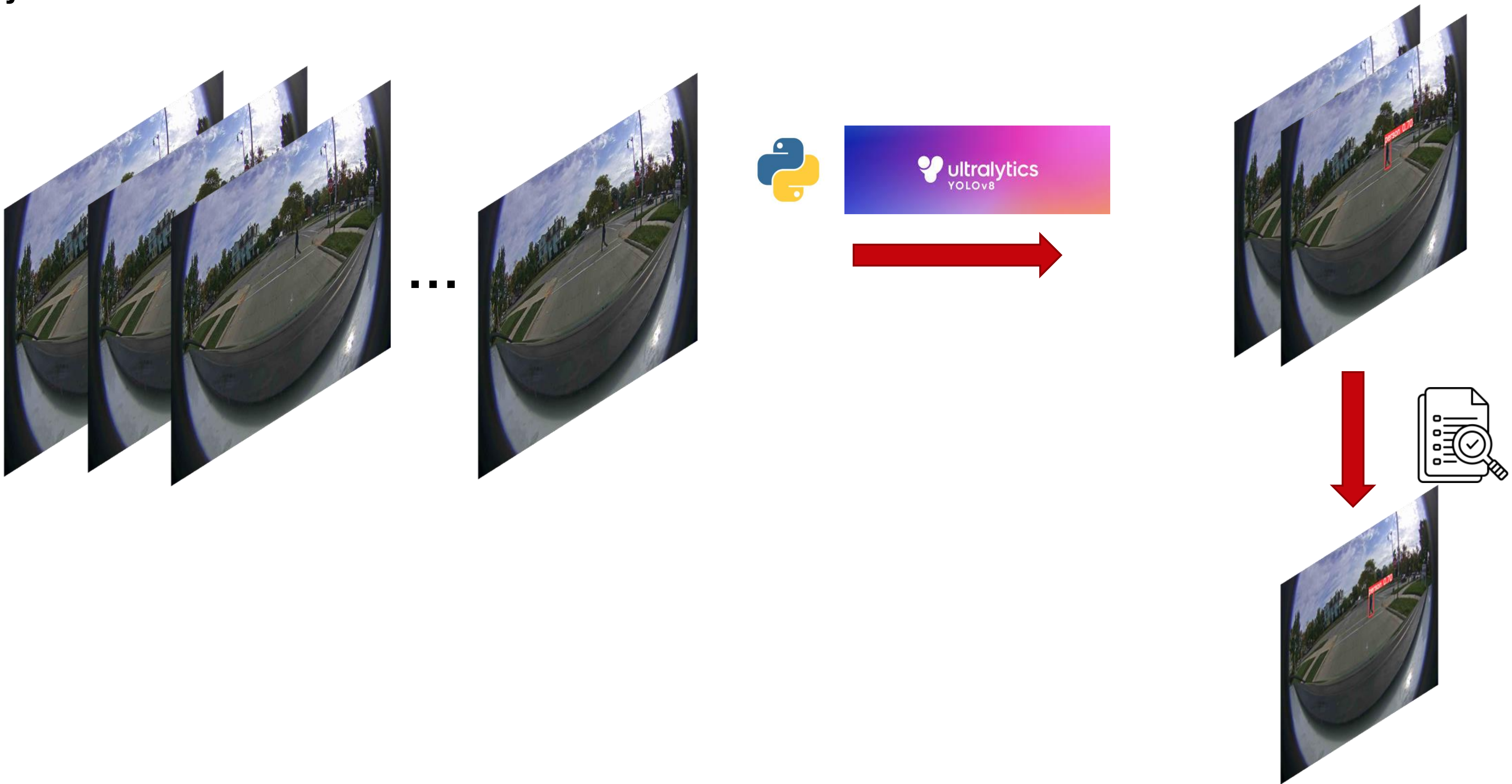
Data Preparation

- Object detection in an image

ultralytics
YOLOv8

Data Preparation

- Object detection in a video



Data Preparation

- AV-VRU Interactions

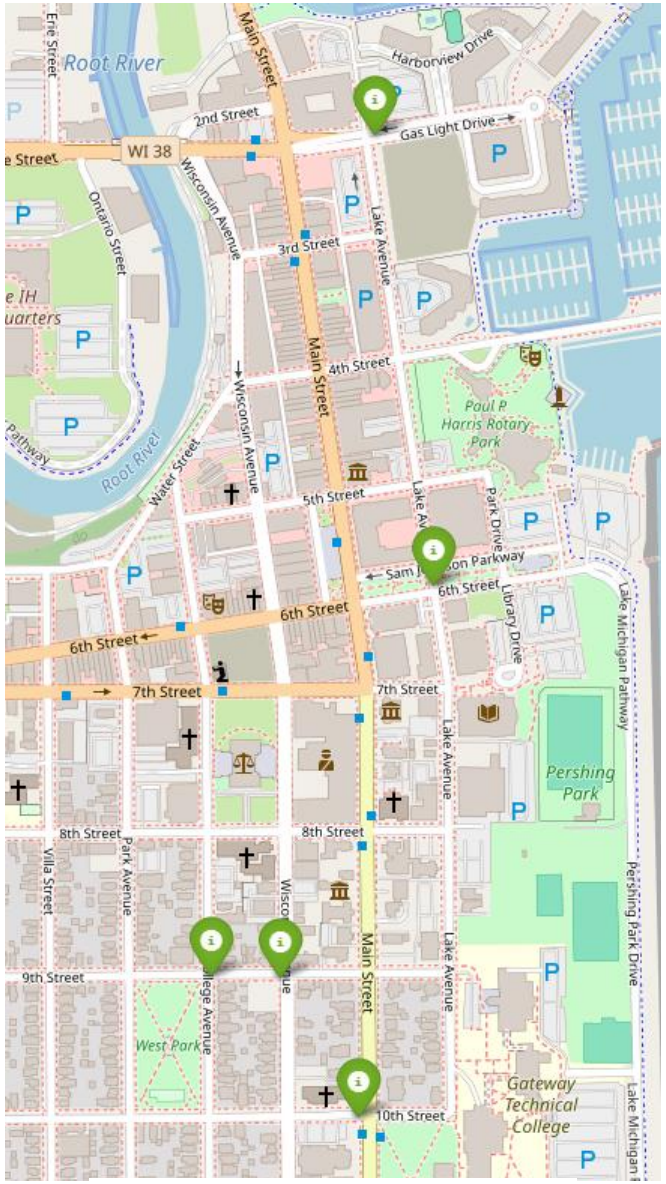
T_1 - 5 seconds | T_1 | T_2 | T_2 + 5 seconds

Before | During | After

Results

- Five AV-VRU interactions

An example of an interaction



Locations of interactions

Results

- The average duration is 18 seconds
- The AV has a higher speed before the interaction than during and after the interaction
- The AV has a relatively high volatility of speed while interacting with VRUs

Descriptive Statistics

Event		1	2	3	4	5
Date		10/23/23	11/10/23	10/23/23	10/23/23	10/23/23
Duration (seconds)		5.81	15.82	9.81	37.74	20.82
Speed_before (mph)	Mean	9.33	9.31	0.09	14.45	18.24
	STD	0.58	4.25	0.24	0.07	0.46
	Min	7.05	2.66	0.01	14.13	17.31
	Max	9.61	14.51	1.19	14.57	18.97
Speed_during (mph)	Mean	0.96	2.06	0.16	0.95	3.62
	STD	1.76	3.02	0.27	2.64	5.72
	Min	0.01	0.00	0.01	0.00	0.00
	Max	6.29	9.69	0.99	13.88	18.97
Speed_after (mph)	Mean	0.05	8.67	4.45	4.18	0.01
	STD	0.09	1.01	2.92	2.51	0.00
	Min	0.01	6.13	0.83	0.00	0.00
	Max	0.46	9.81	9.41	8.07	0.01

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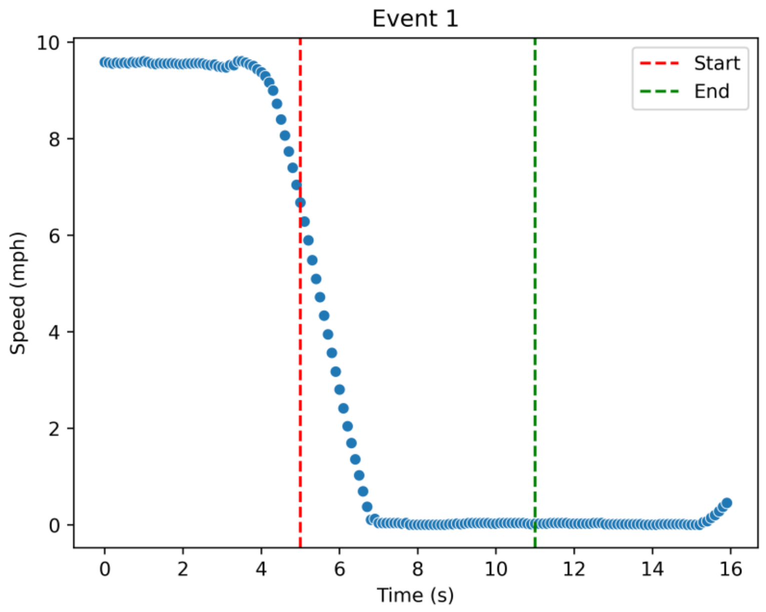
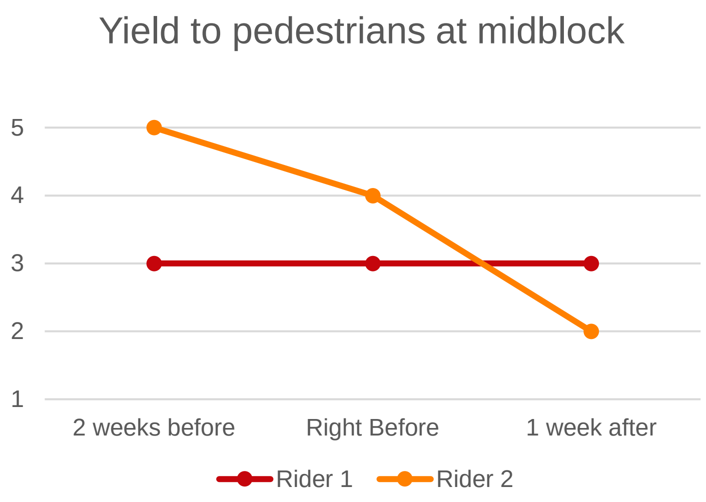
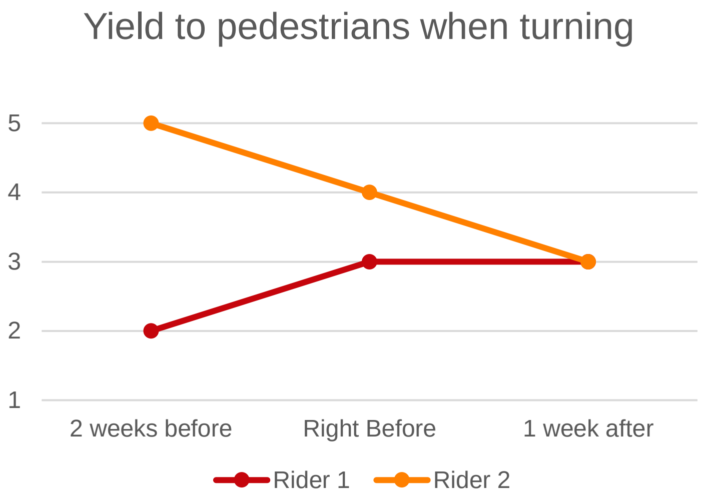
Results

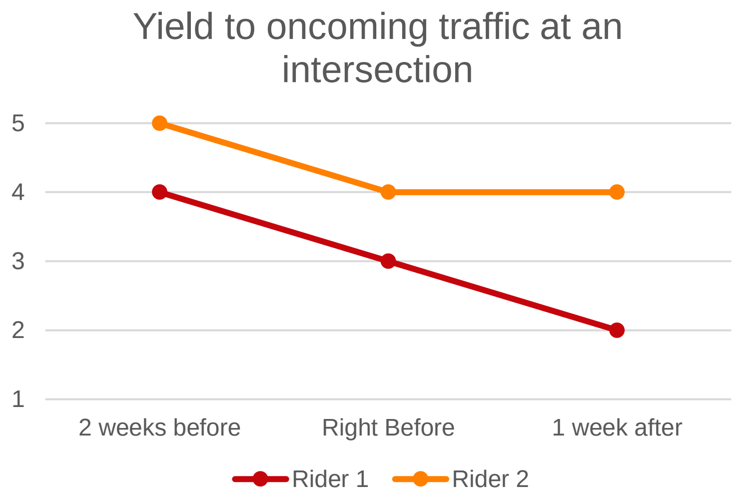
- The AV stopped and the bicyclist drove on the street
- The AV stopped for additional time to check the surrounding environments to make a right turn

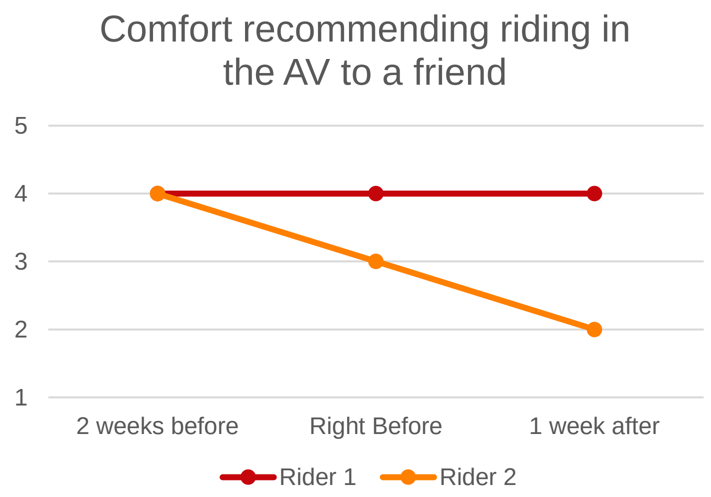


Results





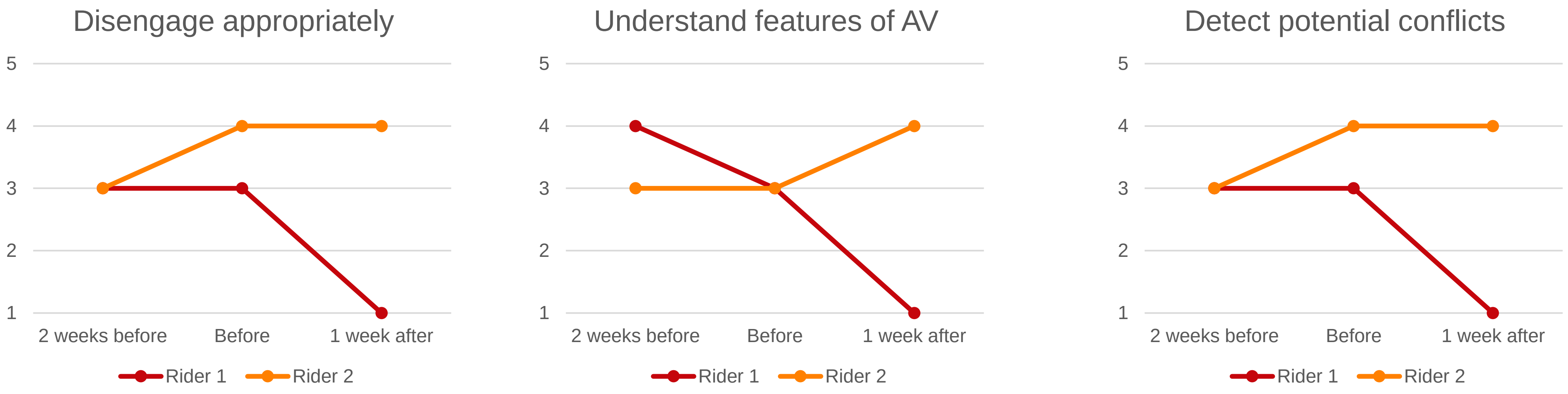




Observations

- Pedestrians
  - I was scared by the way the AV was interacting with pedestrians.
  - I was not comfortable with how close it was getting to pedestrians.
- Oncoming Traffic at an Intersection
  - When making the turn to Main St, it could not handle the vehicle that came from behind the trash truck.

Results



Perceived differences between riders

Conclusions

- AV is cautious while interacting with VRUs, but riders may not perceive it as safe
- Rider attitude toward AVs varies based on factors such as safety experiences and exposure to the technology
- AV has a relatively high speed before interacting with VRUs, its speed drops rapidly after interacting with VRUs and gradually increases after finishing the interaction
- AV has a relatively higher volatility of speed while interacting with VRUs

Limitations and Future Research

- Limitations:
  - Riders and drivers were limited to UW employees due to policy
  - Field test has natural variations in traffic conditions, lighting, GPS quality, etc. that introduces uncontrollable variance
- Future Research:
  - Collect data in more scenarios with more riders and drivers
  - Better ways of detecting road users
  - Additional metrics for evaluating AV's performance

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Thank you

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