New Autonomous Mobility Vision for Michigan

Final Summary

Deliverable #11
MDOT contract no. 2019-0221
December 9, 2019

Content

Overview

Background

- The New Autonomous Mobility Vision for Michigan (NAMV-MI) team was awarded a grant through the Michigan Mobility Challenge (MMC), which was funded by the Michigan Department of Transportation (MDOT) to demonstrate innovative transportation solutions that can solve mobility gaps for seniors, persons with disabilities and veterans.

Project Description

- Assemble, develop, and test two accessible automated electric shuttles for use as first/last mile mobility
- Pilot the vehicles on the center campus of Western Michigan University (change from initial plan of Battle Creek VA Medical Center)
  - The team agreed with the local and National VA leadership that the Battle Creek VAMC environment was not ready for AV technology adoption at this time. The team found overwhelming support at the campus of WMU to provide the same environment and value for Accessible & Automated Mobility solutions. The team is continuing to work with the VA Innovation office to confirm the right time to implement on VA campuses.
- By gathering data related to the use of autonomous vehicles on campuses like Western Michigan University, and the accessibility requirements of a small on-demand shuttle, this project will help guide the design of vehicles that create an autonomous, accessible future for all

Partners and Roles

Pratt & Miller Engineering (PME)
- DOT program of record prime
- Project lead, program management
- Lead technology integrator
- Safety operator support for pilot
- LSV vehicle lead
  - Modifications for accessibility
  - User experience
- Ride hailing software for pilot (not in original scope)

Western Michigan University (WMU)
- Environment mapping
- System simulation for cost/value analysis
- Host site for pilot (not in original scope)
- Safety operator support during testing & vehicle setup

University of Michigan (UM)
- Accessibility and usability technical assistance
- Accessibility and usability evaluation of modified vehicle

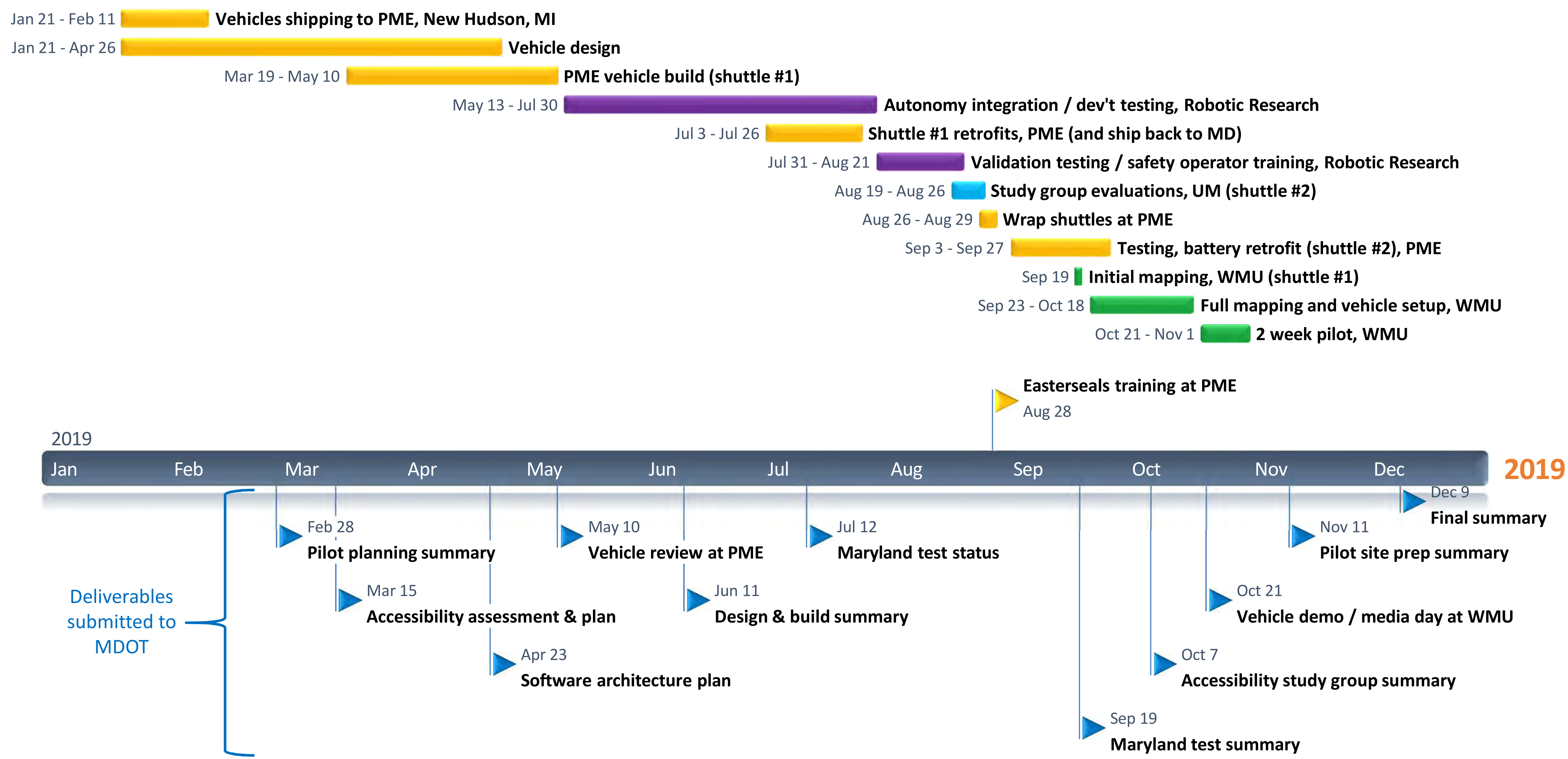
Robotic Research
- Integrate autonomy system & perform validation testing
- Train safety operators
- Provide on-site autonomy setup in Michigan

Comet Mobility
- User experience lead & accessibility SME
- Mobility strategy and pilot deployment
- Work with all partners to develop ConOps for project
- MDOT/project promotion

Easterseals
- Liaison with accessibility community
- Training for interacting with persons with disabilities
- Help create user survey and communicate results

Kevadiya
- Original ride hailing solution (not used in pilot)
  - Create ride hailing software, passenger app
  - Create safety operator interface for ride queue

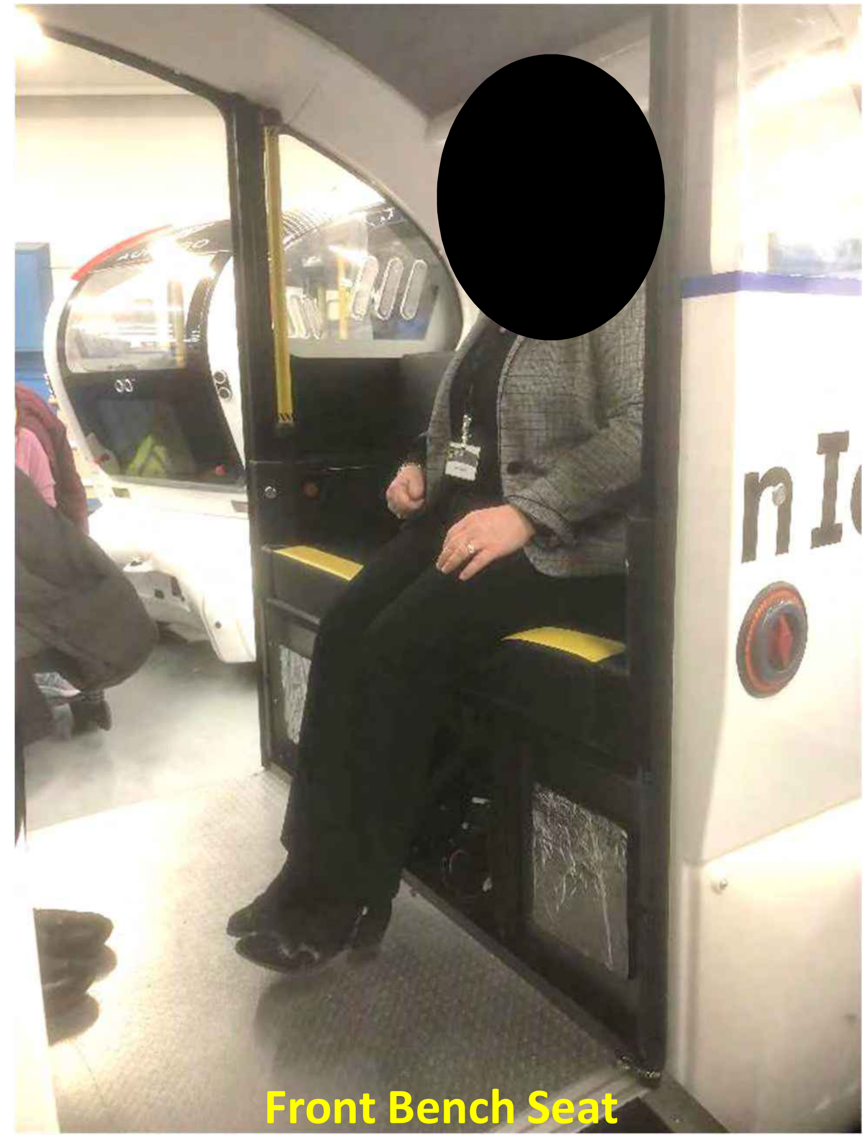
Project Timeline as Executed



Initial Accessibility Assessment
Baseline Vehicle - Interior

- Baseline vehicle was a compact 4-person shuttle
- Two bench seats; one forward-facing and one rearward-facing
- The volumes under the bench seats housed critical chassis components
  - Portions of wheel wells
  - Steering system
  - Brake master cylinder and actuator
  - Electric motor
  - Rear axle and halfshafts
  - Portion of battery pack

Rear Bench Seat



Front Bench Seat

Initial Accessibility Assessment
Baseline Vehicle – Wheelchair Accessibility

- The only way a wheelchair fit in the baseline vehicle was facing sideways, between the two bench seats
- Current accessibility regulations for public transportation vehicles* require at least one wheelchair securement location if the vehicle is less than 22 ft in length
- The wheelchair securement orientation can be in a forward or rearward facing direction*; side-facing is not allowed

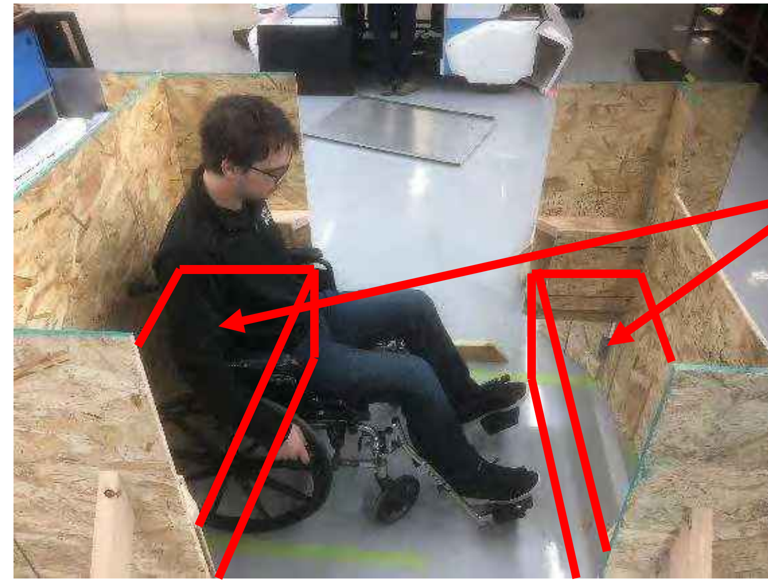
**USDOT (2017). 49 CFR, Part 38: ADA Accessibility Specifications for Transportation Vehicles. USDOT, Washington, DC.*

Initial Accessibility Assessment
Interior Buck

A wood buck was created at PME to evaluate the circulation space inside the shuttle with various proposed modifications (assumes extended wheelbase and relocation of various components)

Represents front wall of existing bodywork

Represents additional space created by rotating steering and brake system components, which allows more room for wheelchair footrests while maneuvering the wheelchair into position



Volume realized through wheelbase increase and bench seat removal

Represents rear wall of existing bodywork

Initial Accessibility Assessment
Workshop with Interior Buck

- Manual wheelchair evaluation
  - Ingress/egress is not difficult if wheelchair footrests are not extended
  - Extended footrests require opening the opposite vehicle door to maneuver
  - Remaining room accommodates safety operator and one additional passenger

- Front wheel drive power wheelchair evaluation
  - Egress difficult due to length of wheelchair
  - Remaining room only accommodates safety operator (no additional passenger)

Design Requirements

- Must accommodate one wheelchair
  - Clear floor space for secured wheelchair must be a minimum of 48” long x 30” wide *
  - Wheelchair must be secured
  - Wheelchair occupant must be secured
  - Wheelchair occupant must be facing forward when in the secured position

- Must accommodate two people in addition to the wheelchair occupant
  - Safety operator
  - Companion for wheelchair occupant
  - These passengers should not encroach on the 48” x 30” clear floor space designated for the wheelchair occupant

- Access ramp slope will be less than 1:8 when deploying to a 6” curb, and no more than 1:8 when deploying to ground
  - Vehicle design allows for low step height to minimize angle of ramp ingress and egress

- DESIGN CONSTRAINTS:
  - Major bodywork modifications are out of scope
  - The GVW and limited interior volume of the shuttle restricts wheelchair accommodation to manual wheelchairs with a combined wheelchair and occupant weight of 400 lbs

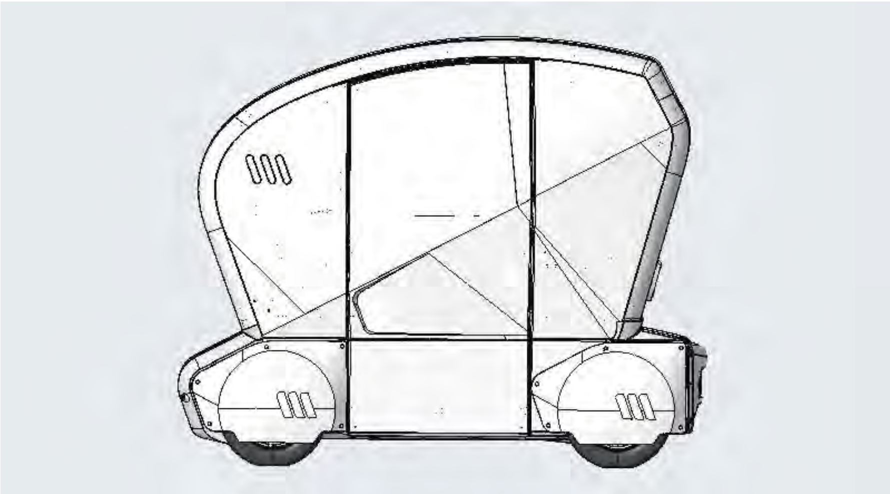
** USDOT (2017). 49 CFR, Part 38: ADA Accessibility Specifications for Transportation Vehicles. USDOT, Washington, DC.*

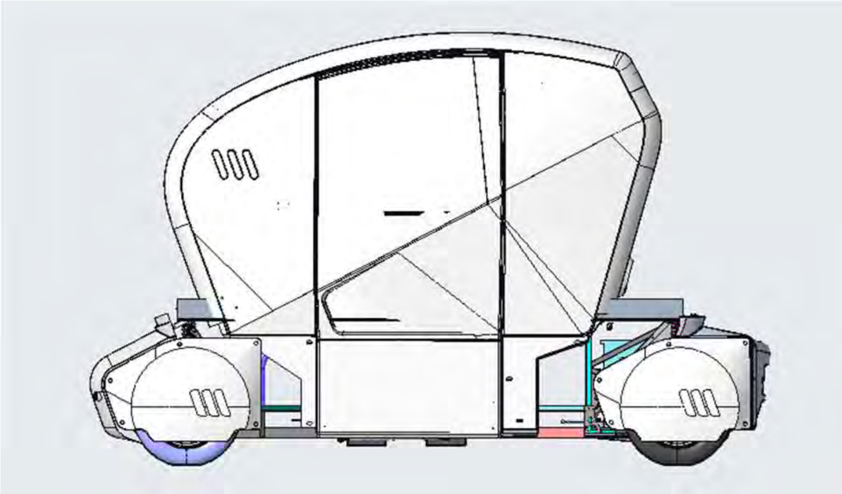
Maximizing Interior Volume

Through the following actions, the interior volume was maximized within the original bodywork:

- Extend the wheelbase 26 inches
    - Translate front axle forward, along with steering and brake system components housed under the base vehicle's bench seat
    - Rotate steering and brake systems to further increase interior volume
    - Translate rear axle rearward, along with powertrain components housed under the base vehicle's rear bench seat

- Replace base vehicle's bench seats with fold-down seats, to allow sufficient interior circulation space for wheelchair to maneuver prior to securement





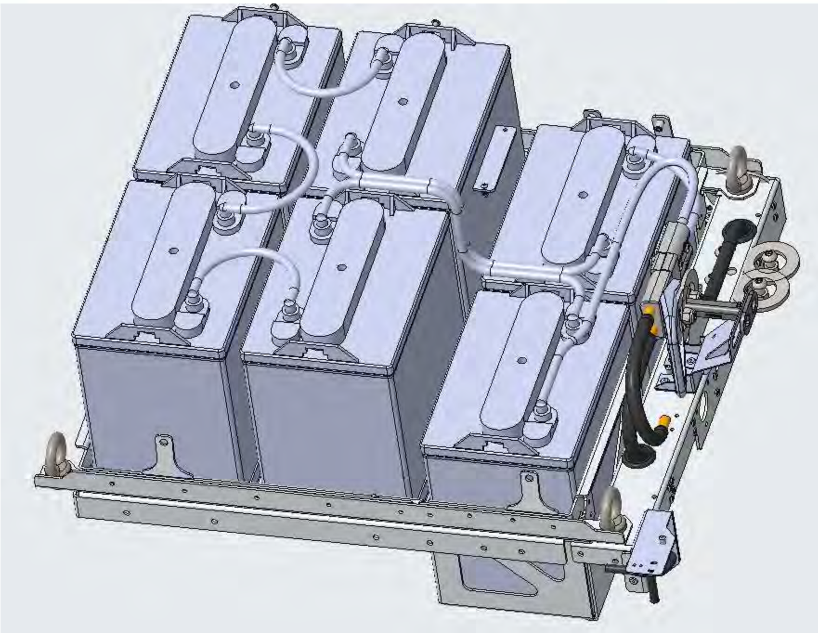
Design
Original vs. Modified Vehicle

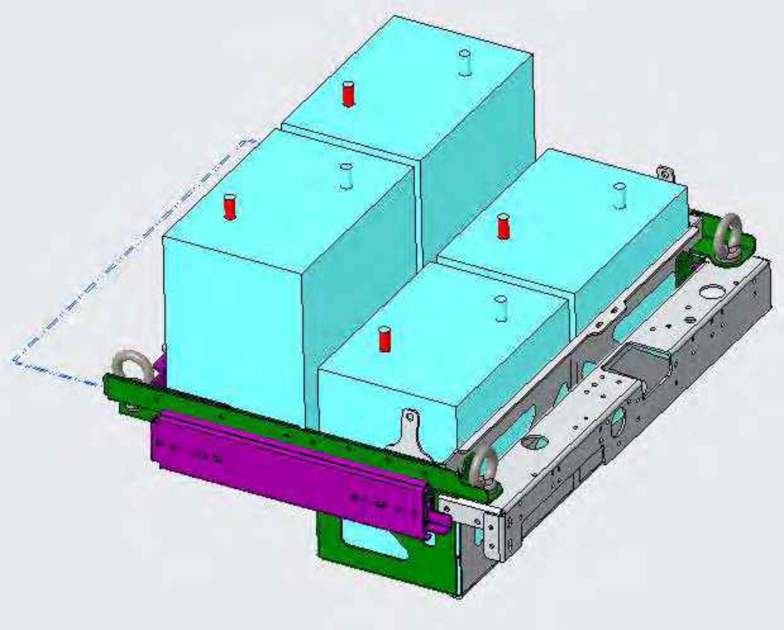
	Original Vehicle	Modified Vehicle
Wheelchair station	None	Forward-facing wheelchair station, 30x48” clear floor space, accommodating one manual wheelchair with combined wheelchair & occupant weight of 400 lbs
Number of passengers	Four passenger (no wheelchairs)	Four passenger (no wheelchairs) OR three passenger, including one wheelchair
Wheelbase (in)	63.8	89.7
Curb weight (lb)	1534	1600
GVW (lb)	2204	2350
Ramp	29” wide, 1:6.5 overall ramp slope No on-board stowage	28” wide, 1:8 overall ramp slope On-board stowage under floor
Usable door opening	29.5”	31.25”
Turn circle (ft)	20	30

Design
Significant Modifications

- Extended wheelbase
  - Translate front axle forward, along with steering and brake system components housed under the base vehicle's bench seat
  - Rotate steering and brake systems to further increase interior volume
  - Translate rear axle rearward, along with powertrain components housed under the base vehicle's rear bench seat
  - New bodywork panels
- Hinged door at wheelchair footrest height for increased wheelchair turning space
- Restraint structures
  - Wheelchair securement
  - Wheelchair occupant three-point belt
  - Rearward-facing passenger lap belt
- Structural modifications to accommodate dynamic load cases at increased GVW
- Modified front suspension geometry to decrease steering rack loads
- Modified battery tray to create packaging space for restraint systems and accommodate new battery pack
- Electrical architecture
  - New lithium iron phosphate batteries
  - Backup battery for 12V bus
  - Relocated e-stops
- Autonomy system
  - Sensor mounting
  - Packaging of electrical components
- Ramp and ramp stowage system
- Redesigned door mechanism to allow wider opening for ingress/egress and ramp packaging
- Front armrest removal and relocation of associated electrical components

Design
Batteries


BEFORE (flooded lead acid)


AFTER (lithium iron phosphate)

- Reduced battery pack weight by 264 lbs
- Reduced volume by 33%
  - Allowed packaging space for wheelchair restraints
- Maintained similar energy capacity
- Increased operating temperature range
- Internal BMS (state of charge, charge levelling)
- Increased safety
  - Battery will disconnect itself for certain conditions (over temp, over voltage, etc.)

Design
Wheelchair Securement System

Rear wheelchair and lap belt restraint anchors are in rear wall

Front wheelchair restraint anchors are in floor

Structure added to rear of vehicle to provide shoulder belt anchor

Wheelchair secured, with Safety Operator and additional passenger

Components:

QRT MAX Kit (Q'Straint)	Cable Release Claw Assembly
Omni Flanged L-Track	Omni Flanged End Cap
14" Webbing Loop	Buckle
Pin Connector	

Design
Wheelchair Ramp Slope - Regulatory

- For accessibility to sites, facilities, buildings, and elements, the ADA ramp slope requirement is 1:12
  "405.2 Slope. Ramp runs shall have a running slope not steeper than 1:12."[1]

- For transportation, a ramp slope of 1:4 is allowed under the current Code of Federal Regulations if the ramp is deployed to ground:
  "(5) Slope. Ramps shall have the least slope practicable and shall not exceed 1:4 when deployed to ground level….."[2]

- A 1:4 slope is very difficult to navigate in a manual wheelchair. Recognizing this, the Architectural and Transportation Barriers Compliance Board created a rule on 12/14/2016 that revises existing accessibility guidelines for non-rail vehicles. According to federalregister.gov, "The final rule is effective January 13, 2017. Compliance with the final rule is not required until DOT revises its accessibility standards for buses, over-the-road buses, and vans acquired or remanufactured by entities covered by the ADA to be consistent with the final rule."[3] Here are some interesting quotes from the supplementary information for this rule on federalregister.gov:

  "…The 2016 Non-Rail Vehicle Guidelines revise and simplify the existing guidelines regarding running slope for ramps in non-rail vehicles. The existing guidelines specify a range of maximum running slopes for vehicle ramps depending on nature of deployment (e.g., deployment to sidewalk or roadway), with 1:4 being the steepest permitted maximum running slope for ramps deployed to the roadway. However, years of field experience and research studies have shown that 1:4 ramps are difficult to use and have resulted in safety concerns for many transit operators and passengers who use wheeled mobility devices. Newer vehicle and ramp designs now make deployment of ramps with lesser slopes feasible. Accordingly, the final rule specifies a maximum running slope of 1:6 for ramps deployed to roadways or curb-height bus stops, and 1:8 for ramps deployed to boarding platforms in level boarding bus systems."[3]

  "There were also documented incidents of wheelchairs and their occupants tipping over backwards going up bus ramps with 1:4 slopes."[3]

Reference links:
[1] https://www.access-board.gov/guidelines-and-standards/buildings-and-sites/about-the-ada-standards/ada-standards/chapter-4-accessible-routes
[2] https://www.ecfr.gov/cgi-bin/text-idx?c=ecfr&rgn=div5&view=text&node=49:1.0.1.1.28&idno=49#se49.1.38_123
[3] https://www.federalregister.gov/documents/2016/12/14/2016-28867/americans-with-disabilities-act-ada-accessibility-guidelines-for-transportation-vehicles

Design
Wheelchair Ramp

Design considerations

- Based on the team's determination that existing ramp slope regulations were not adequate, and input from the University of Michigan Inclusive Mobility Lab, a ramp slope target of 1:8 was established
    - 7-foot long ramp when loading from ground level
        - Required for pilot
    - 3-foot long ramp when loading from 6 inch curb
- Need ability to unload to ground level in an emergency

First modified shuttle – "two track" ramp

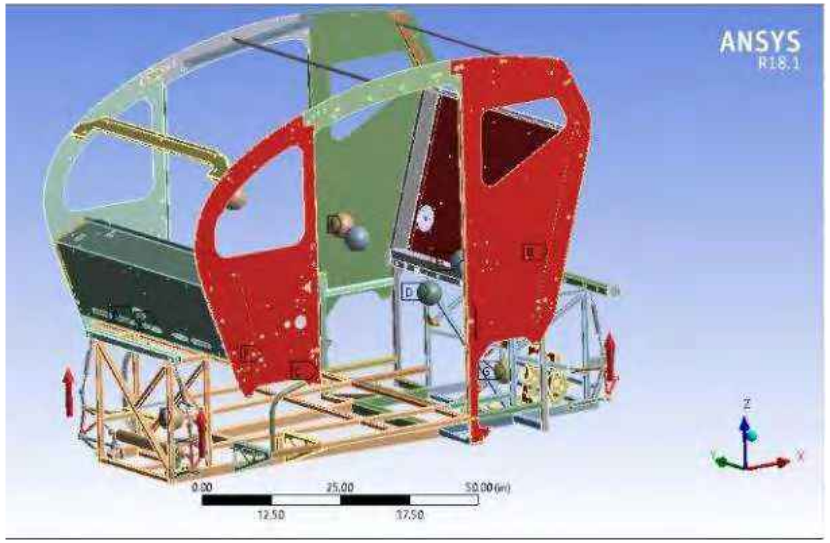
- Stows in box under floor
- Risk of user missing ramp on egress
- Inner side guards interfere with some low foot rests

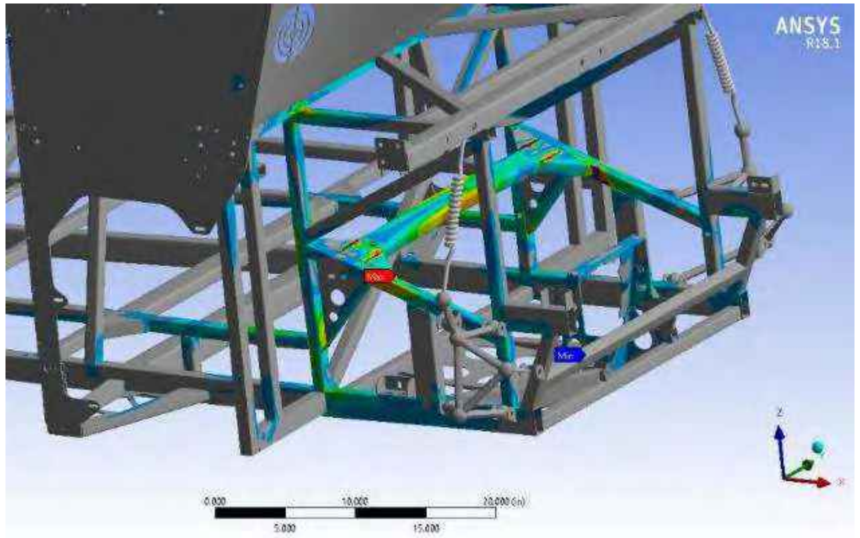
Second modified shuttle – full width ramp

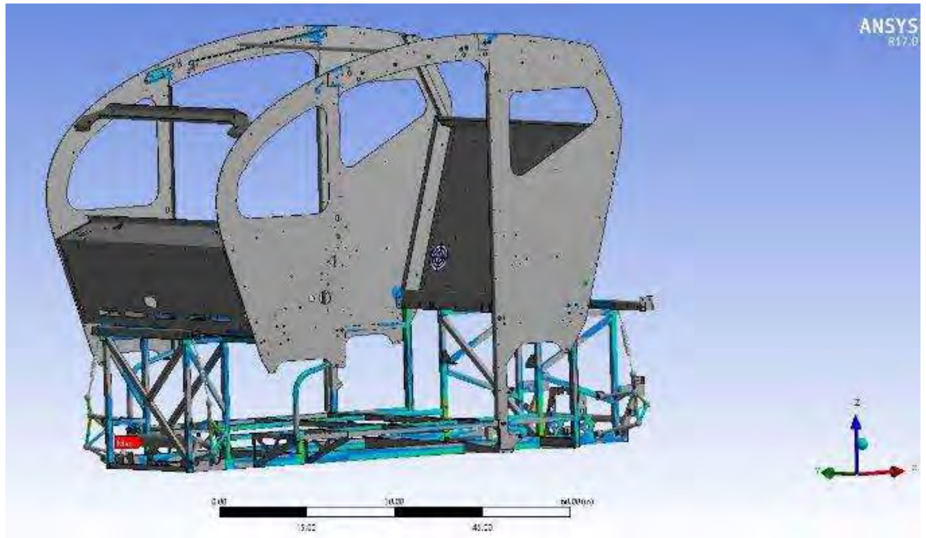
- Single telescoping ramp with fold-out transition
- Ramp stows below vehicle floor on guides
- Guides allow ramp to be stowed and deployed quickly
- Width constrained to 28" by fixed door mechanism components

Design
Structural Analysis

- Road load inputs applied at wheel center and contact patch depending on load
- Modifications to original structure driven by
  - Addition of restraint anchors for wheelchair and occupants
  - Part placement and component repackaging
  - Need for reinforcement in existing structure
  - Newly defined floor space
  - Ergonomic needs of passengers
  - Heavier vehicle weight and increased payload







Build Photos


Teardown


Teardown


Fixture set-up


Frame modification


Frame painting


Reassembly


Reassembly


Reassembly


Reassembly


Nearing completion

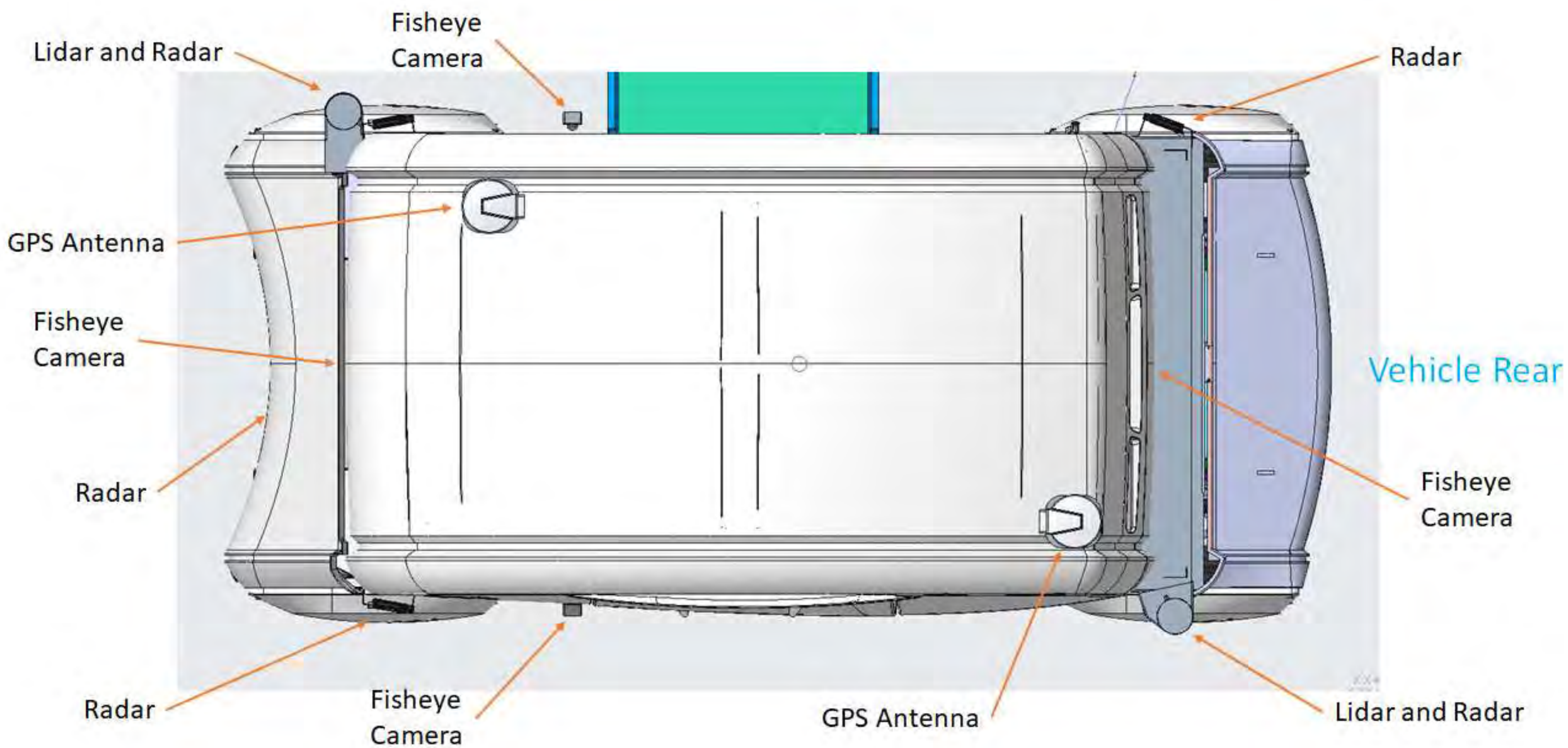
Autonomy (A-kit) Overview:

- Sensors and Data Collection
- Obstacle Detection/Tracking/Prediction
- Route Planning

Sensor Overview:

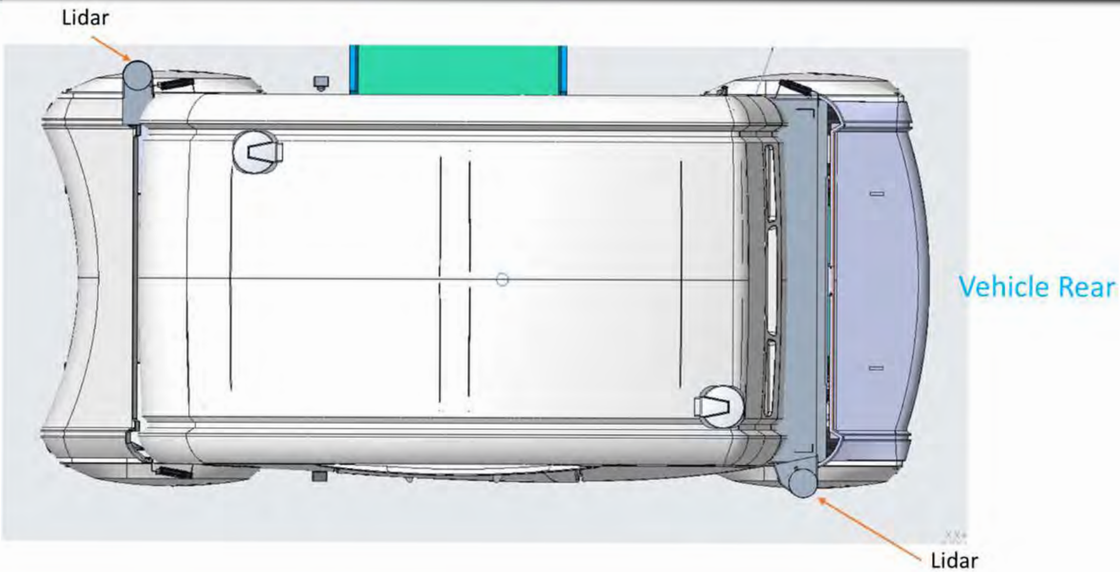
- LIDAR excel at 3D modeling of objects at near to medium ranges
- Radar excel at detecting moving objects like vehicles near to long ranges
- Cameras excel at object recognition

Autonomy Sensor Placement

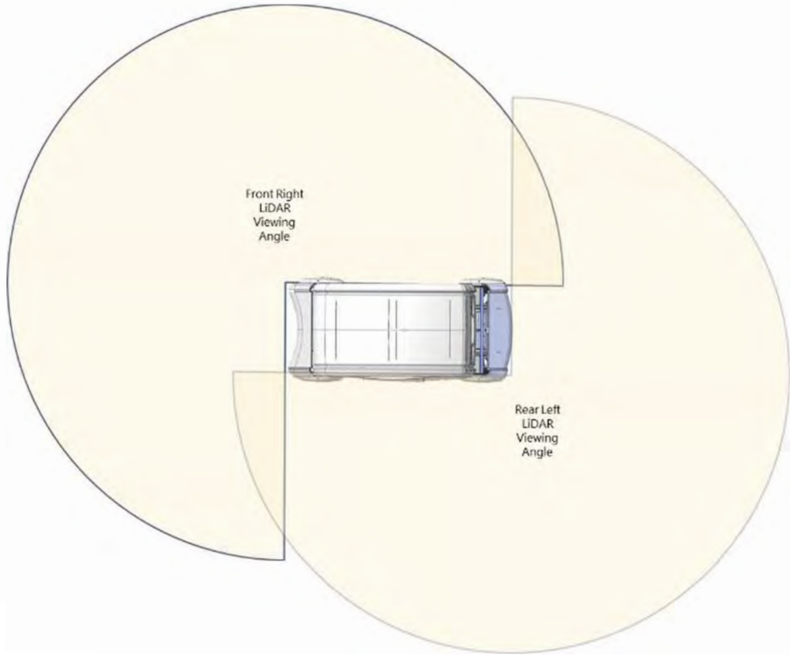


- Externally mounted autonomy hardware includes:
  - Sensors (2 Lidars, 4 Cameras, 5 Radars)
  - 2 GPS Antennas
- Internally mounted autonomy hardware includes:
  - 3 Computers (AM1, AM2, nSight)
  - 1 RR-N-140 Navigation System
  - 1 Cellular Modem
  - 2 Network Switches
- The Installed Sensors include:
  - 2 Velodyne VLP-16 Lidars
  - 1 Delphi ESR Radar
  - 4 Delphi SRR2 Radars
  - 4 Fisheye Cameras

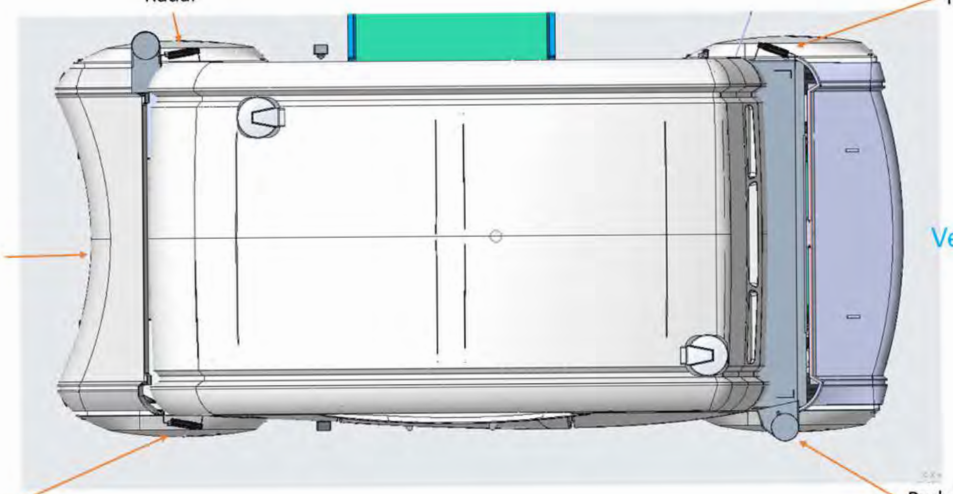
LIDAR



- 2 Velodyne VLP16 LIDARs
- Direct measurement of range and direction
- Not affected by lighting conditions
- Degraded by dust or fog

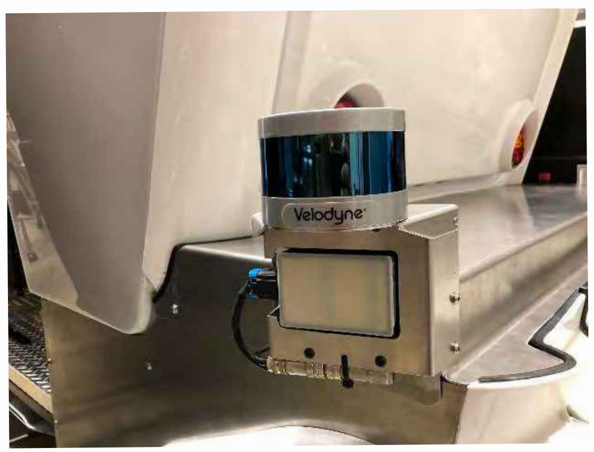


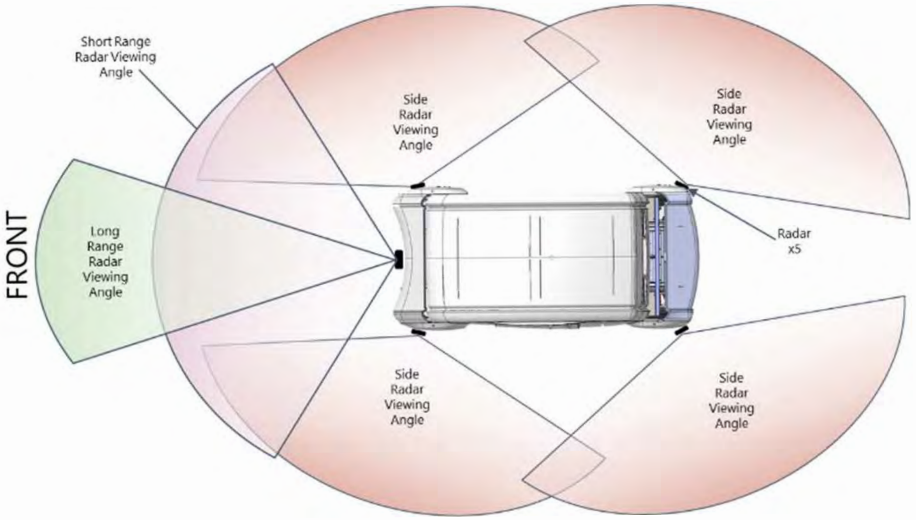
Autonomy Integration
Radar



- 1 Delphi ESR Radar
- 4 Delphi SRR2 Radars

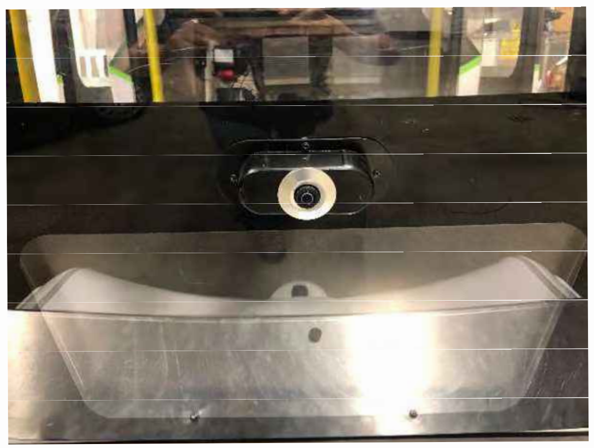
- Direct measurement of range
- Direct measurement of relative velocity
- Not affected by lighting conditions
- Less sensitive to dust or fog

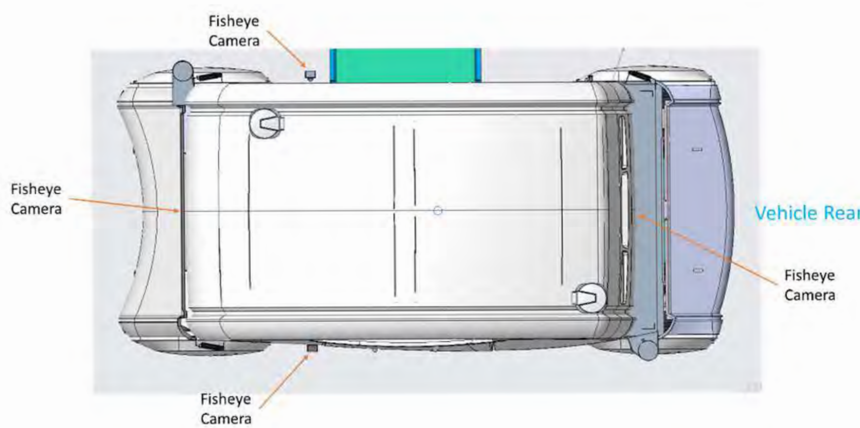


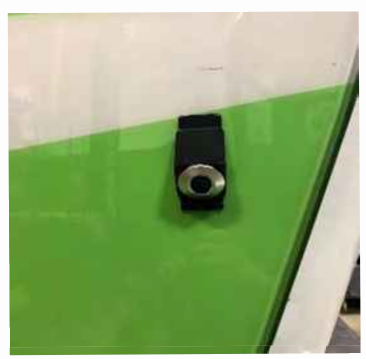


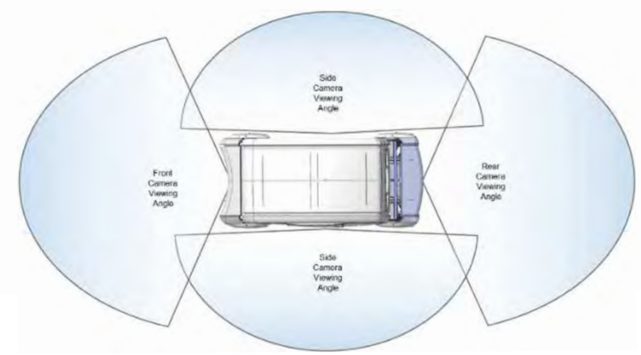
Autonomy Integration
Cameras

- 4 Cameras
- High resolution
- Direct measurement of color and direction
- Sensitive to lighting conditions
- Sensitive to dust or fog



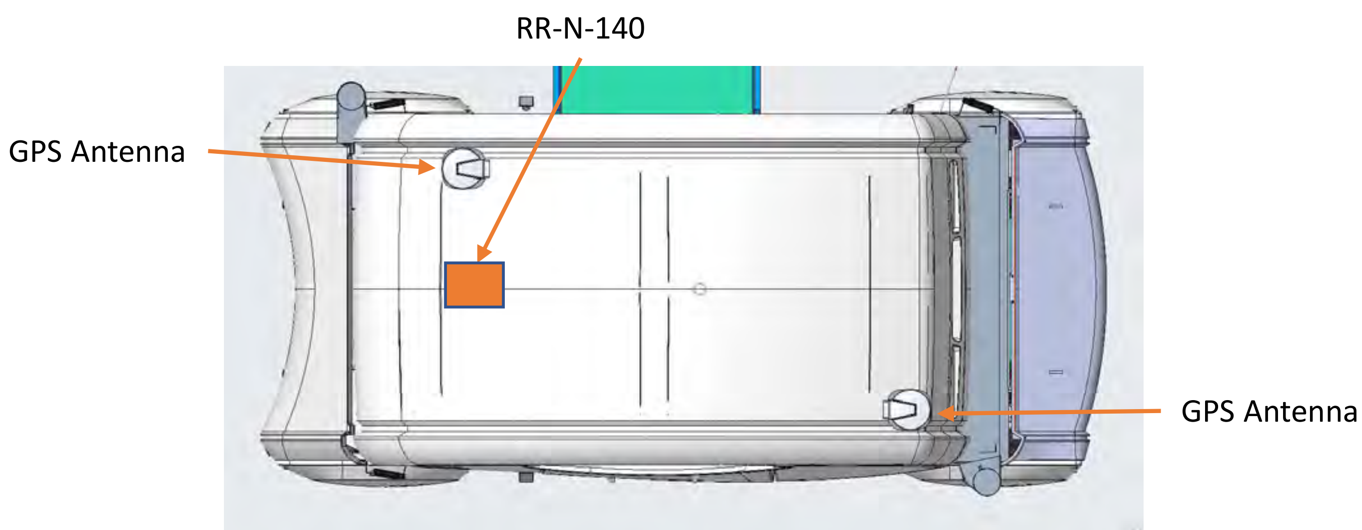






Autonomy Integration
RR-N-140 Navigation System

Performance	
Relative Position	0.5% DT(Distance Travelled)
Horizontal Position Accuracy (RMS)	Single Point L1/L2: 1.2m With RCTM correction: 0.01m+1ppm
Heading Accuracy	2.0 m Baseline 0.08° 4.0 m Baseline 0.05°
Maximum Velocity	515 m/s
Angular Rates	±1000 °/s
Angular Bias Stability	≤0.05 °/hr

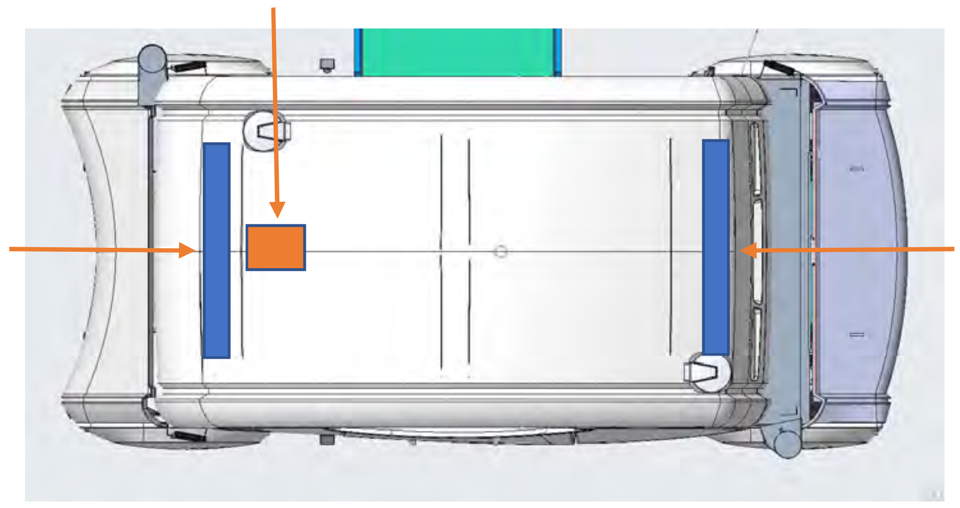


Autonomy Integration
Front and Rear Enclosures

- All Autonomy Kit hardware is mounted within 3 locations:
  - Front Enclosure behind front seats
  - Rear Enclosure behind rear seats
  - Under front floor boards

- The internally mounted hardware includes:
  - 3 Computers (AM1, AM2, nSight)
  - 1 RR-N-140 Navigation System
  - 1 Cellular Modem
  - 2 Network Switches

- The majority of the components are mounted within the front and rear enclosures. Only the RR-N-140 Navigation system is mounted under the front floor boards.



Test Plan

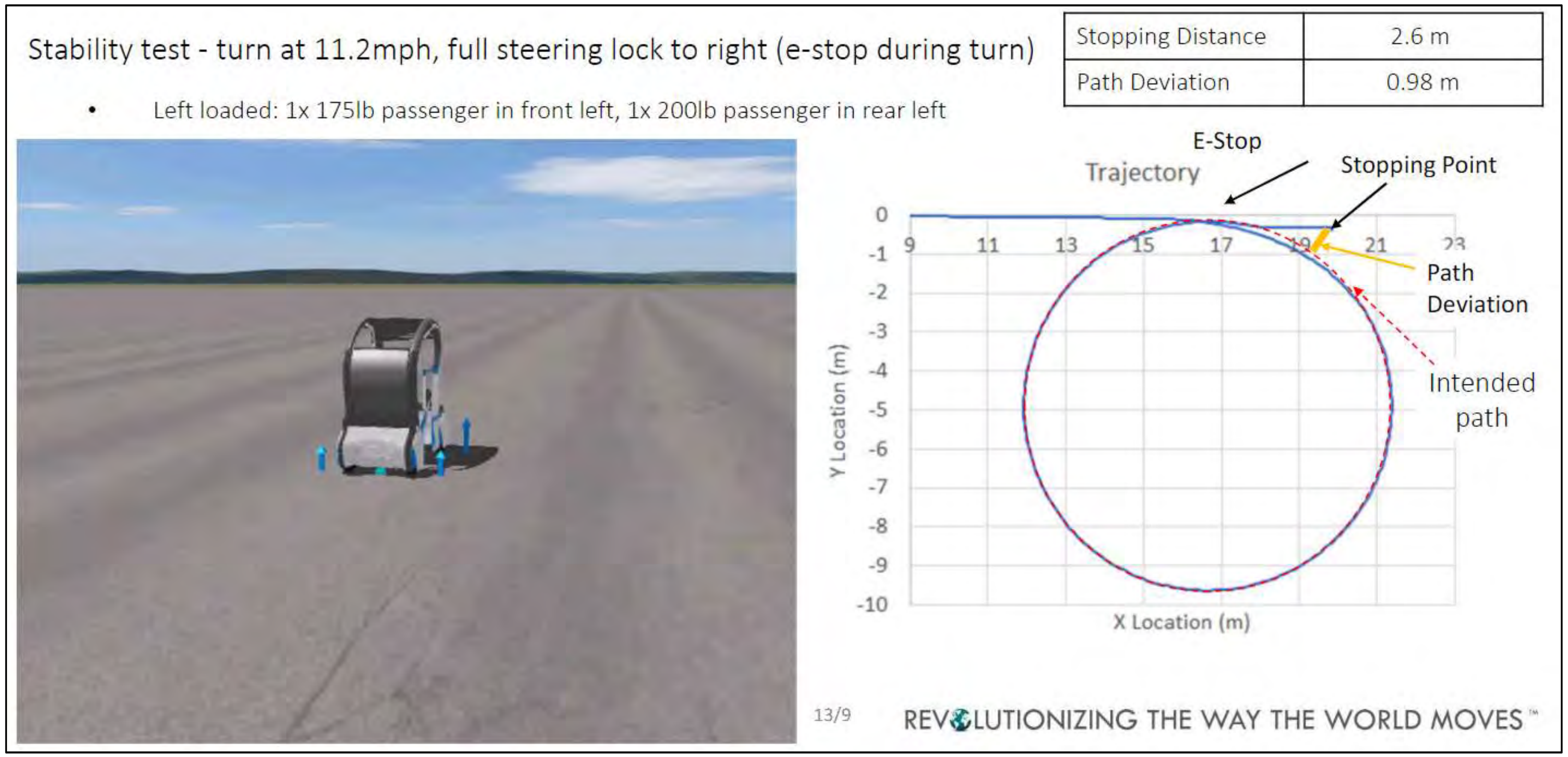
- The test plan included tests for each of the following:
  - Base Platform Behavior
    - Manual Control
    - Estop Behavior
    - Max accel, decel, speed in both Manual and Autonomous Modes
    - Brake Startup Tests
  - Obstacle Detection
    - Max obstacle detection distance for Pedestrian and Vehicle
  - Obstacle Avoidance
    - Autonomous tests to avoid static and dynamic obstacles.
    - Vehicle tests include: Following a vehicle, vehicle following us, vehicles crossing our path at intersections
    - Pedestrian crossings
    - Does vehicle stop within safe tolerance?
  - Robotic Behavior
    - Verify the robotic behavior in a number of scenarios
    - Intersections
    - Stop Signs
  - Vehicle range determination
  - Operation at various loadings (one person, GVW)

Testing
Base Vehicle Tests

- All of the following were tested and verified:
  - Motor brakes apply on power loss
  - Brakes apply on A-kit communications loss
  - All Estop Buttons function
  - Estop Stopping distance (see subsequent slides)
  - Steering behavior when Estop engages:
    - Steering will command to zero position (straight) when an Estop occurs.
    - Risk was assessed through simulation (see next slide)
- When the Xbox controller loses communications, it defaults to autonomous control
  - This was an unacceptable risk so a check was added in the A-kit software to check for controller comms loss
  - In order for the vehicle to operate in autonomous mode, the safety operator must keep a button depressed on the Xbox controller

Testing
Simulation of E-stop in Turn

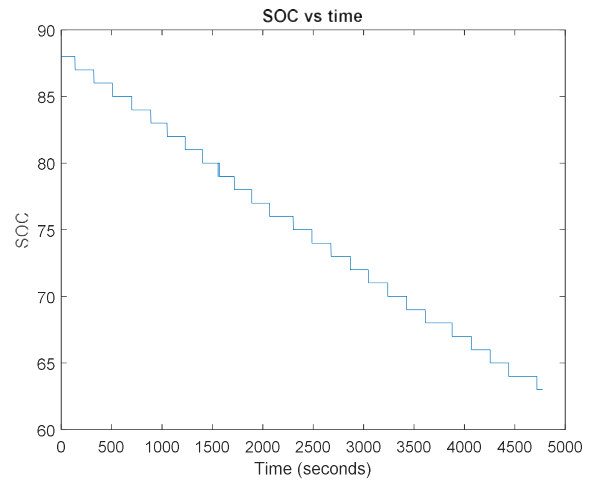
- Steering is commanded to straight-ahead when E-stop is pressed
- CarSim model used to predict path deviation when navigating full-lock turn at 11.2 mph (top speed in autonomous mode)
  - Physical testing of this worst-case scenario was not practical due to limitations of test facility
  - Actual speed in turn will be significantly less than 11.2 mph, because autonomous system will limit lateral acceleration
  - Top speed during WMU pilot will be limited to 3.4 mph
- At 11.2 mph, path deviation is predicted to be 0.98m; will be less in practice due to lower speed



Stopping Distance	2.6 m
Path Deviation	0.98 m

Testing
Battery Range

- Functional lithium iron phosphate batteries were not available until after Robotic Research autonomy testing was complete
- Battery range is dependent on duty cycle
  - Duty Cycle #1 - Robotic Research test loop (autonomous mode, 11 mph top speed)
    - Tested with lead acid batteries
      - 7.5 miles over 2.8 hours
    - Lithium iron phosphate estimate
      - 11.7 miles over 4.4 hours
  - Duty Cycle #2 - PME test loop (manual mode, 6.7 mph top speed)
    - Tested with lithium iron phosphate
    - Drove 7 miles over 1.3 hours on flat grade, state of charge (SOC) decreased 25%
    - Extrapolates to 5.3 hours of drive time, or 28.5 miles.



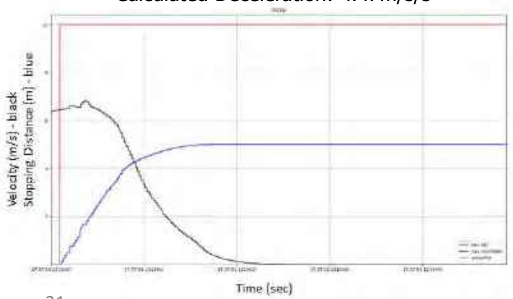
- Duty Cycle #3 – WMU pilot (autonomous mode, 3.4 mph top speed due to pedestrian area)
  - Tested with lithium iron phosphate
  - Includes lower top speed, but also a sustained grade (uphill going north, downhill going south)
  - 2% loss in SOC going north; 1% loss going south
  - Estimated range of 30 round trips or approximately 7.5 hours

Testing
E-stop Tests

- The Estop system was tested to verify safe behavior and stopping distance at various speeds and loads
- Tested both in autonomous and manual mode (sample data shown below)
- During an Estop event, the base platform commands steering to zero position

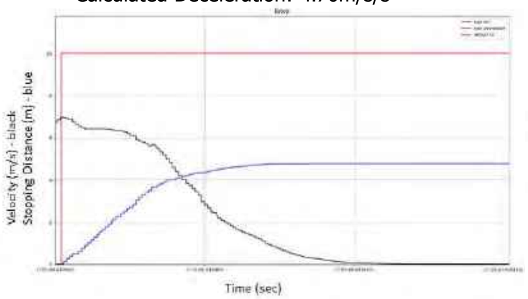
Estop Test 1

- Autonomous Mode
- Commanded Speed 7.0m/s
- Max Actual Speed: 6.7m/s
- Load: Full Load (4 people)
- Stopping Distance: 5.02m
- Calculated Deceleration: 4.47m/s/s



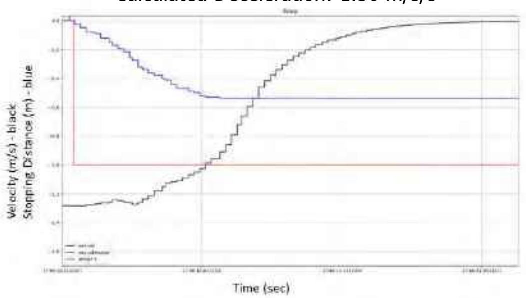
Estop Test 2

- Autonomous Mode
- Commanded Speed 7.0m/s
- Max Actual Speed: 6.7m/s
- Load: Off Center Load (2 people on left side only)
- Stopping Distance: 4.77m
- Calculated Deceleration: 4.70m/s/s



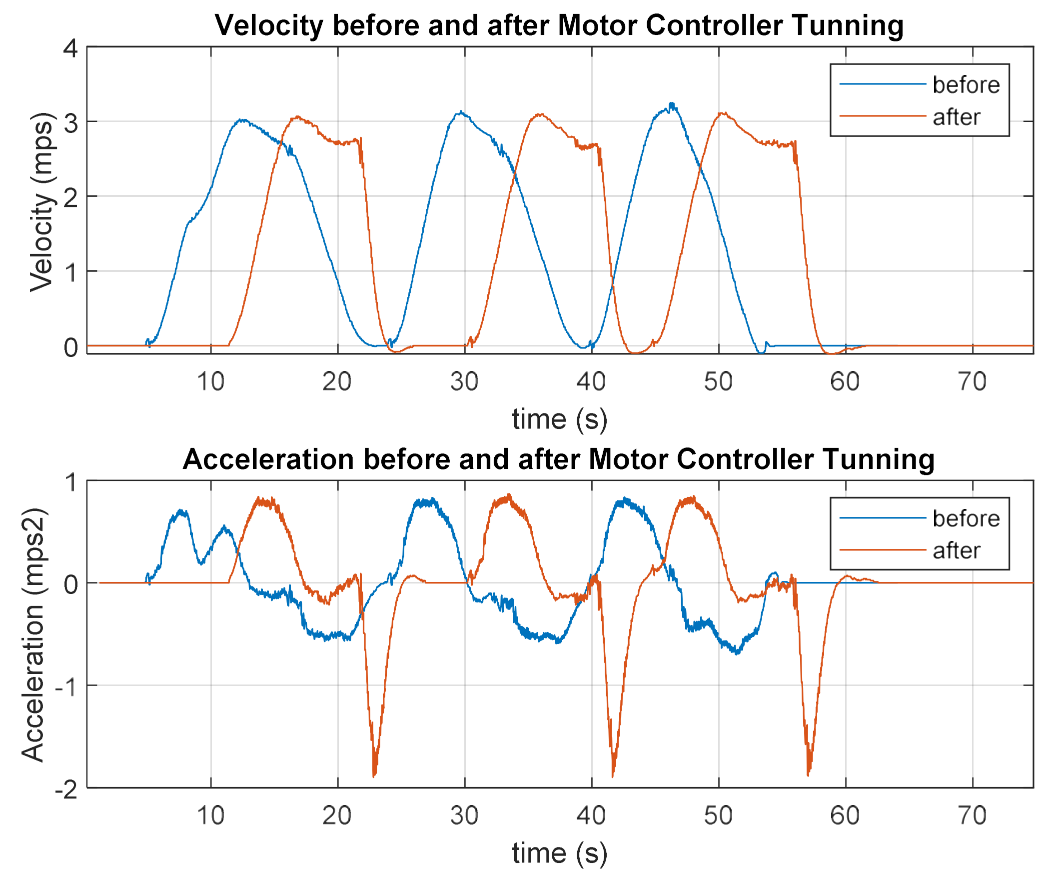
Estop Test 3

- Manual Mode
- Reverse – Max Speed allowable
- Max actual speed: -1.3m/s
- Load: Full Load (4 people)
- Stopping Distance: 0.54m
- Calculated Deceleration: 1.56 m/s/s



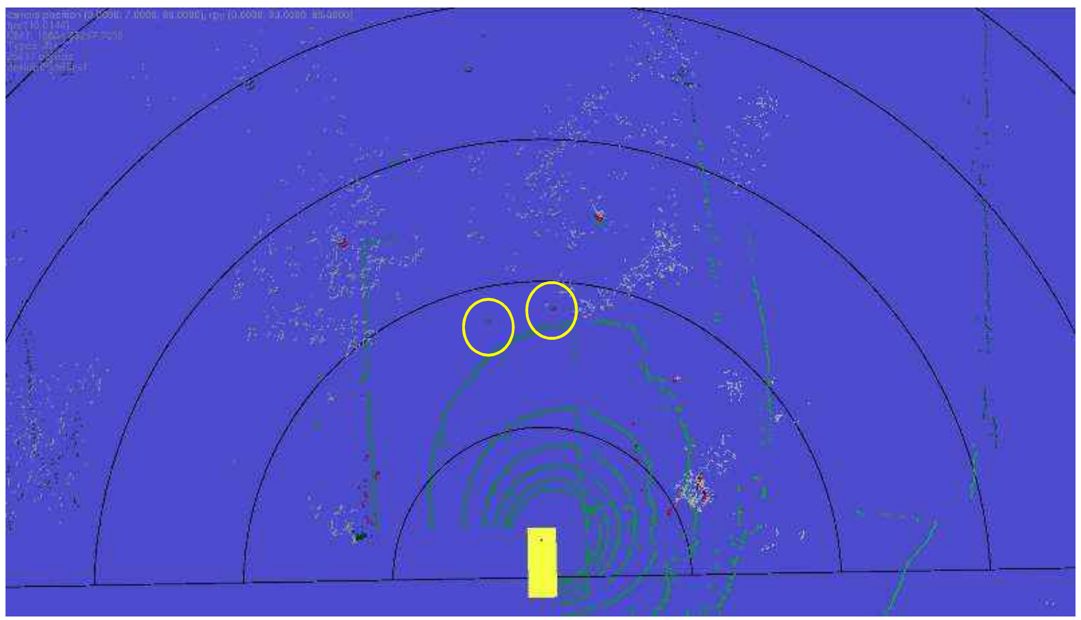
Testing
Regen Deceleration Tests

- By design, it is not possible to modulate the hydraulic brakes and motor brake; those systems are designed for parking and emergency stopping only
- During normal driving, deceleration is accomplished through regenerative braking
- Initially, the vehicle was not decelerating fast enough using only regenerative braking
- Regenerative braking parameters within the traction motor controller were adjusted
- After adjustments, maximum deceleration increased significantly and was sufficient for vehicle control in autonomous mode



Testing

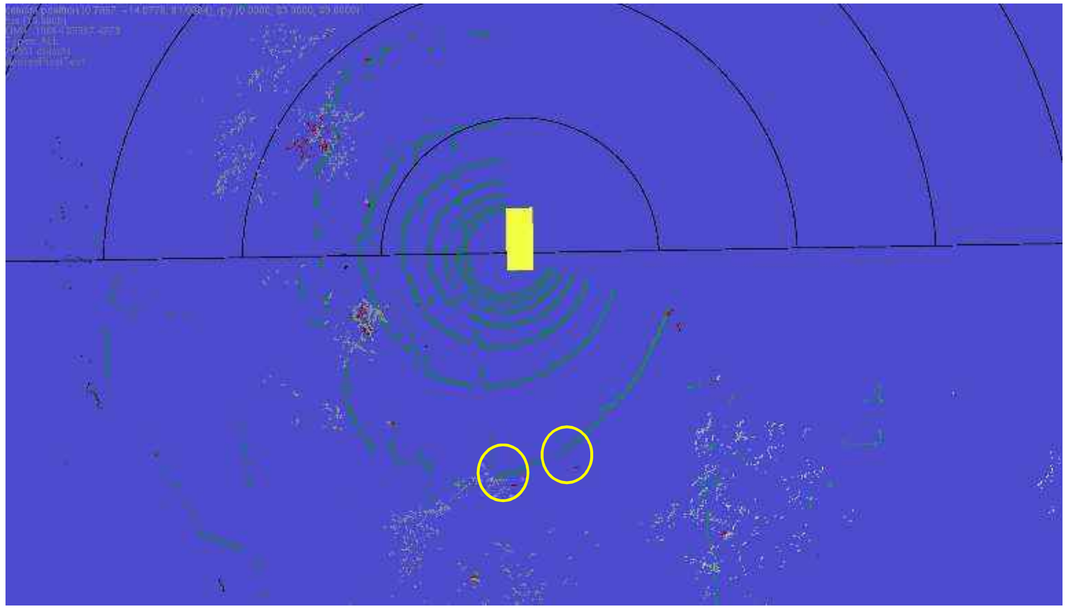
Perception Tests: Forward LIDAR



- Test Results from front lidar sensor unit
- Top image shows camera frame of test scene with car (on left) and pedestrian (on right)
- Bottom image shows overhead lidar output of test scene where the circled red points indicate car and pedestrian.
  - Red pixels are obstacle
  - Green pixels are ground
  - White pixels are cover/overhang
- Tests were performed by parking a car and a mannequin side-by-side and driving the robot towards subjects until our classification software consistently classified both subjects as obstacles
- The distance from the vehicle to the obstacle was then recorded

Obstacle Type	Furthest Distance Seen
Pedestrian	19 meters
Vehicle (Black Sedan)	17 meters
Vehicle (White Sedan)	21 meters

Perception Tests: Rear LIDAR



- Test Results from rear lidar sensor unit
- Top image shows camera frame of test scene with car (on left) and pedestrian (on right)
- Bottom image shows overhead lidar output of test scene where the circled red points indicate car and pedestrian.
  - Red pixels are obstacle
  - Green pixels are ground
  - White pixels are cover/overhang
- Tests were performed by parking a car and a mannequin side-by-side and reversing the robot into subjects until our classification software consistently classified both subjects as obstacles
- The distance from the vehicle to the obstacle was then recorded

Obstacle Type	Furthest Distance Seen
Pedestrian	19 meters
Vehicle (Black Sedan)	17 meters
Vehicle (White Sedan)	21 meters

Testing

Perception Tests: Stopping Before Obstacles

- The following objects were set along a robot's autonomous path
- Robot commanded to follow path at 5.0m/s
- Robot stopped before obstacles and the distance from the front center of the vehicle to the center of the obstacle was recorded.

Obstacle Type	Distance from Obstacle When Stopped (meters)
Traffic Barrel	9.5 meters
Static Mannequin (3ft tall)	5.3 meters

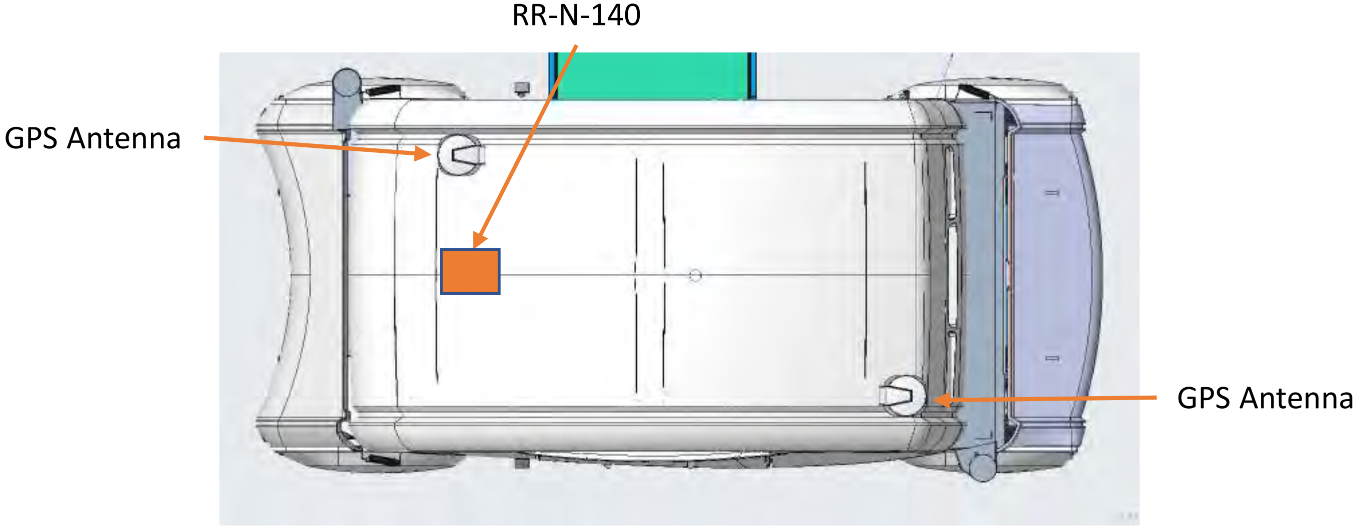
Perception Tests: Radar

- The robot was parked at the bottom of a three-way intersection
- A test vehicle was instructed to cross the intersection from side to side
- The max distances the radar tracks on test vehicle were recorded
- This was done for both the front-facing side radars and rear-facing side radars
- The detection differences between front and rear are near the edges of the radar detection ranges.

Radar Unit	Maximum Distance Car Seen
Front Radar	75 meters
Rear Radar	80 meters

Testing
RR-N-140 Navigation System

- The localization system was tested to verify performance and accuracy.
- Tests performed:
  - Passed: N140 has less than 1% error per distance travelled for relative position
  - Passed: N140 can connect to RTK Basestation and converges to less than 0.1m
  - Passed: N140 map registration is less than 0.3m
  - Passed: GPS antenna SNR is greater than 46db



Testing
Autonomous Behavior

- The autonomous system behavior was tested under different scenarios.

- Passed: Verify Autonomous system navigates Intersections correctly
  - Intersections with vehicular cross traffic
  - Intersections with Stop Signs
- Passed: Vehicle follows command path (staying within lane)
- Passed: Turn Signal Functionality
- Passed: Ability to traverse uphill and downhill at 6% grade
- Passed: Ability to traverse around pedestrians and vehicular traffic

Accessibility and Usability Evaluation of the Modified Shuttle

Overview

Study Objectives: To engage people with mobility impairments in an accessibility and usability evaluation of the modified shuttle and identify design recommendations for improvement.

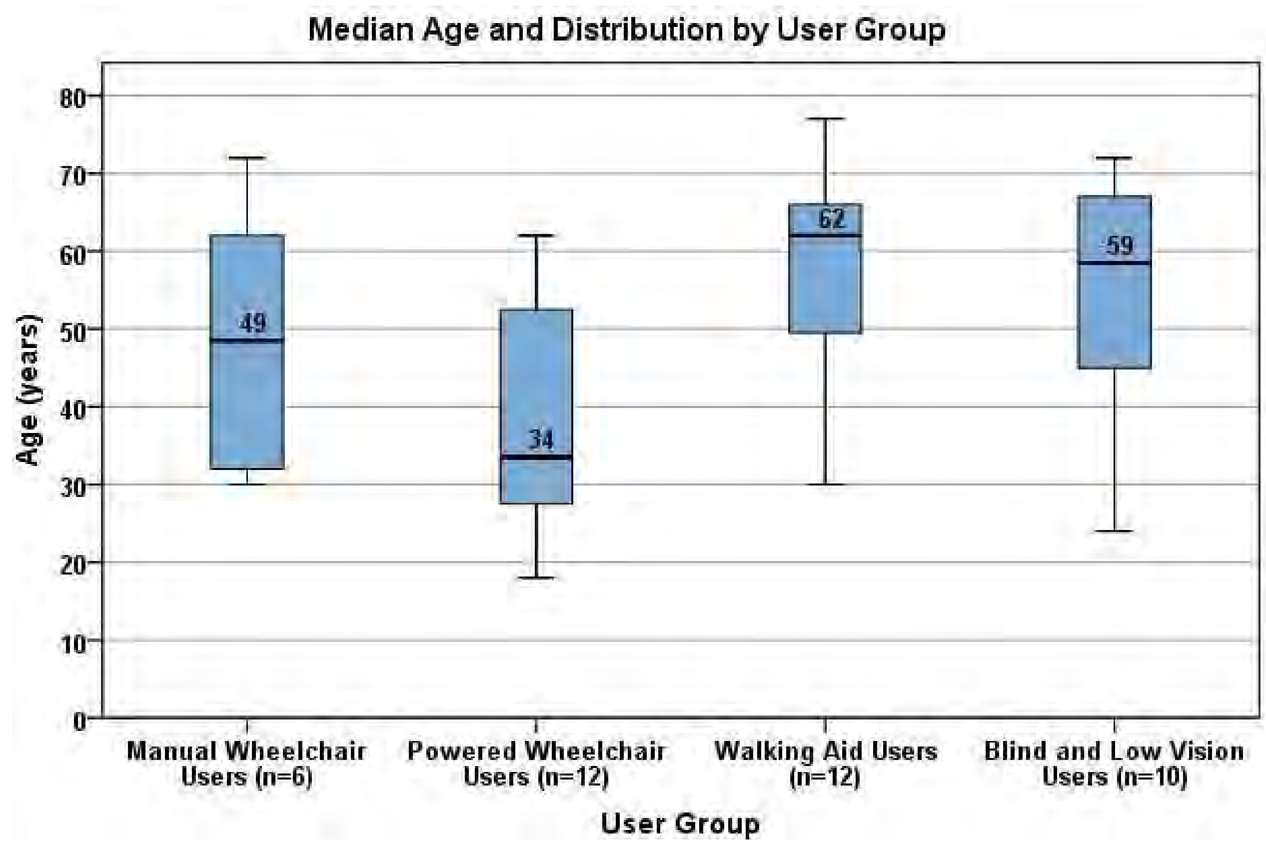
- **Accessibility**: we assessed whether users could independently complete key tasks of ingress, seating or wheelchair securement, egress
- **Usability**: obtained feedback about difficulty experienced, safety concerns when performing above tasks.

Study Procedure

- Initial demographic interview about general health, travel patterns and preferences
- Semi-structured interview with researcher after performing following tasks on a stationary, parked shuttle:
  - ✓ Enter vehicle, either stepping into or by access ramp
  - ✓ If ambulatory: tried both front & rear-facing seats and seat-belts
  - ✓ If using wheeled mobility device: maneuver to and use securement area, device securement performed by researcher
  - ✓ Exit vehicle
- 60-75 minutes per participant; given honorarium
- Entire process audio recorded for transcription and analysis

Study Sample

- Recruited participants from various SE Michigan disability organizations
- 40 participants
  - 16 (40%) men, 24 (60%) women
- Median age: 53.5 years, range: 18 to 77 years.
- Diverse medical conditions, most had multiple conditions
  - arthritis (15)
  - spinal cord injuries (7)
  - cerebral palsy (3)
  - multiple sclerosis (3)
  - stroke (3)



- 4 user groups based on mobility device used
  - Manual wheelchair users, n = 6
  - Powered wheelchair users, n = 12 (includes 1 scooter user)
  - Walking aid users, n = 12 (used either walker or cane for ambulation)
  - Blind and low-vision users, n = 10 (used either white cane or service animal)

Accessibility and Usability Evaluation of the Modified Shuttle

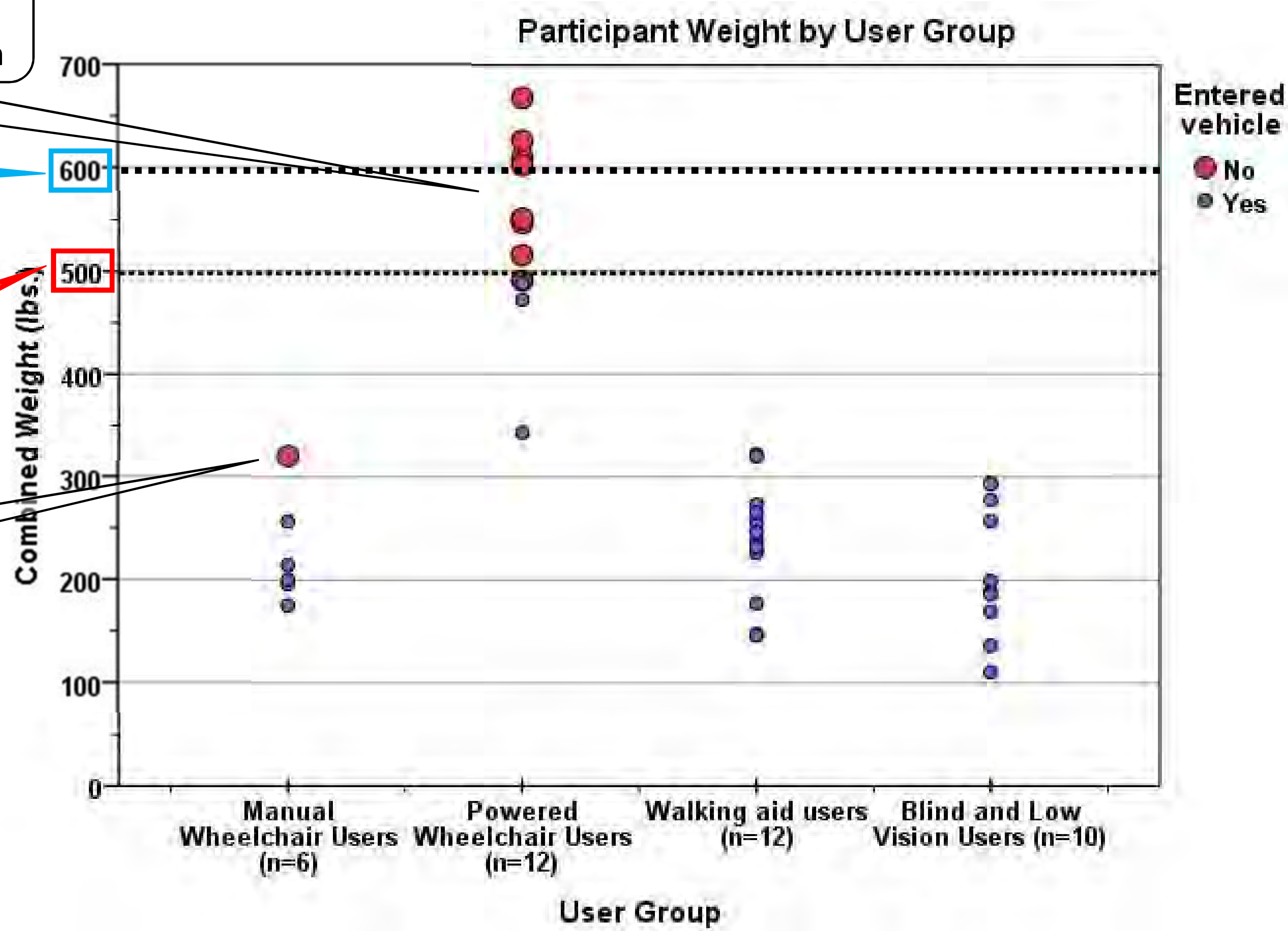
Findings: weight limit

Powered wheelchair users: 539±86 lbs.
Only 4 of 12 below 500 lbs. weight limit
1 participant (497 lbs) declined due to safety concern

ADA Accessibility Standards
Min. 600 lbs. design load for access ramp

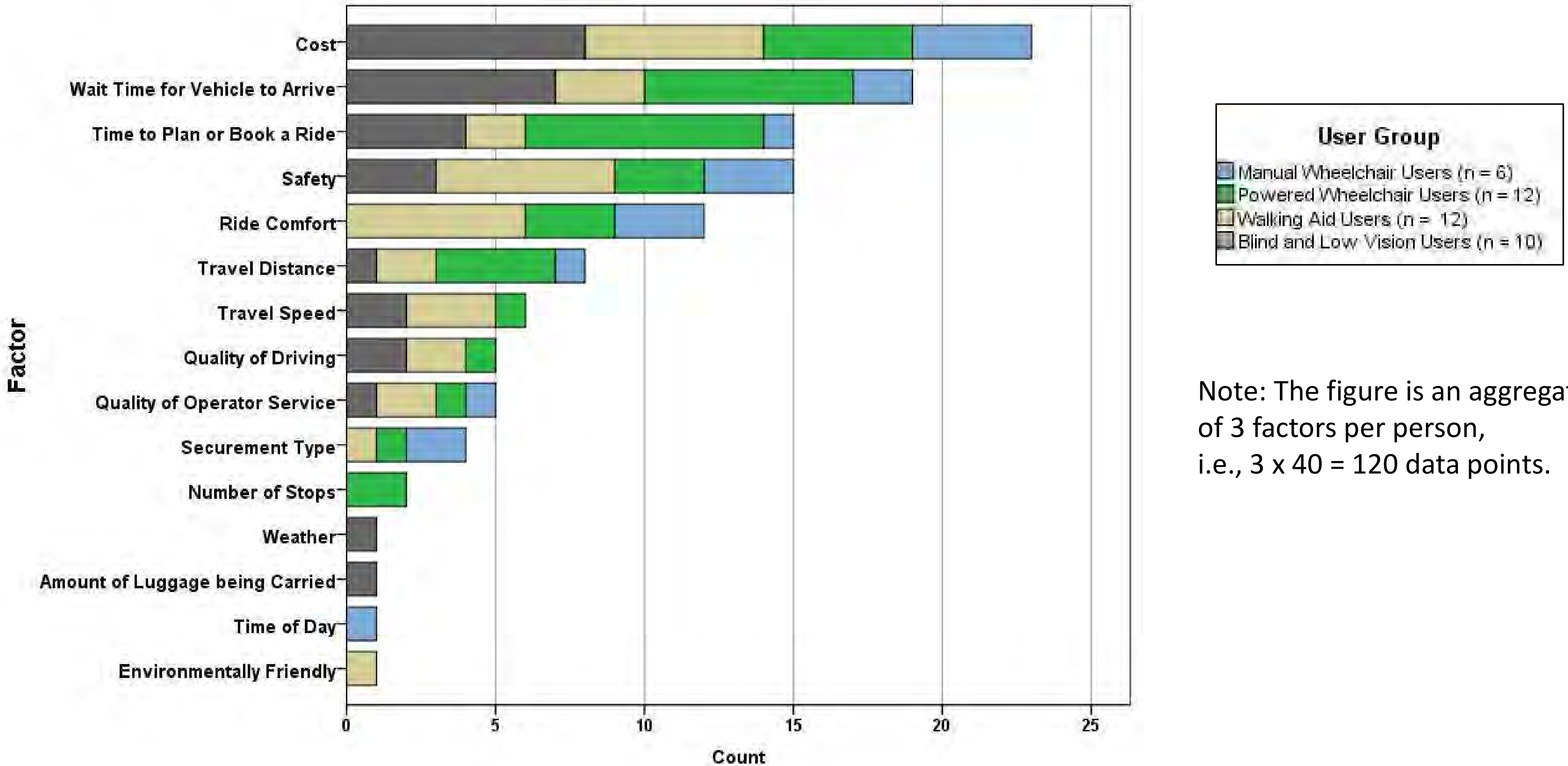
Access ramp weight limit
450 lbs. weight limit for the access ramp
500 lbs. with added support beneath for this study

Manual wheelchair users: 227±53 lbs.
N=1 wide wheel camber; did not fit on ramp.
Ramp slope reported acceptable



Findings: Important factors affecting mode choice

Q: List the 3 most important factors you consider when deciding which mode of transportation to take



Note: The figure is an aggregate of 3 factors per person, i.e., 3 x 40 = 120 data points.

Findings: Perceptions about AVs (before evaluation)

Q: Have you ever been a passenger in an autonomous vehicle?

	Manual Wheelchair users (n = 6)	Powered Wheelchair users (n = 12)	Walking aid users (n = 12)	Blind and low-vision users (n = 10)	Total (n = 40)
Yes	1*	0	1*	1*	3 (7.5%)*
No	5	12	11	9	37 (92.5%)

** Participant had used the NAVYA driverless shuttle at U-M campus*

Q: Do you think that autonomous vehicles can benefit you/your travel habits?

	Manual Wheelchair users (n = 6)	Powered Wheelchair users (n = 12)	Walking aid users (n = 12)	Blind and low-vision users (n = 10)	Total (n = 40)
Yes	6	10	9	9	34 (85%)
No	0	0	2	1	3 (7.5%)
Other	0	2	1	0	3 (7.5%)

Findings: Perceptions after evaluation

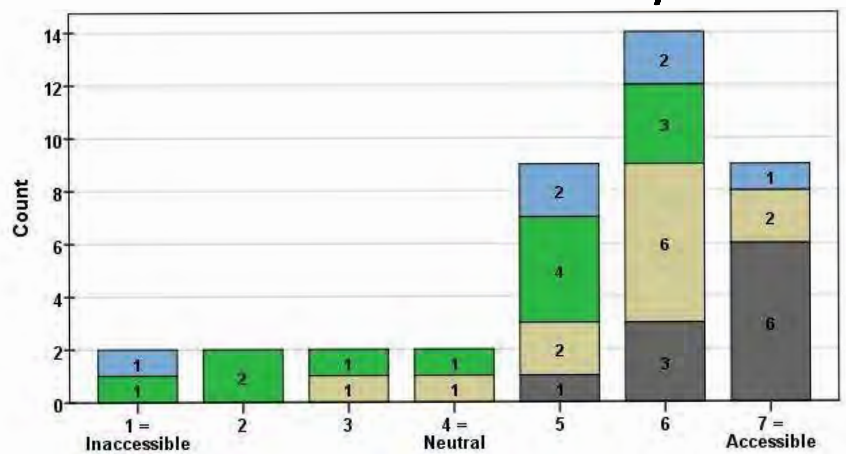
Q: Would you be interested in riding this driverless shuttle if it were operational or in service?

	Manual Wheelchair users (n = 6)	Powered Wheelchair users (n = 12)	Walking aid users (n = 12)	Blind and low-vision users (n = 10)	Total (n = 40)
Yes, without reservation	5	3	3	9	20 (50%)
Yes, only if an operator were able to help me	1	7	8	0	16 (40%)
No, I would not be interested in riding this shuttle	0	1	1	0	2 (5%)
I don't know	0	1	0	1	2 (5%)

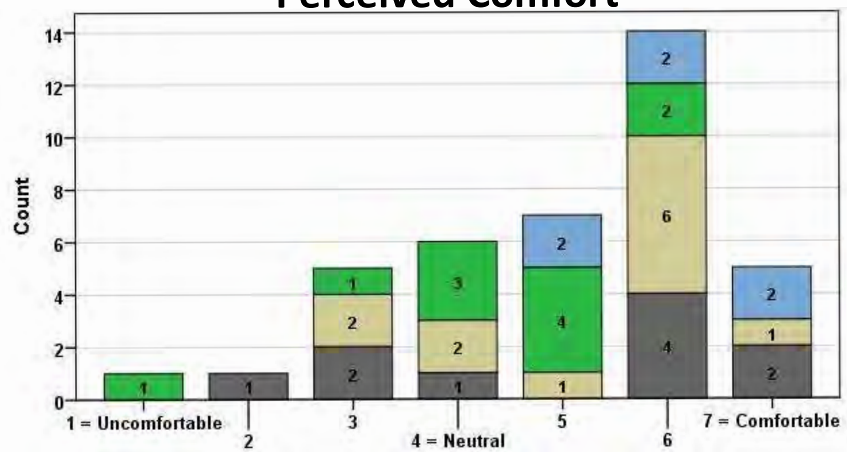
Findings: Post-evaluation feedback

Q: Indicate your general outlook about this vehicle on the following 7-pt scales:

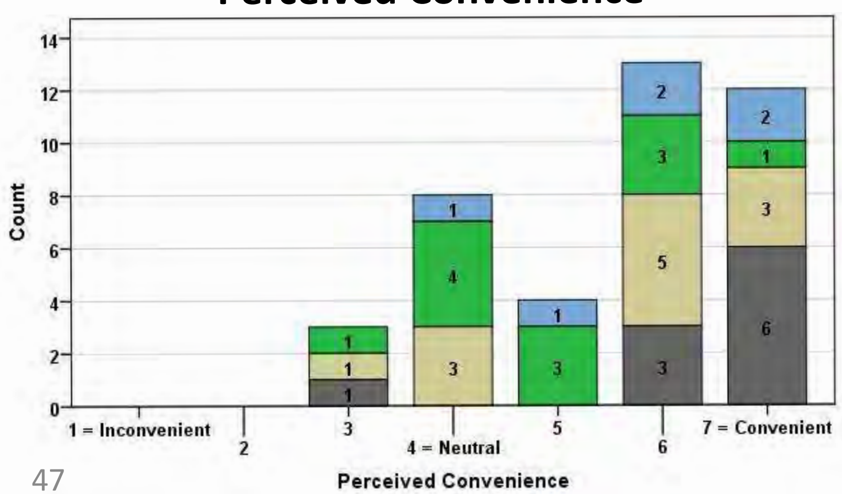
Perceived Accessibility



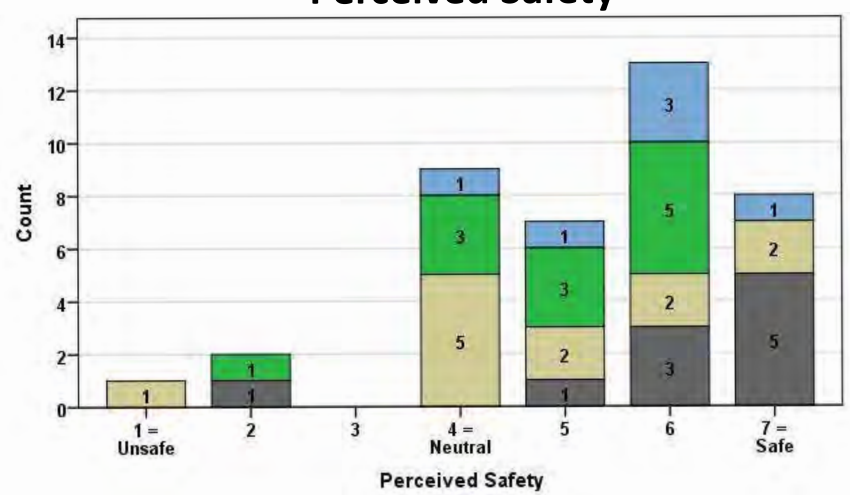
Perceived Comfort



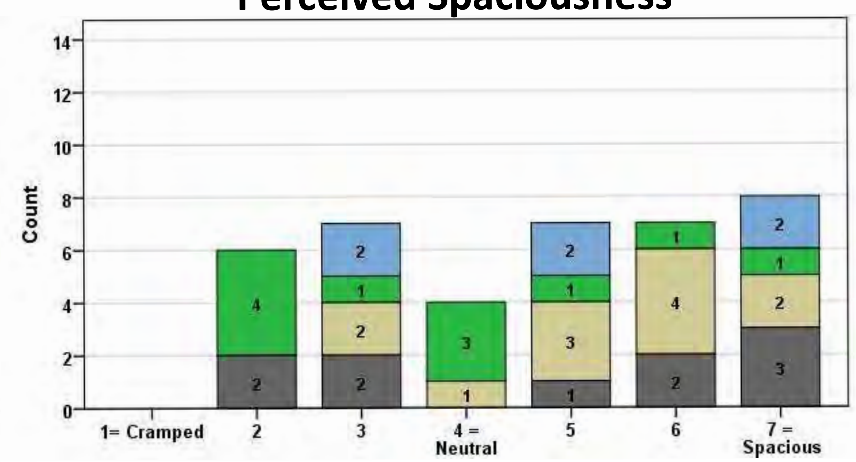
Perceived Convenience



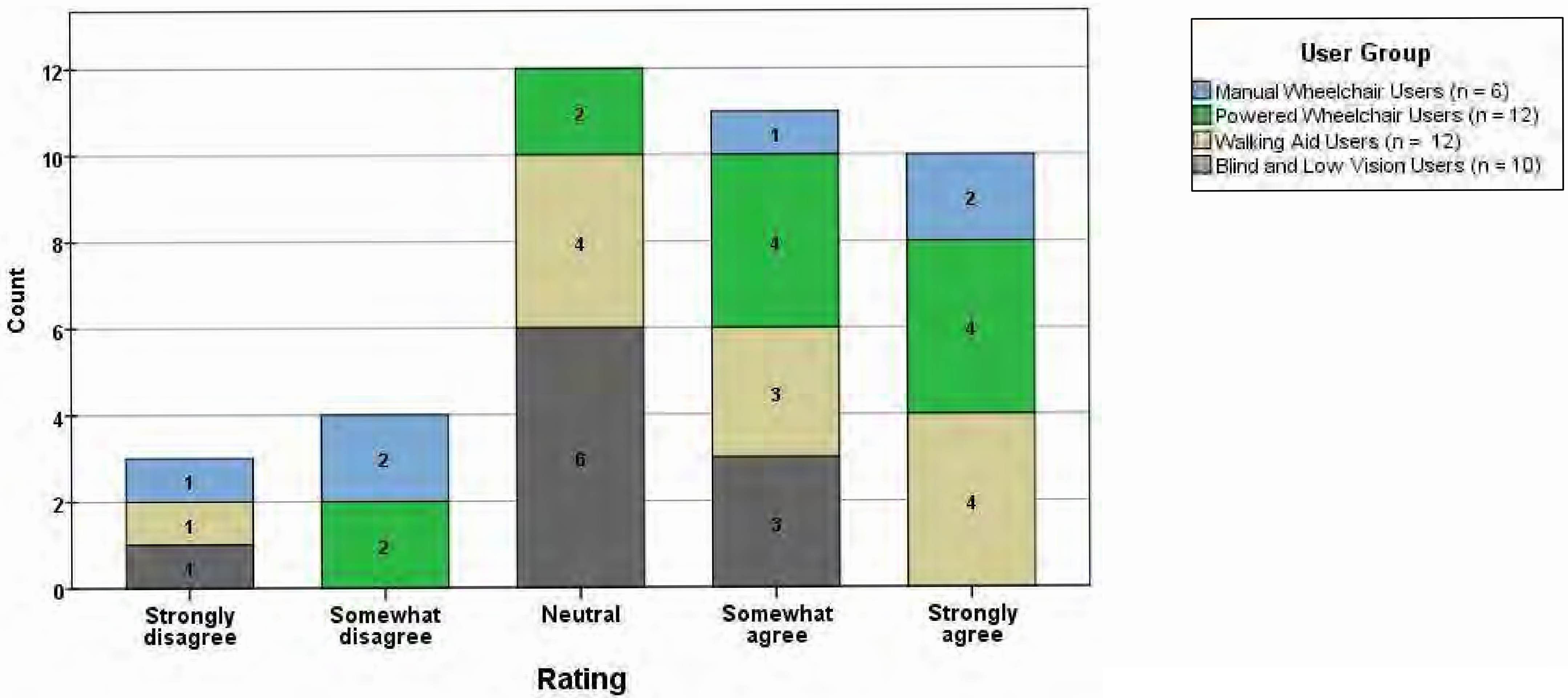
Perceived Safety



Perceived Spaciousness

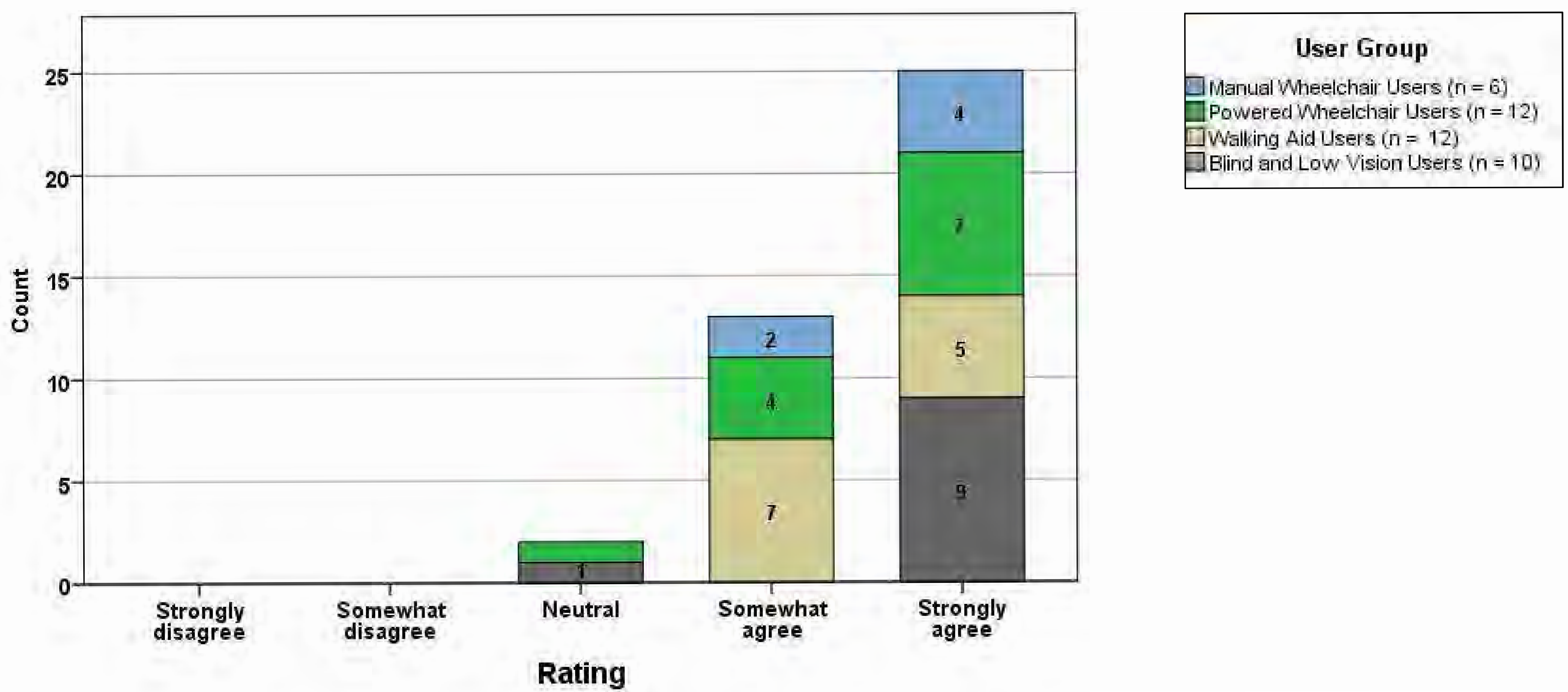


Q: Rate your level of agreement with the following statement:
"I would prefer to use the vehicle with other passengers in the vehicle as well."



Findings: Post-evaluation feedback

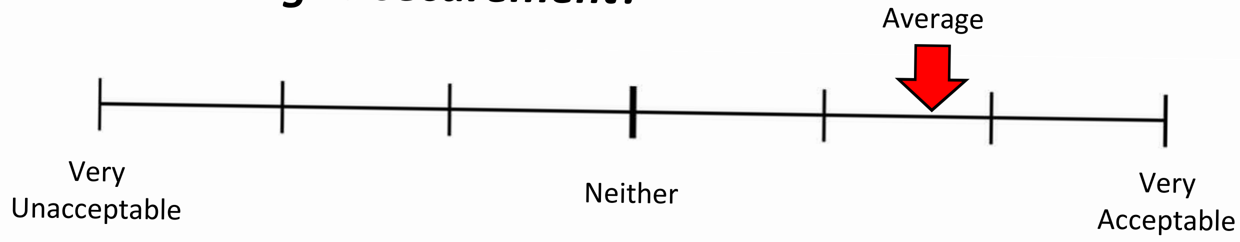
Q: Rate your level of agreement with the following statement:
"Given that I had access to the vehicle, I predict that I would use it."



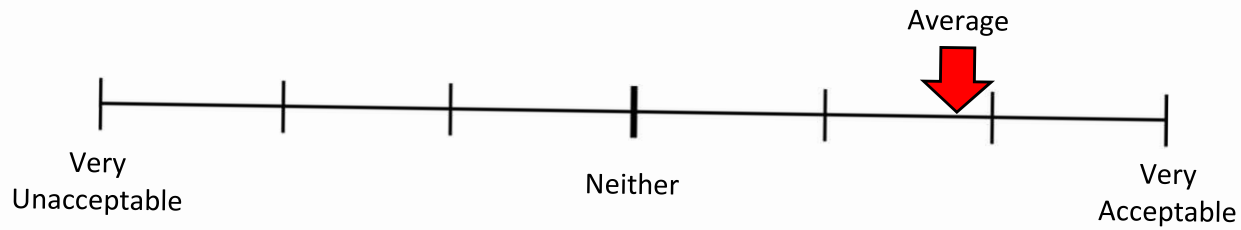
Commonly reported positive and negative comments, and design recommendations

Accessibility and Usability Evaluation of the Modified Shuttle
Findings: Manual Wheelchair Users (n=6)

Q: How acceptable was the open floor space in the shuttle for maneuvering to securement?

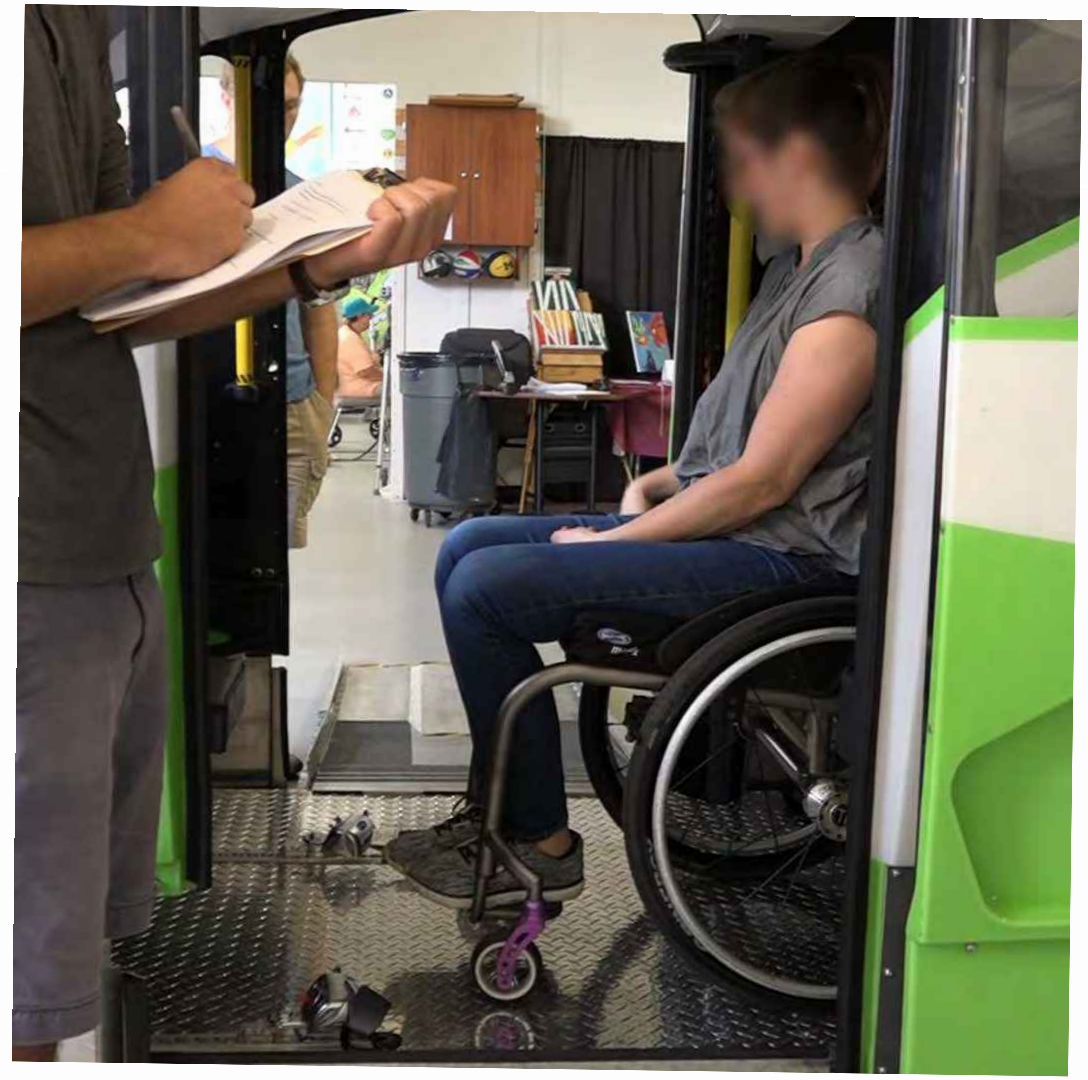


Q: How acceptable is the vehicle's securement system?



Interview Highlights

- Majority said the vehicle interior floor space was adequately spacious; 2 users reported the space felt cramped
- 1 user liked the vehicle doors sliding to the side, takes less space than doors that swing outwards



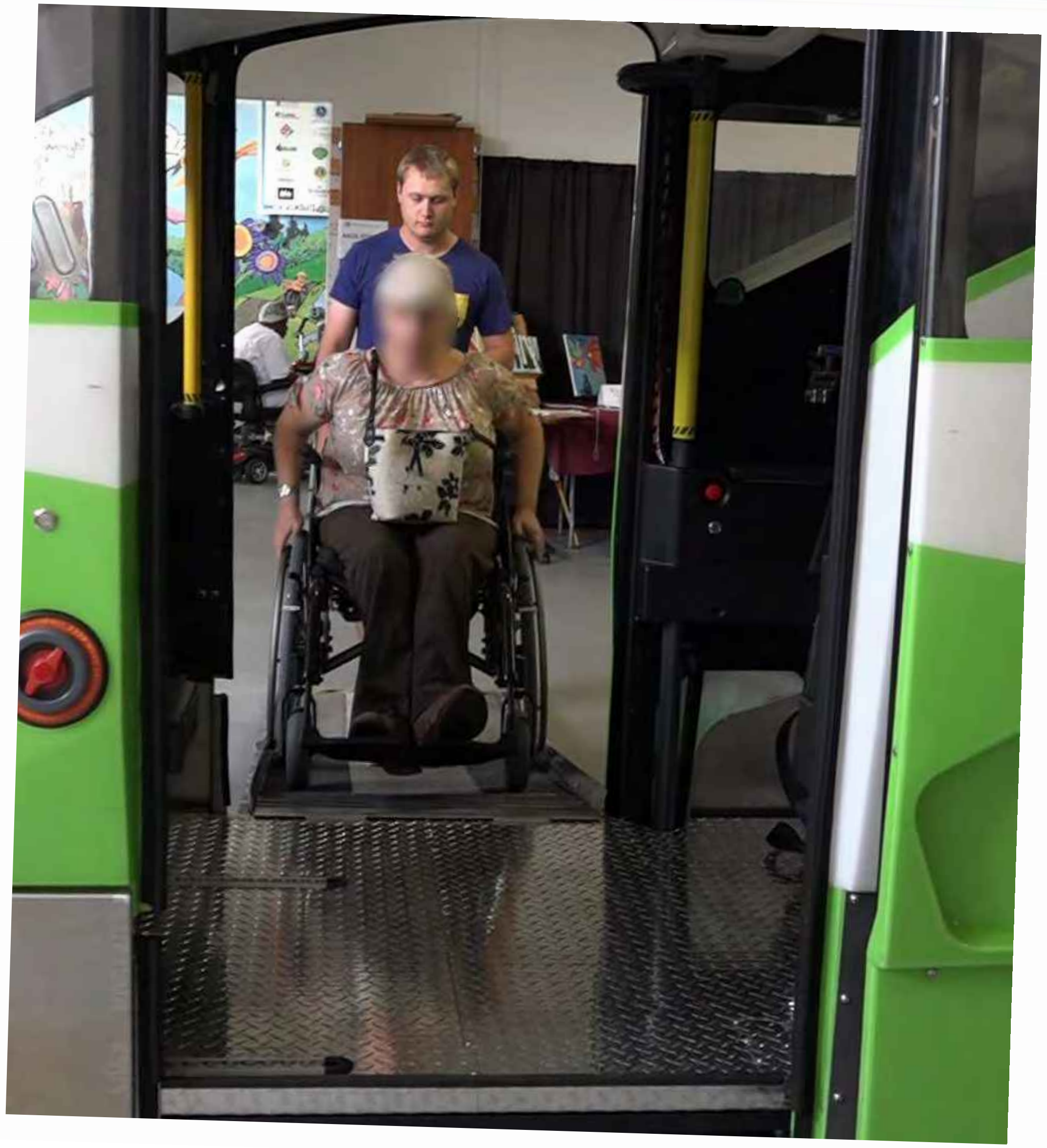
Accessibility and Usability Evaluation of the Modified Shuttle
Findings: Manual Wheelchair Users (n=6)

Q: Would you suggest the addition of instructional aids to make correct securement positioning more clear?

Yes: n = 4 **No**: n = 2

Other Interview Highlights

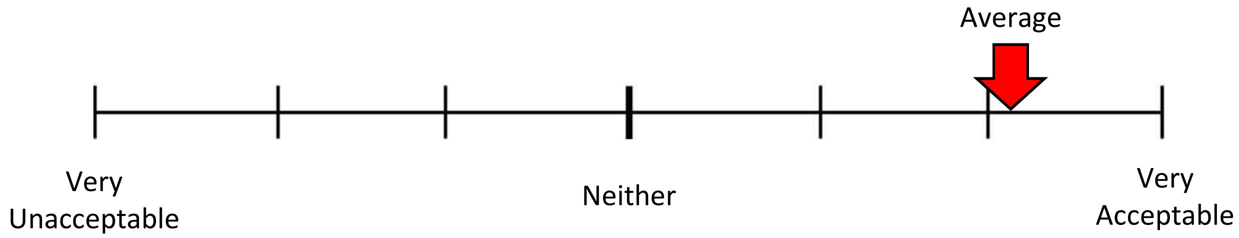
- Narrow ramp width (currently <30in.), resulting in a tight fit for most wheelchair users. One participant was unable to enter due to insufficient ramp width.
- Participants had difficulty ascending the second segment of the ramp, where the ramp gradient noticeably increases

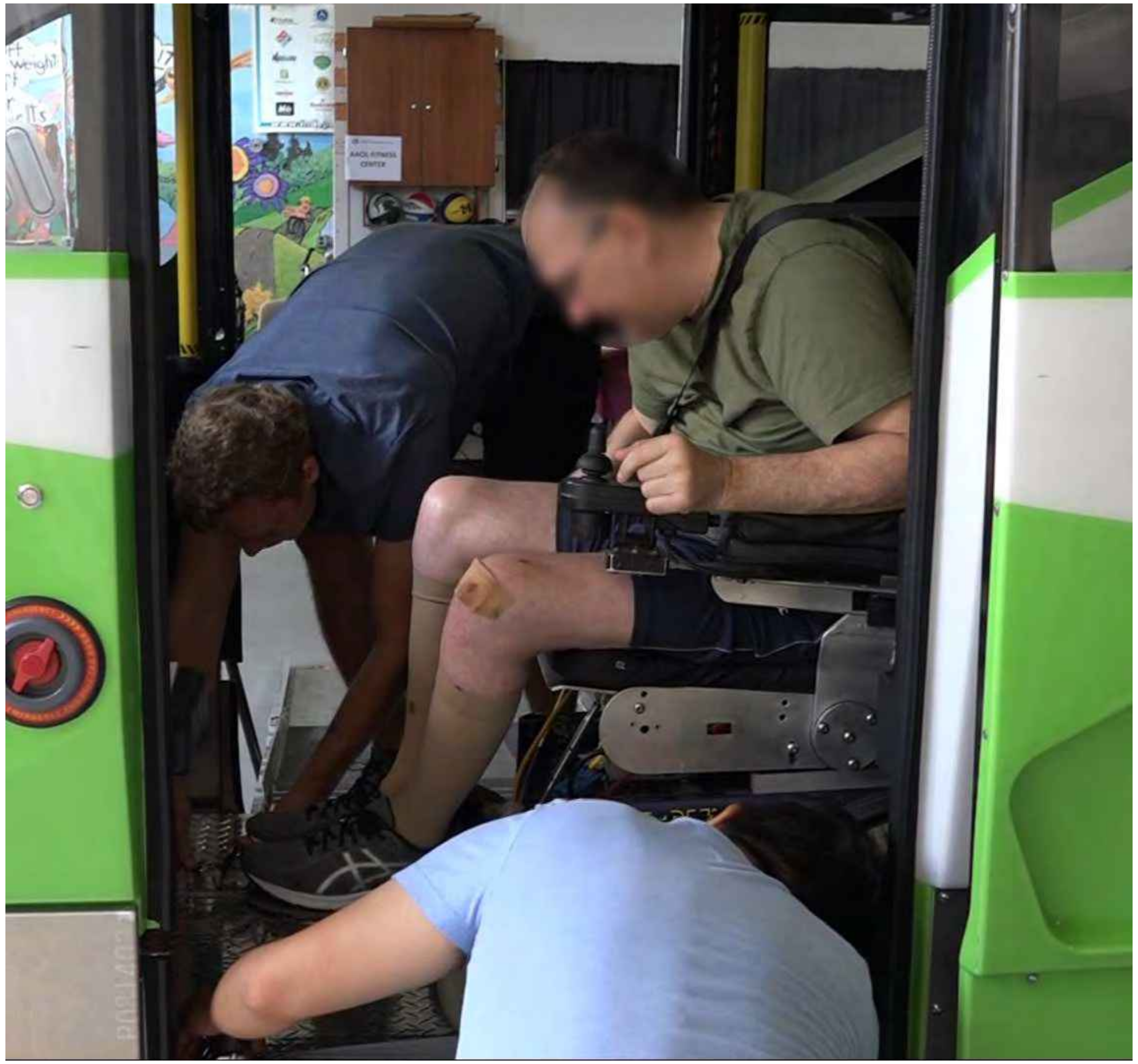


Accessibility and Usability Evaluation of the Modified Shuttle

Findings: Powered Wheelchair Users (n=11)

Q: How acceptable is the vehicle's securement system? **(n=10)**





Note: Only 3 powered wheelchair users entered the vehicle; rest provided feedback from outside the shuttle after observing the design and function of the securement system

Interview Highlights

- All participants that entered vehicle were able to maneuver into securement area
- Majority said vehicle interior felt adequately spacious; 4 users were concerned about inadequate space
- Most users did not think the current ramp slope would be an issue for their powered wheelchair

Findings: Powered Wheelchair Users (n=11)

Q: Would you suggest the addition of instructional aids to make correct securement positioning more clear?

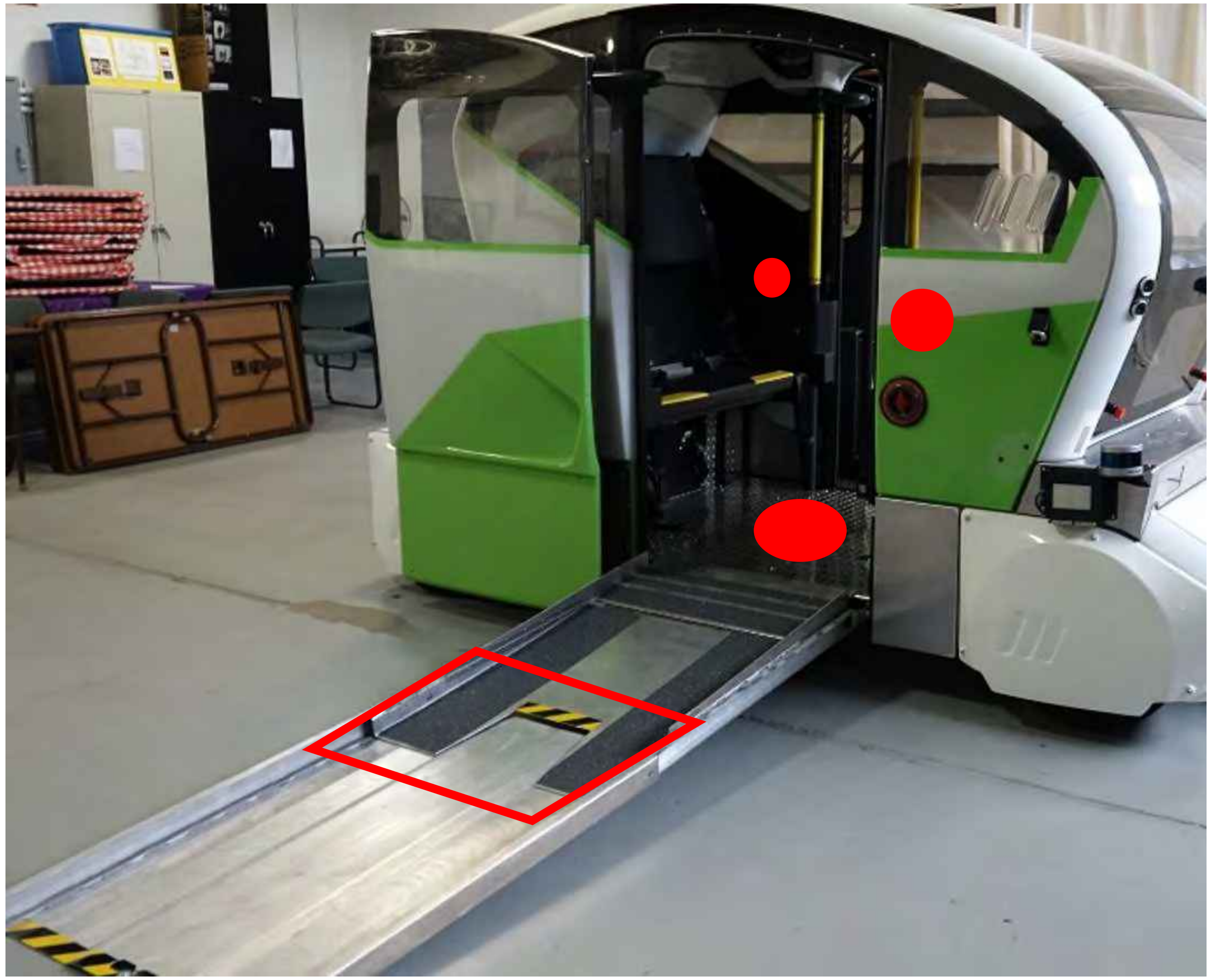
Yes: n = 9 **No**: n = 2

Other Interview Highlights

- Participants were concerned users with larger powered wheelchairs and scooters would have difficulty maneuvering inside the shuttle, especially if an operator or another passenger were sitting inside
- Participants felt that requiring an operator to manually deploy the access ramp reduces the benefit of an automated vehicle

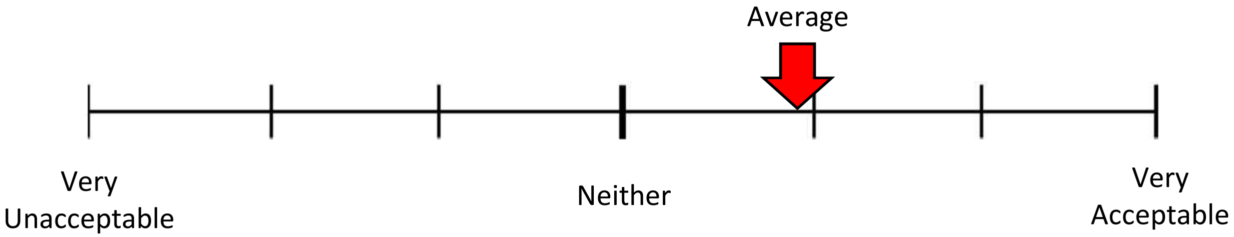
Recommendations

- Automated ramp deployment to reduce dependence on operator
- Decrease ramp gradient at the second segment, and reduce the dip at the middle portion of the ramp where the two ramp segments meet.
- Increase the weight capacity of the ramp to accommodate more powered devices
- Increase ramp width and door width by about 2in. each to accommodate a larger population of powered and manual wheelchair users and increase ease of ramp ascent-descent
- Provide a display on the floor, interior wall, or exterior of the vehicle to provide instruction on how wheelchairs should be oriented inside the vehicle.



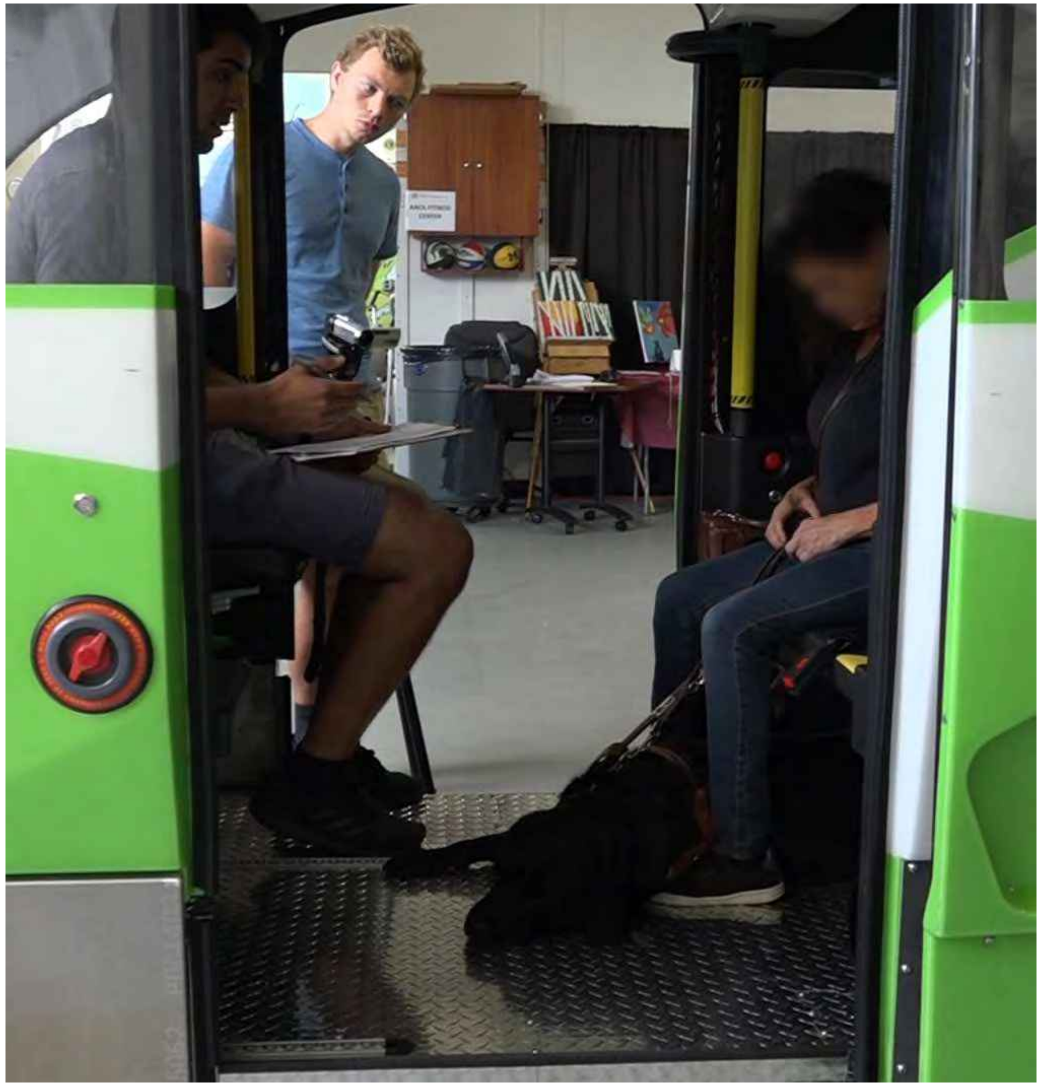
Note: early in the project, it was determined that the pilot must be limited to manual wheelchairs under 400 lbs. due to the size and weight capacity specifications of the baseline vehicle.

Q: How acceptable do you find the bench seat design in terms of seat-pan height, width, depth, and seat back?



Interview Highlights

- Difficulty with step-up when boarding from street-level (10.25in)
  - 6 walker users requested ramp for entry/exit
- Vertical grab bars positioned on inner side of doorway were useful for the few participants who noticed it
- Bench seat height (18in.) and backrest was adequate
- Anterior windshield helped provide line of sight and awareness of exterior surrounding



Findings: Walking Aid Users (n=12)

Q: From the rear-facing single-seat, can you reach a stop button in case of an emergency? (n=11)

Yes: n = 3 **No**: n = 8

Interview Highlights

- Rear-facing single seat was too high (~23in.) for many participants
- Participants had a lot of difficulty finding and reaching the emergency stop button on front panel (behind the rear-facing single seat)
- Participants reported concerns about the lack of friction provided by the floor material; potentially more slippery when wet
- Few commented on the need for rear window, windows that open, possibly even a sun-roof

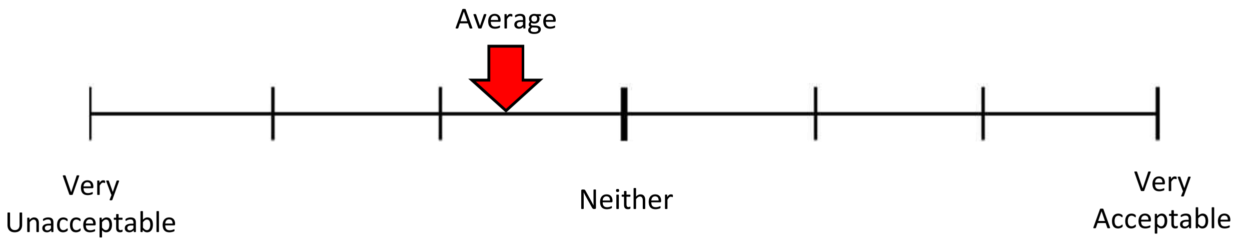
Findings: Blind and Low-vision users (n=10)

Interview Highlights/feedback

- Step height into the vehicle was comfortable for most participants
- Width and height of the doorway made vehicle entry comfortable for most participants
- Both, forward-facing bench seat and rear-facing single-seat provided adequate legroom
- Reported height and width of forward-facing bench seat was adequate for single passenger

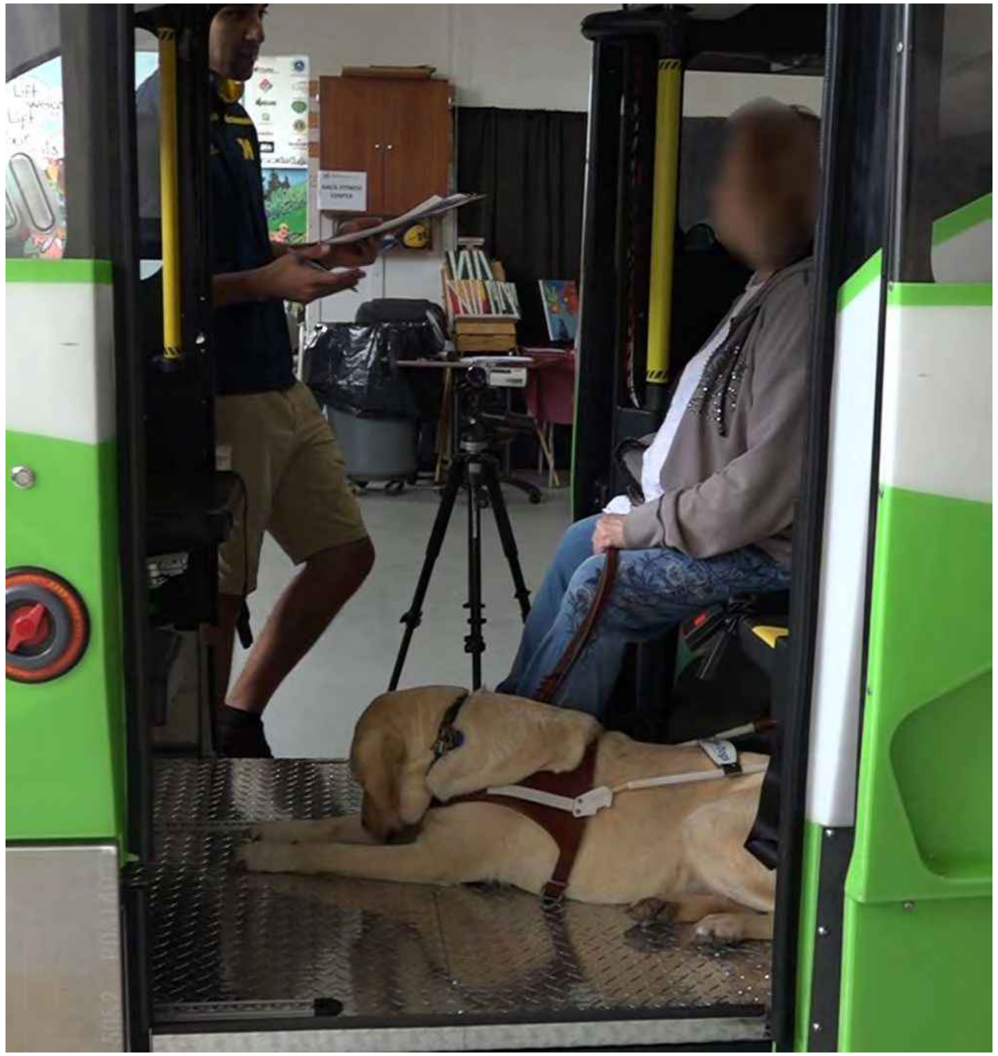
Findings: Blind and Low-vision users (n=10)

Q: How acceptable do you find the <u>rear-facing single seat</u> design in terms of seat-pan height, width, depth, and seat back?



Q: From the rear-facing single-seat, can you reach a stop button in case of an emergency? (n=9)

Yes: n = 4 **No**: n = 5



Other Interview Highlights

- Participants, especially those with service animals, reported concerns about the lack of friction provided by the floor material
- For both forward- and rear-facing seats, participants expected to find a shoulder belt much like the seatbelt in a car

Design Recommendations

- Reposition emergency stop buttons on the front side of the vehicle to more closely match the relative position of the buttons on the rear side of the vehicle to the bench seat; voice-based interaction could be an alternative
- Use a higher-friction floor material to minimize slips during sudden stops, turns, for passengers and their belongings, service animal, etc.
- Provide vertical grab bar(s) on the exterior of the vehicle adjacent to the door (- or interior, such that it is noticeable from outside) to indicate the vehicle's entry point, and to provide support for passengers as they step into the vehicle
- Lower the height of the rear-facing single seat to more closely match that of the forward-facing bench seat (~18in.)

Accessibility Study Conclusions

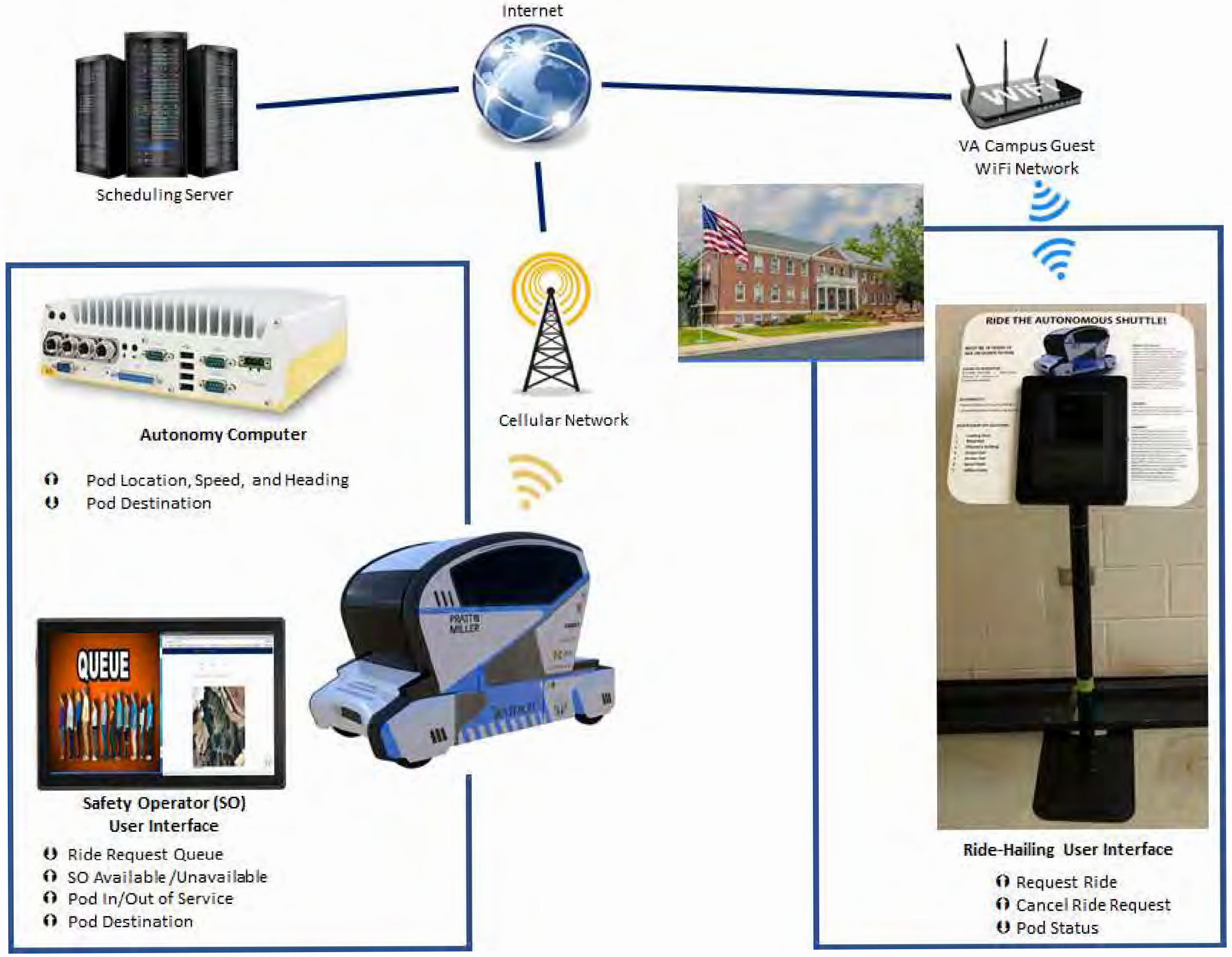
- User evaluations helped identify a number of key design barriers and recommendations
  - ➢ Early user engagement is critical to accessible and inclusive design; also helps promote public understanding and trust of AVs
- Usability issues and design needs differed by user group
  - ➢ Need to consider effects of vehicle modifications on diverse users and impairments, i.e., inclusive design
- Inclusion of all users not possible due to technical constraints of the modified shuttle
  - ➢ Ex: weight restriction; limited interior clear floor space
  - ➢ Pilot deployment would likely exclude heavier powered wheelchairs and electric scooters
  - ➢ Reinforces need for accessibility considerations earlier in the AV design process
- Accessibility modifications in first phase of the project were mostly successful
  - ➢ Static user evaluations found no urgent usability challenges before pilot deployment
  - ➢ Field evaluations during pilot deployment may uncover additional usability and safety issues.

Completed Vehicle
After Build, Autonomy Integration, and Testing – Side Views

Completed Vehicle
After Build, Autonomy Integration, and Testing – Additional Views

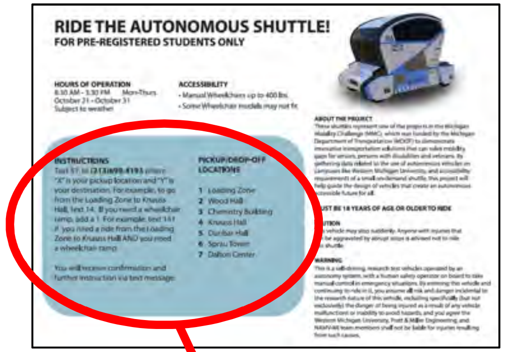
Ride Hailing Original Plan

- The original plan was developed with the Battle Creek VAMC in mind
  - Smaller pool of potential riders than WMU center campus
- Description
  - Developed in conjunction with Kevadiya
  - Kiosks with tablets at each pickup point, available to anyone that uses them
  - Riders use tablet to hail ride
  - No personal information collected
  - Not accessible for persons with vision impairments
- Challenges for WMU site
  - Need a way to limit potential pool of riders, or give priority to certain populations (students with disabilities, Veterans)
  - Large population of students with vision impairments, who navigate campus independently



Ride Hailing
New Solution for WMU Site – Rider Interface

- Description
  - Developed by Pratt & Miller Engineering
  - No kiosks/tablets
  - Riders use their personal phone to hail a ride via text message
  - No personal information collected, other than the number from which the rider's text originated
  - Ability to prioritize pre-registered phone numbers provided by the Disability Services for Students (DSS) group at WMU
  - Text messaging is accessible for students with vision impairments



Poster hung at all pickup locations

INSTRUCTIONS

Text XY, to **(213)699-4193** where "X" is your pickup location and "Y" is your destination. For example, to go from the Loading Zone to Knauss Hall, text 14. If you need a wheelchair ramp, add a 1. For example, text 141 if you need a ride from the Loading Zone to Knauss Hall AND you need a wheelchair ramp.

You will receive confirmation and further instruction via text message.

PICKUP/DROP-OFF LOCATIONS

1 Loading Zone
2 Wood Hall
3 Chemistry Building
4 Knauss Hall
5 Dunbar Hall
6 Sprau Tower
7 Dalton Center

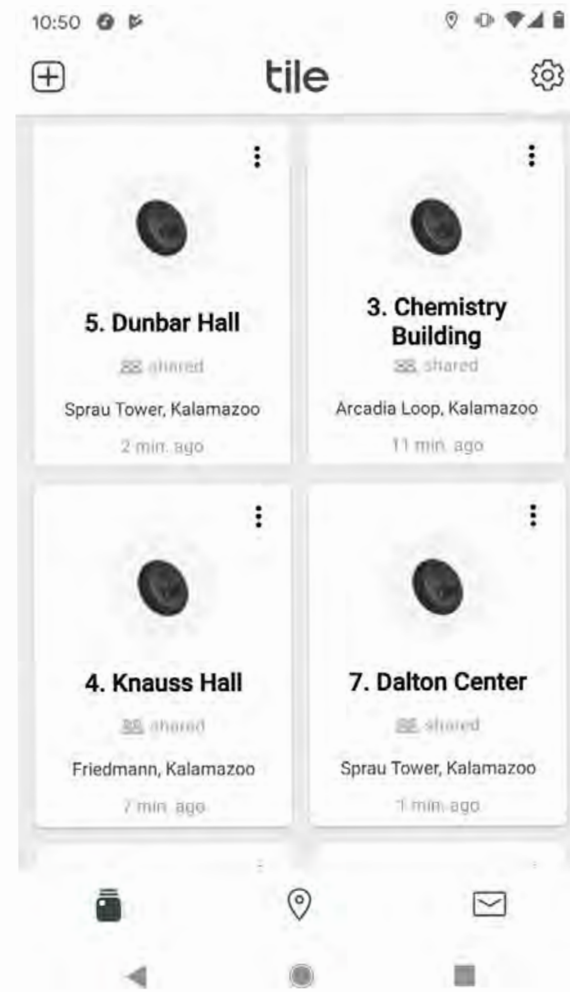
Ride Hailing
New Solution for WMU Site – Safety Operator Interface

- The safety operator interface runs on a ruggedized tablet mounted inside the shuttle
- Displays all ride requests
- Highlights any rides from pre-registered numbers; in the case of the WMU pilot, this feature is used to prioritize students with disabilities that are pre-registered through Disability Services for Students (DSS)
- Allows safety operator to input status of ride request (Arrived, Cancel, Reject, Picked up Passenger, etc.)
- Allows safety operator to change shuttle status (In-Service, Out-of-Service)
- Allows safety operator to define maximum queue length (if maximum exceeded, any new ride requests other than those from pre-registered numbers will not be accepted)

Ride Hailing
Locating Shuttle Stops (for Riders with Visual Impairments)

- Rider uses a GPS-based phone app to navigate close to shuttle stop
  - WMU autonomous shuttle stops are available in both BlindSquare and Nearby Explorer apps
  - Limited by GPS accuracy (usually within 30 feet)

- Rider rings a Tile finder (product of Tile Inc.) and follows the sound to the shuttle stop
  - Requires rider to set up a free Tile account with their WMU email address prior to using the shuttle service for the first time
  - The seven Tiles are then shared with that rider’s account



Example of shuttle stops in Tile app

Pilot Site Preparation
On-Site Approvals Obtained

Safety Review

- Chief of Police, Scot Merlo

Leadership Approval

- Dr. Edward Montgomery, WMU President
- Pete Strazdas, Vice President of Facilities Management
- Scott Merlo, WMU Chief of Police
- Dr. Steve Butt, Dean of the College of Engineering
- Dr. Terri Goss Kinzy, WMU Vice President for Research
- Dr. Koorosh Naghshineh, Mechanical Engineering Department Head
- Jayne Fraley-Burget, Director of Disability Services for Students
- Dr. Jennifer Bott, WMU Provost and Vice President for Academic Affairs


President Montgomery


Dr. Terri Kinzy


Dr. Naghshineh

Pilot Site Preparation
Safety Operator Preparation

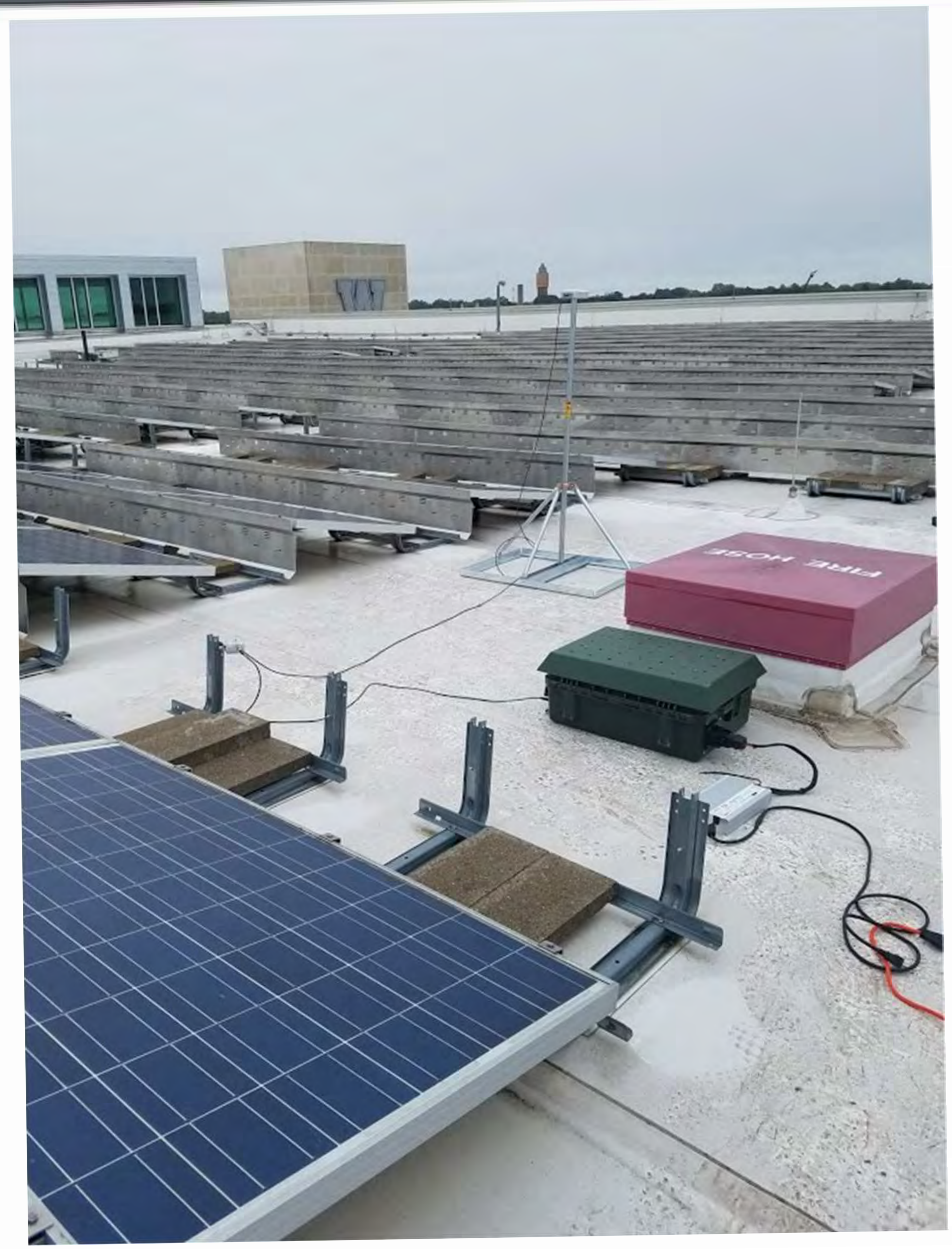
- Completed safety operator training from Robotic Research, including operation of autonomy kit
- Completed Easterseals training for "Providing Excellent Customer Service for Older Adults and People with Disabilities", conducted at PME 8/28/2019
- Acknowledged reading and understanding the safety operator manual created by PME and Robotic Research
- Completed at least five training laps of the Western Michigan University route in autonomous mode, acting as a safety operator under the supervision of Robotic Research personnel
- Completed training in operating the on-board accessibility devices (ramp and restraints), conducted at PME on 8/30/2019 and 9/6/2019
- Must wear safety operator vests during pilot operations (pictured)

Easterseals handout created for NAMV-MI project

Safety operator vest

Pilot Site Preparation
RTK Base Station Setup 9/12

- Real-time kinematic (RTK) positioning is used to improve positional accuracy of the shuttle
- WMU team installed the RTK base station on the roof of Sangren Hall
- Confirmed with Robotic Research that it was online and active

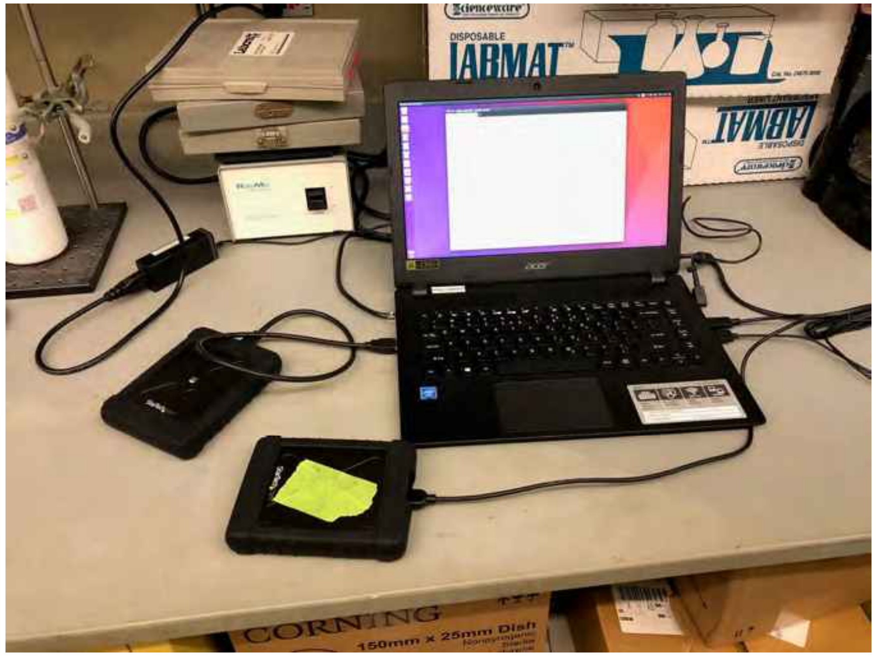


Pilot Site Preparation
Garage Provided by WMU Facilities

- Accommodates both shuttles and spares/supplies
- Temporarily disabled after-hours overhead door alarms to allow team to work late
- Added additional 120V circuit, to allow charging of both shuttles simultaneously
- Secure area, with access cards provided for key team members

Pilot Site Preparation
Data Uploading Station

- Data uploader computer provided by Robotic Research
- Secure room with ethernet provided by WMU
- Vehicle data uploaded every day from both shuttles to Robotic Research server



Pilot Site Preparation
WMU Article 9/19

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(269) 387-8400

Autonomous vehicle research rolling onto WMU campus

Contact: Erin Flynn
September 19, 2019

KALAMAZOO, Mich.—Transportation of the future has arrived on the Western Michigan University campus.

Research involving an autonomous electric shuttle officially kicked off **Thursday, Sept. 19**. The $2.1 million project, funded through the Michigan Mobility Challenge announced by former **Gov. Rick Snyder** last year and administered by the **Michigan Department of Transportation**, focuses on improving transportation options for people with disabilities.

Two autonomous shuttles will be tested on the WMU campus.

"I'm pleased to see that **Pratt & Miller** has brought this important project to campus and appreciate the work of people across the University to pilot this important advance in mobility," says **WMU President Edward Montgomery**. "WMU is committed to serving our students and society. This project is an excellent example of that; applying the knowledge of our world-class faculty and students to develop and test cutting-edge transportation technology."

MDOT, Pratt & Miller Engineering, WMU, the **University of Michigan**, **Kevadiya Inc.**, **Robotic Research**, **Comet Mobility** and **Easterseals** are all collaborating on the project.

https://wmich.edu/news/2019/09/55431

Pilot Site Preparation
Static Display 10/3

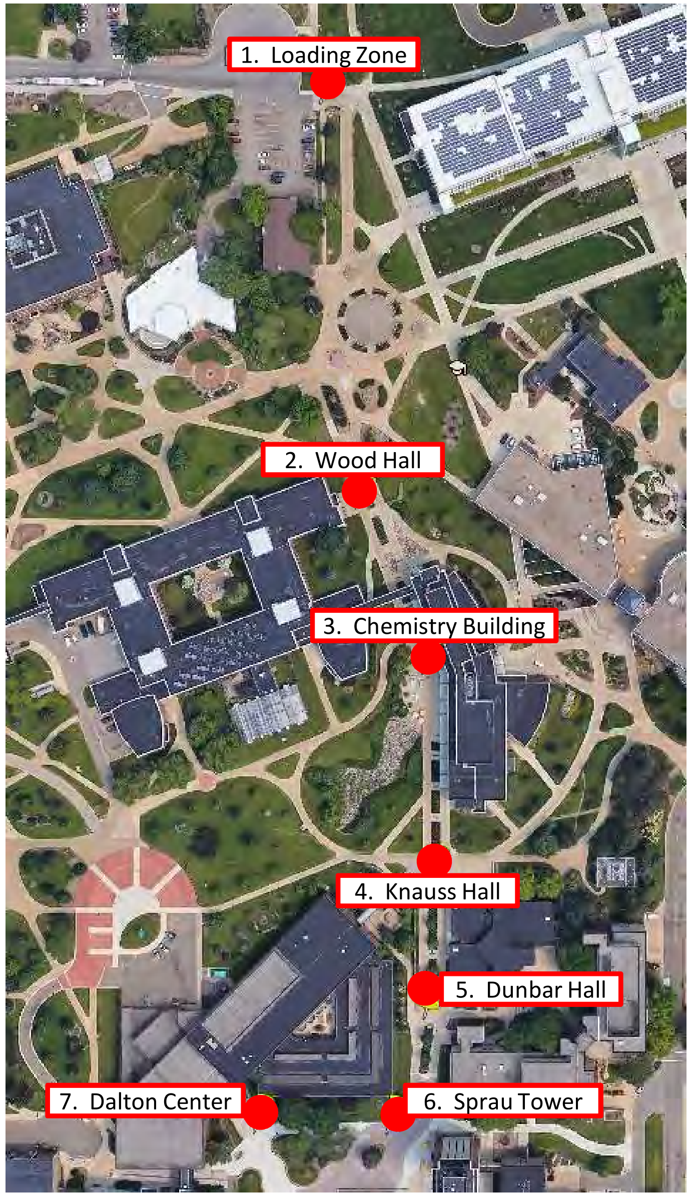
- Displayed vehicle at “flag poles” on center campus
- Answered questions from passersby
- One participant was impressed enough to sketch the vehicle!

Pilot Site Preparation
WMU President 10/3

- Reviewed vehicle with President Montgomery and his wife
- WMU graduate student Johan Fanas, who attended Safety Operator training at Robotic Research's facility in Maryland, gave them a ride in manual mode

Pilot Site Preparation
Route Determination

- Evaluated various walking paths to determine best route for autonomous operation; considerations included:
  - Width of path
  - Proximity of landscaping features and other objects
  - Typical volume of pedestrian traffic
- Route selection and mapping procedure conducted 9/19-10/5
- Final route between Loading Zone (north end) and fountain area (south end)
- Seven pickup/drop-off points as shown on map



Pilot Site Preparation
Landscaping

- Worked with WMU Facilities and groundskeepers to trim ornamental grass, creating a friendlier environment for the autonomy system (grass pictured before trimming)

- Before trimming, grass blowing over the paved path would occasionally lead to false object detection, resulting in the vehicle slowing down or stopping on the path

Pilot Site Preparation
Rider Recruitment - Initial Effort

- WMU Disability Student Services (DSS) and Office of Military and Veterans Affairs sent emails to their respective students to recruit participants
- Multiple emails resulted in a total of nine (9) pre-registered student participants, all through DSS

Western Michigan University
Center for Disability Services

~ 1200 students registered with DSS (Disability Student Services)

Office of Military and Veterans Affairs
Western Michigan University

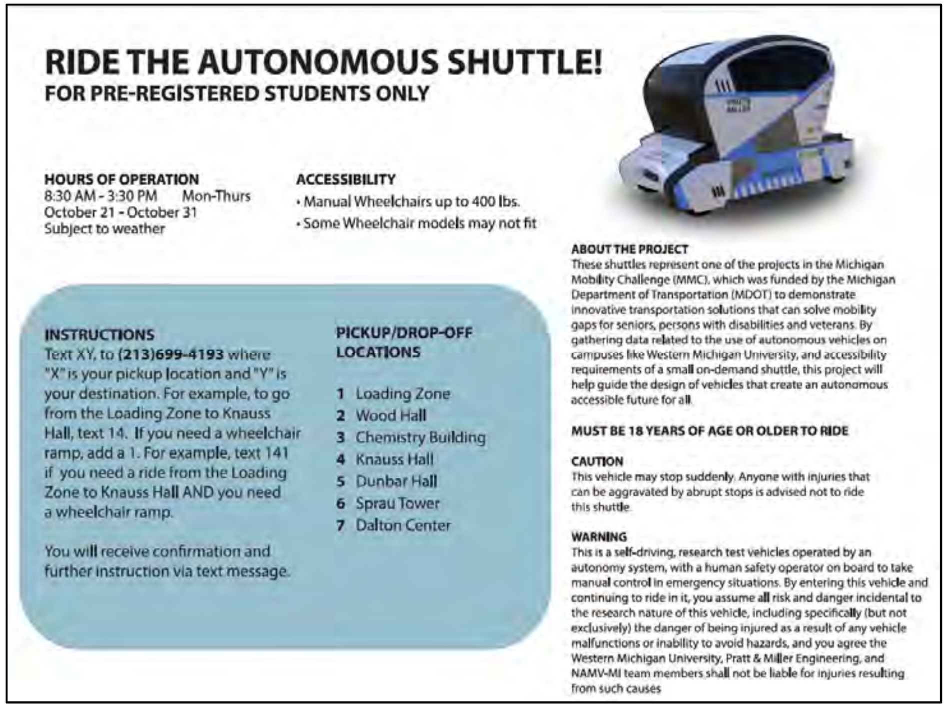
~ 800 students registered with Military and Veterans Affairs

Pilot Site Preparation
Rider Recruitment - Additional Efforts

- Based on low response level from students registered with DSS, the following actions were taken to recruit more riders:
    - Instructional flyers were created and handed out on center campus
    - An Instagram post (images below) was created by WMU Communications to encourage the general student population to hail rides, with a link to a new website providing instructions
    - Emails were sent to engineering undergrad students, encouraging them to ride the shuttles and provide feedback in class

Pilot Site Preparation
Signage

Yard signs placed along route to generate awareness



Maps and posters with ride hailing instructions placed at all pickup/drop-off locations

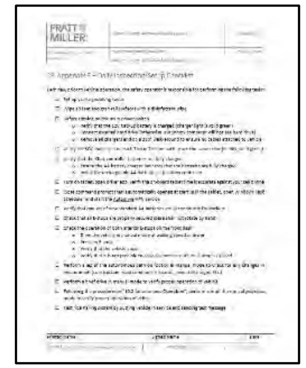
Street decals to identify shuttle stops
(Note: These particular decals were prone to peeling due to rain, and some did not last for duration of pilot. They were not necessary, as riders could consult map or, for those with visual impairments, use the GPS and Tile system.)

Pilot Site Preparation
Operations – Daily Checklists

To ensure proper vehicle maintenance and safety, the safety operators complete and sign daily checklists, one in the morning prior to shuttle service, and one in the evening after shuttle service ends.

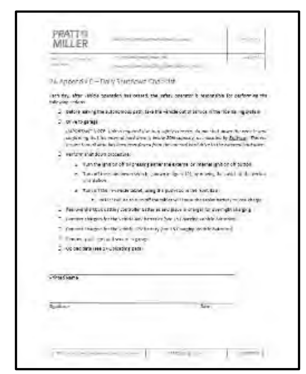
Select items from daily morning checklist:

- Place yard signs along route (signs not placed on high-wind days)
- Disinfect seats and grab rail surfaces
- Verify batteries are at 100% state of charge
- Prepare external hard drives for data collection
- Prepare on-board tablet for ride hailing service
- Verify proper operation of the two E-stops on the front dash
- Perform a brief drive in manual mode to verify proper operation of vehicle
- Perform a lap of the autonomous path on foot or in manual mode to check for any changes in environment
- Test ride hailing system by putting vehicle in service and sending test message



Select items from evening checklist:

- Take the vehicle out of service in the ride hailing system
- Confirm data transfer to external hard drive prior to vehicle shutdown
- Shut down vehicle and connect chargers
- Remove yard signs and secure in garage
- Upload data to Robotic Research server

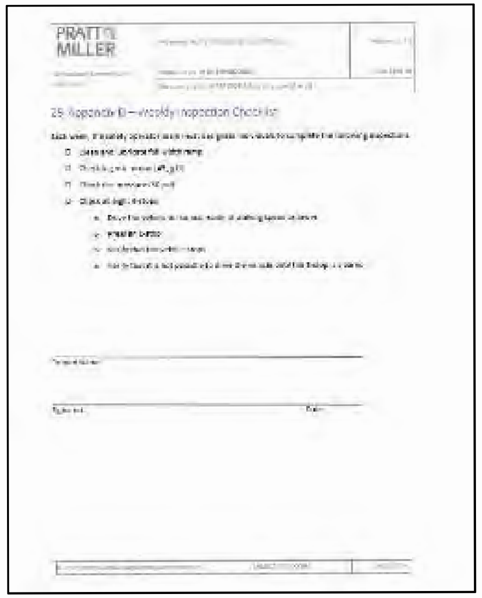


Pilot Site Preparation
Operations – Weekly Checklists

The safety operators complete and sign weekly checklists, which include routine maintenance.

Select items from weekly checklist:

- Clean and lubricate full width ramp
- Check lug nut torque
- Check tire pressure
- Verify proper operation of all eight E-stops


PRATT MILLER

Pilot Site Preparation
Other Activities

- Tested wheelchair ramp on-site with a student volunteer that uses a wheelchair
- Verified required cellular coverage for proper vehicle operation
- Created emergency contact list and placed in each shuttle
- Created warning statement to post in shuttles and include on various instructional material (website, posters, flyers)
- Provided first responder information to WMU police department
- Developed Communications Plan to prepare NAMV-MI team members for interaction with media

Media Day / Vehicle Demo
Event Details

Date:	October 21st, 2019
Location:	Sangren Hall, WMU
Time:	1:45-2:45 PM
Notable attendees:	Lt. Governor Garlin Gilchrist Jean Ruestman (MDOT) Fred Featherly (MDOT) Jeff Mason (MEDC) Edward Montgomery (WMU President) Paula Davis (WMU Communications) Clive D'Souza (University of Michigan) Rush Patel (Robotic Research) Carol Wright (Easterseals) Comet Mobility team Pratt & Miller team Various media

Lt. Governor Gilchrist addressing the crowd

Media Day / Vehicle Demo
PME Press Release and Video

Automated Shuttle Makes Its Way Through the Campus of WMU

Pratt & Miller along with the MEDC, MDOT/PlanetM, and WMU Focus Mobility Efforts on Students with Disabilities

Like 0 Share Tweet Share

New Hudson, MI – October 23, 2019 – Western Michigan University (WMU) hosted Michigan's Lt. Governor, Garlin Gilchrist, along with many other government officials earlier this week to view and ride in an automated shuttle funded under the $8 Million Michigan Mobility Challenge.

For the shuttle portion of the program, Pratt & Miller Mobility partnered with academia and industry to use technology and innovation to solve mobility gaps, which is the overarching goal of the $8 Million Michigan Mobility Challenge.

"We were thrilled to be selected by the MEDC/PlanetM and MDOT to lead the automated shuttle program," said Christopher Andrews, Pratt & Miller Director of Mobility. "Our team embraced the challenge. We brainstormed with a panel of students with disabilities to address a variety of concerns and implemented the best solution possible. The learnings from this program will inform the design of future vehicles to accommodate all people. There is still a lot of work to do to ensure equity, dignity, and mobility for all, and PME plans to be at the forefront of these efforts."

Government officials, who were able to take one of the first rides in the shuttle, exited the vehicle with great reviews. "It was smooth," said Lt. Governor Gilchrist. "We made some pretty tight turns and passed pedestrians without any issues."

During the event the Lt. Governor was able to meet with students with disabilities attending the event. "I was so impressed with the amount of time he [Gilchrist] spent with the students," said Andrews. "This type of interaction is why this event was so important. Our government officials must understand the issues folks with disabilities contend with—we can absolutely do better for this large portion of the population."

About Pratt & Miller

Pratt & Miller is a product development company that through technology and innovation, solves customers' most technical and complex challenges in the Motorsports, Defense, and Mobility industries.

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Link to press release and video:

https://www.prattmiller.com/news/article/538

Media Day / Vehicle Demo
Media Links

https://www.woodtv.com/news/kzoo-and-bc/western-michigan-launches-autonomous-shuttle-program/

Includes vehicle footage, Travis (student using wheelchair), Zach Asher, Jeff Mason, Jean R.

https://wwmt.com/news/local/western-michigan-university-unveils-self-driving-shuttle-pilot-program-vehicle

Includes interview with Lt. Governor Gilchrist

https://nbc25news.com/news/state/western-michigan-university-debuts-autonomous-shuttles-to-help-students-with-disabilities

https://news.engin.umich.edu/2019/10/inclusive-autonomous-shuttle-service-for-physical-disabilities/

Video of study group at Ann Arbor Center for Independent Living

https://fox17online.com/2019/10/21/lt-gov-gilchrist-says-first-ride-in-driverless-shuttle-at-wmu-was-smooth/

Includes Lt. Governor Gilchrist, Jean Ruestman, and Taylor (student who is blind)

https://www.woodtv.com/news/kzoo-and-bc/western-michigan-launches-autonomous-shuttle-program/

https://wmich.edu/news/2019/10/56105

https://wmich.edu/news/2019/09/55431

https://fox17online.com/2019/10/21/autonomous-shuttles-being-tested-at-wmu/

https://www.govtech.com/fs/automation/Western-Michigan-University-Driverless-Shuttle-Test-Goes-Live.html

https://wkzo.com/news/articles/2019/oct/22/autonomous-shuttle-project-launches-at-wmu/949690/

https://www.prattmiller.com/news/article/535

Nick Goberville (WMU student, NAMV-MI team member)

https://www.mlive.com/news/kalamazoo/2019/10/testing-of-self-driving-shuttles-begins-at-western-michigan-university.html

https://www.prattmiller.com/news/article/538

Media Day / Vehicle Demo Photos

Lt. Governor Gilchrist meeting two students with disabilities that helped develop the pilot operations on campus

Lt. Governor Gilchrist and Jean Ruestman getting a demonstration ride

Team photo with Lt. Governor Gilchrist

Pilot Statistics
At a Glance

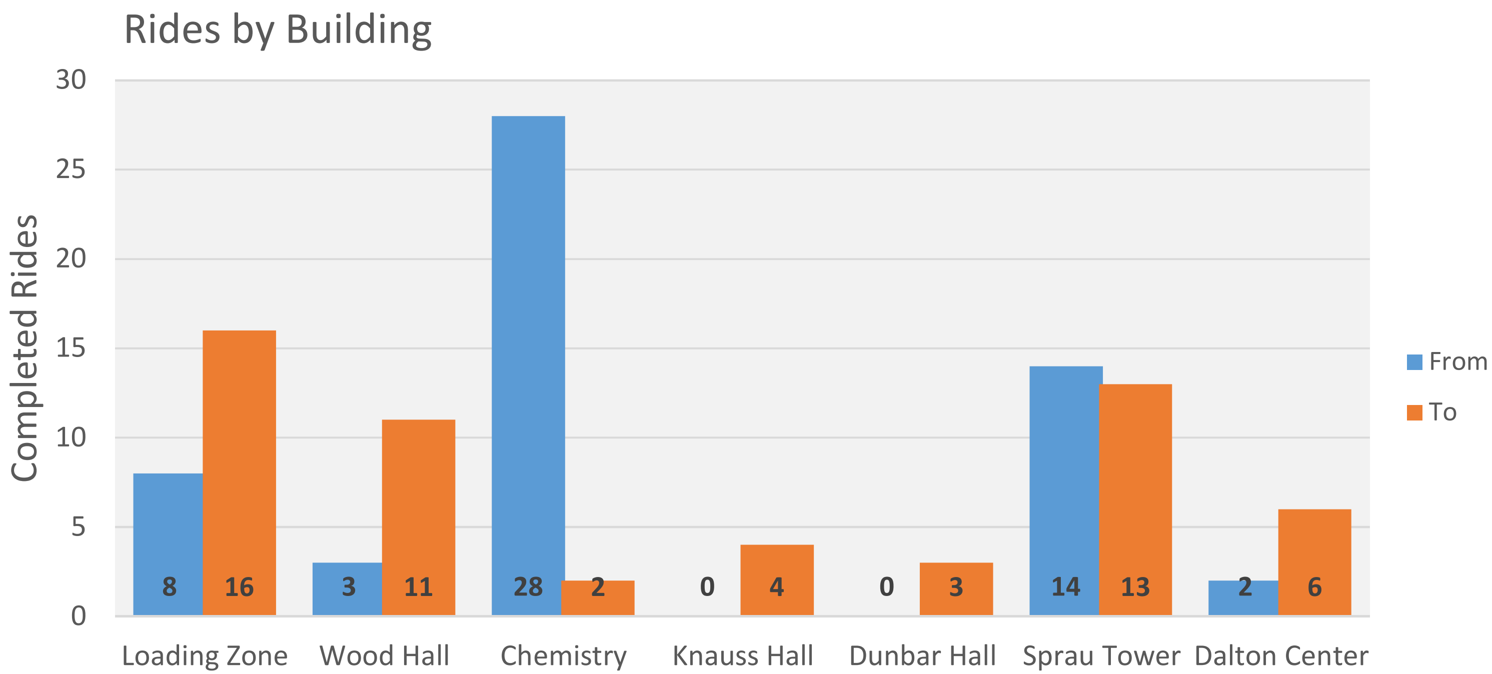
Pilot statistics presented here and in subsequent slides were gathered using the ride hailing software PME developed for this pilot.

Most data was automatically logged by the ride hailing software (e.g. number of ride requests), however, some data presented here relied on the safety operator manually recording certain events (e.g. shuttle arrived, passenger loaded, etc.) in the safety operator interface of the ride hailing app.

Total Rides Completed	55
Rides Completed by Shuttle 1	37
Rides Completed by Shuttle 2	18
Rides Completed Week 1	33
Rides Completed Week 2	22
Abandoned Rides	8
User-cancelled Rides	2
Rides w/ Pre-approved Riders	1
Rides w/ Wheelchairs	0
Most Rides in a Single Day	12
Most Popular Pickup Point	Chemistry Bldg
Most Popular Dropoff Point	Loading Zone

Note: Some rides included multiple passengers. 59 surveys were received from 55 rides.

Pilot Statistics
Rides by Building



The chemistry building was the most popular location from which students requested rides, which is unsurprising giving its central location along the route. This is also where the most ride recruitment was done.

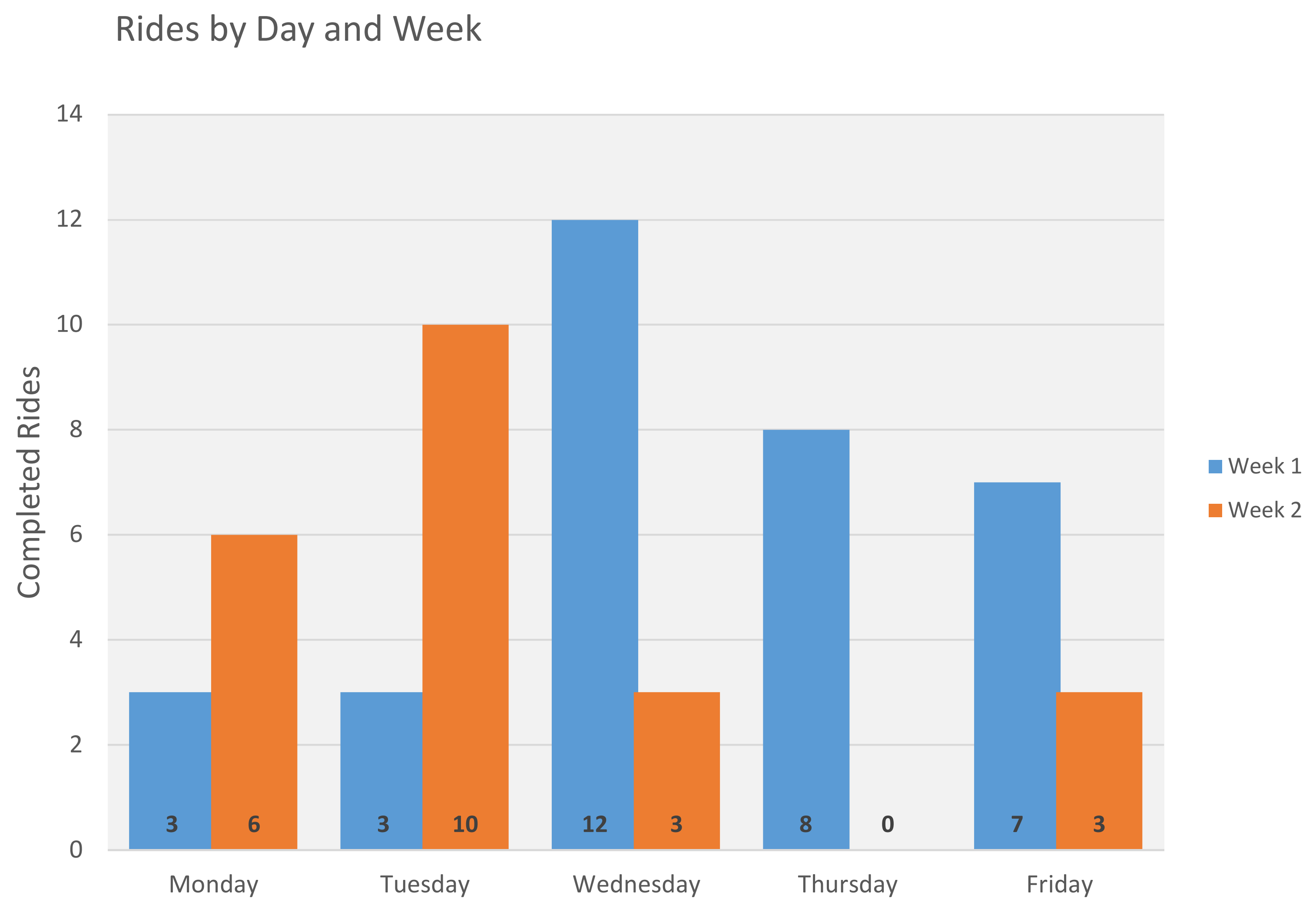
The loading zone, however, was the most popular stop in overall pickup and drop-off requests, which is also unsurprising since the loading zone is where many students arrive/leave campus.

Pilot Statistics
Rides by Day and Week

33 rides were completed the first week of the pilot, and **22** the second.

Ridership was slow the first two days of the first week of the pilot, but then peaked mid-week as ride recruitment efforts increased.

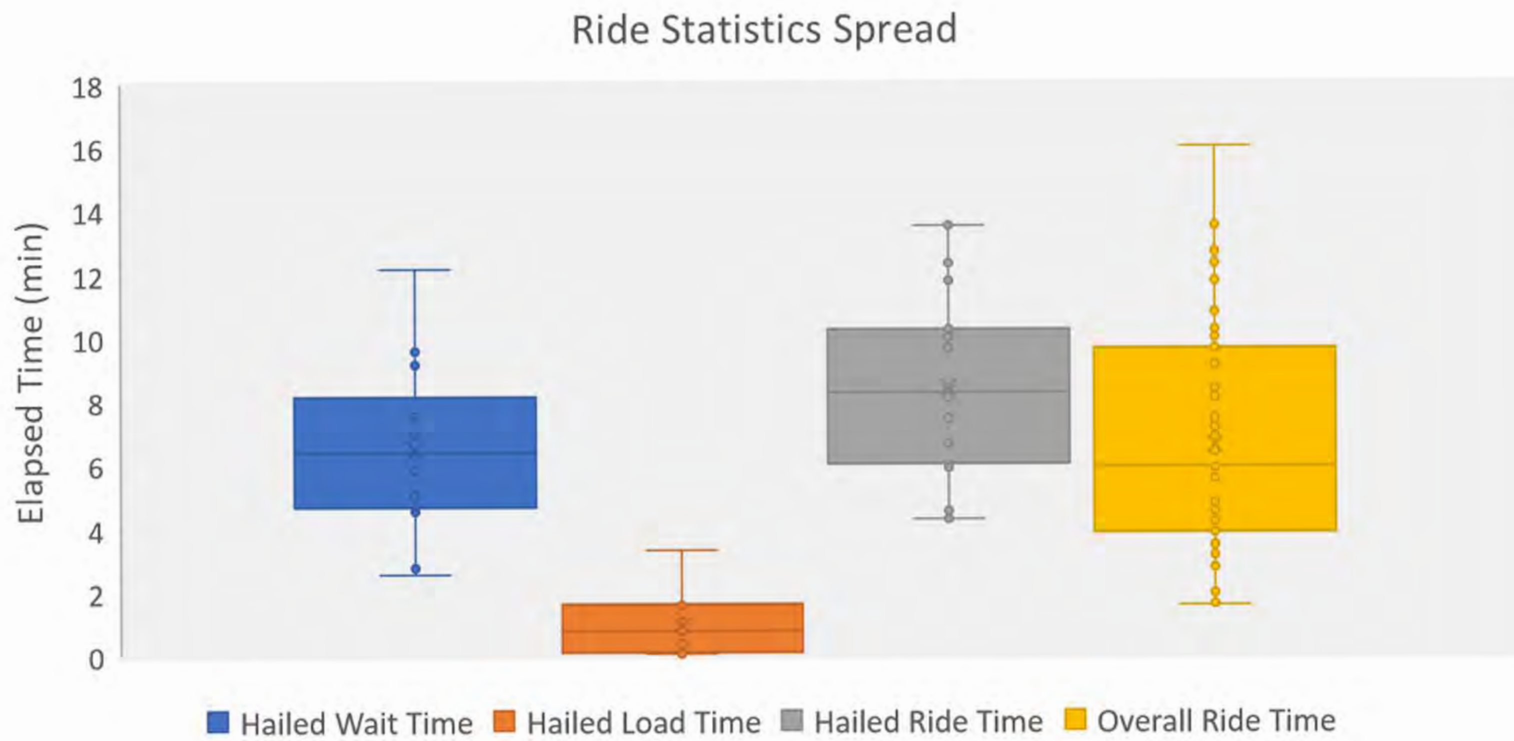
Ridership was strong in the beginning of the second week but then declined as poor weather conditions prevented shuttle operation. Monday saw technical issues that took some time to correct. Wednesday and Thursday had rain all day. Fridays also have the least amount of students on campus, which led to less rides as well.



Pilot Statistics
Ride Times

Passenger wait, load, and ride times varied significantly, most likely due to safety operator errors (e.g. forgot to hit “Picked Up”, “Arrived”, etc.).

Some rides were given to pedestrians that were recruited on the spot, and therefore had very low wait and load times. “Hailed rides”, as shown in the graph, were rides hailed through the normal text-message based ride hailing system.



Time Statistics For Hailed Rides

	Wait Time (min)	Load Time (min)	Ride Time (min)
Average	6.5	.9	8.5
Maximum	12.1	3.3	13.5
Minimum	2.6	0.05	4.3

Overall Ride Time Statistics

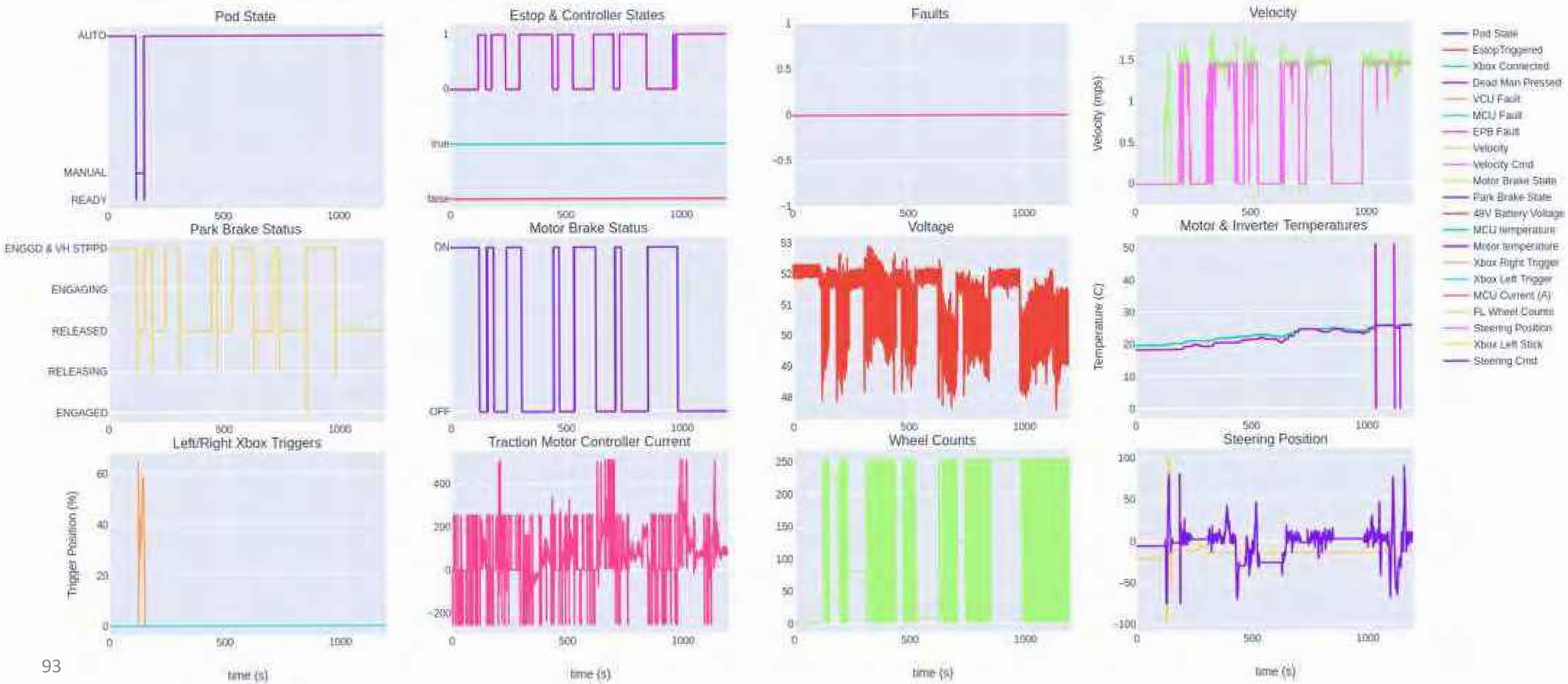
	Ride Time (min)
Average	6.6
Maximum	16.1
Minimum	1.6

Vehicle Monitoring
Overview

- Data was automatically recorded whenever the shuttle was driven autonomously.
- Logs of Battery, Navigation, and Vehicle Data—among other things—were recorded. Log files were recorded in 20-minute increments.
- Log files were saved to an external hard drive on the vehicle.
- At the end of each day of the pilot, the external hard drive was removed from the vehicle and connected to an "upload computer" which uploaded the log files to the "cloud".
- The log files were automatically downloaded from the "cloud". Four plots were then generated from each 20-minute log file:
  - Base Vehicle – Displays vehicle state information, traction motor metrics, wheel encoder status
  - Mapview – Plot of vehicle path over a satellite image of campus
  - Battery - Displays basic battery parameters including State of Charge, Temperature, status, etc.
  - Navigation – Shows vehicle velocity, relative path, odometry, etc.
- The plots were used to help troubleshoot vehicle issues. All of the logs were saved in .html format, which meant that any team member could access and interact with the plots in a browser without requiring any special software.

Vehicle Monitoring
Base Vehicle

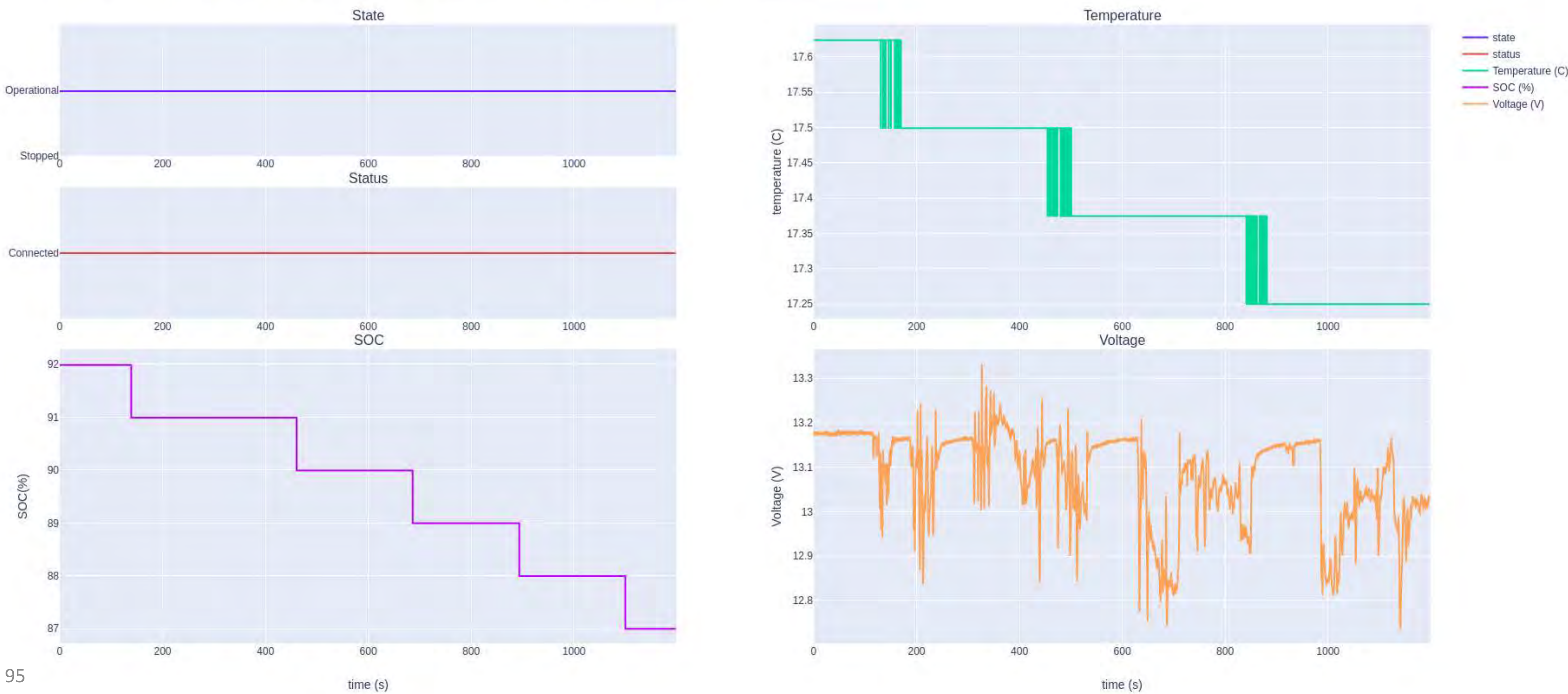
| Date: Oct/30/2019 | Start: 11:51:58 | End: 12:11:58 | Duration: 20.0min



Vehicle Monitoring
Map View

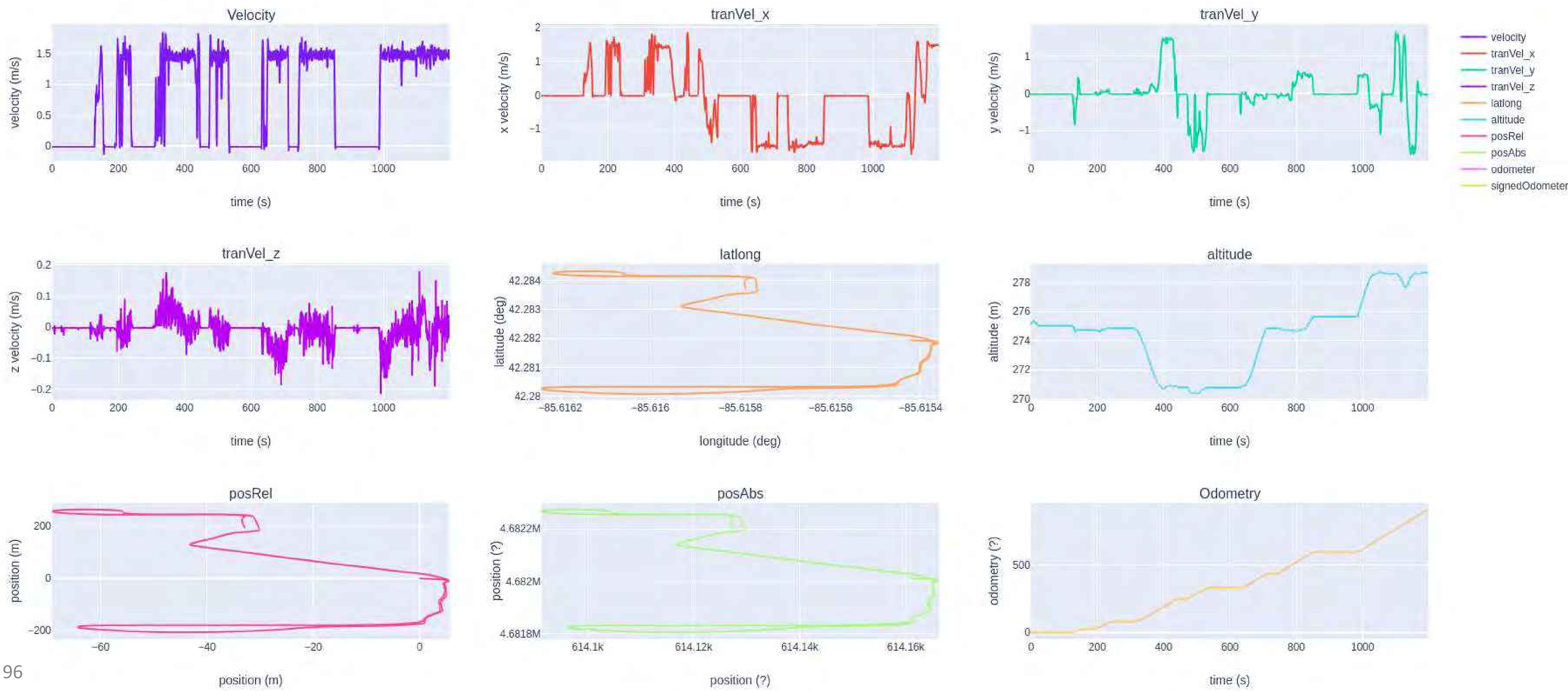
Vehicle Monitoring
Battery

Li-ion Battery (Trojan Trillium TR 12.8-92) | Date: Oct/30/2019 | Start: 11:51:58 | End: 12:11:58 | Duration: 20.0min



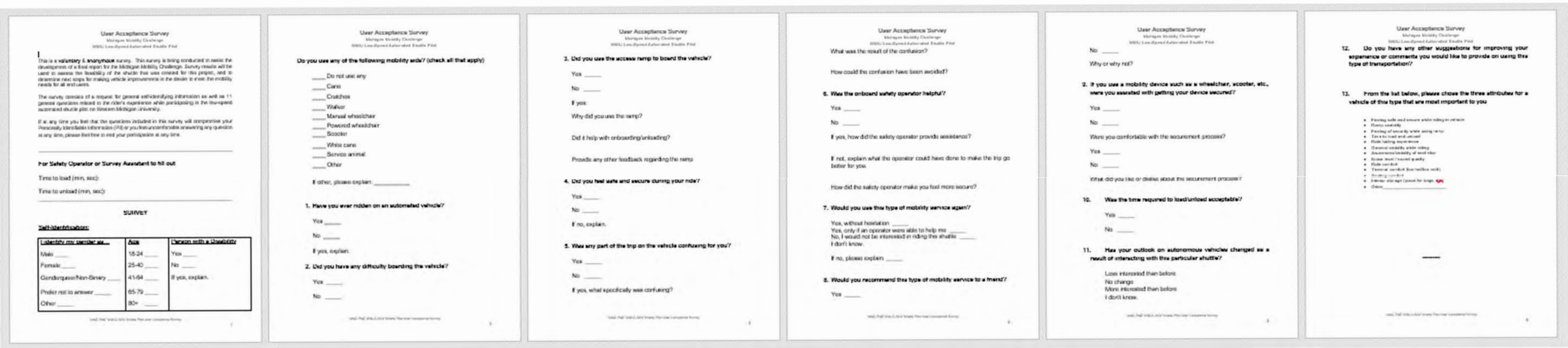
Vehicle Monitoring
Navigation

Localization | Date: Oct/30/2019 | Start: 11:51:58 | End: 12:11:58 | Duration: 20.0min



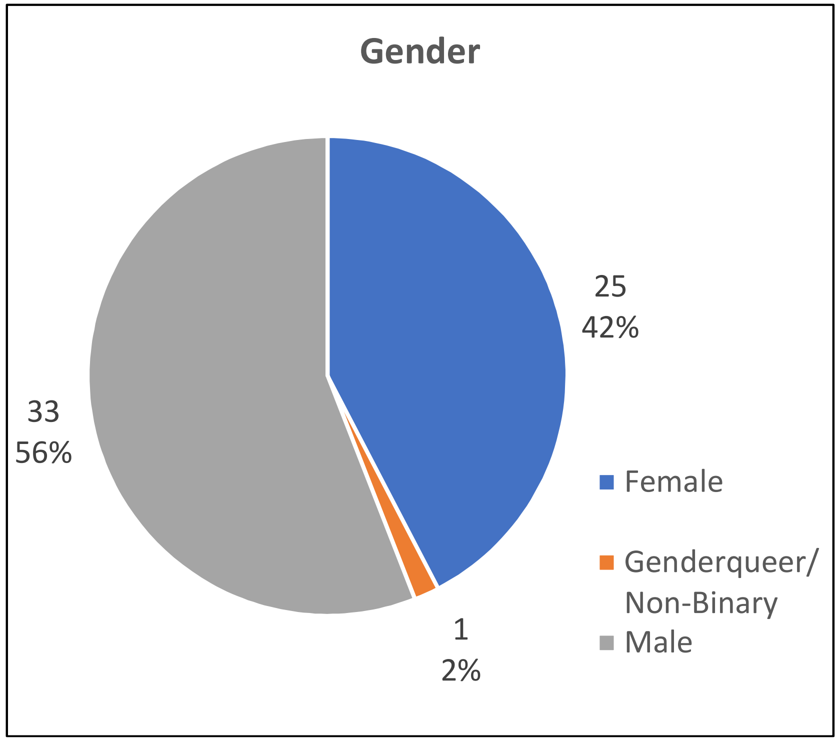
Rider Survey Results
Survey Background

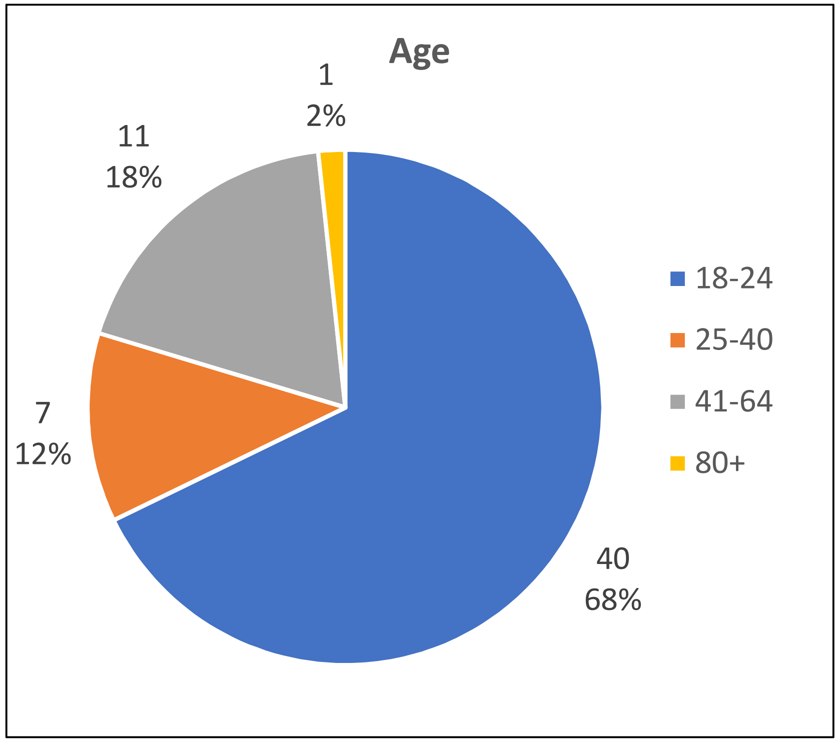
- Developed with input from Comet Mobility, PME, University of Michigan, and Easterseals
- Voluntary and anonymous
- 13 questions
- Administered post-ride by safety operators, Comet Mobility personnel, and volunteers from WMU College of Engineering
- 59 survey responses from 55 trips (note: some trips had multiple riders)
- Purpose is to help identify next steps for making vehicle improvements in the desire to meet the mobility needs for all end users

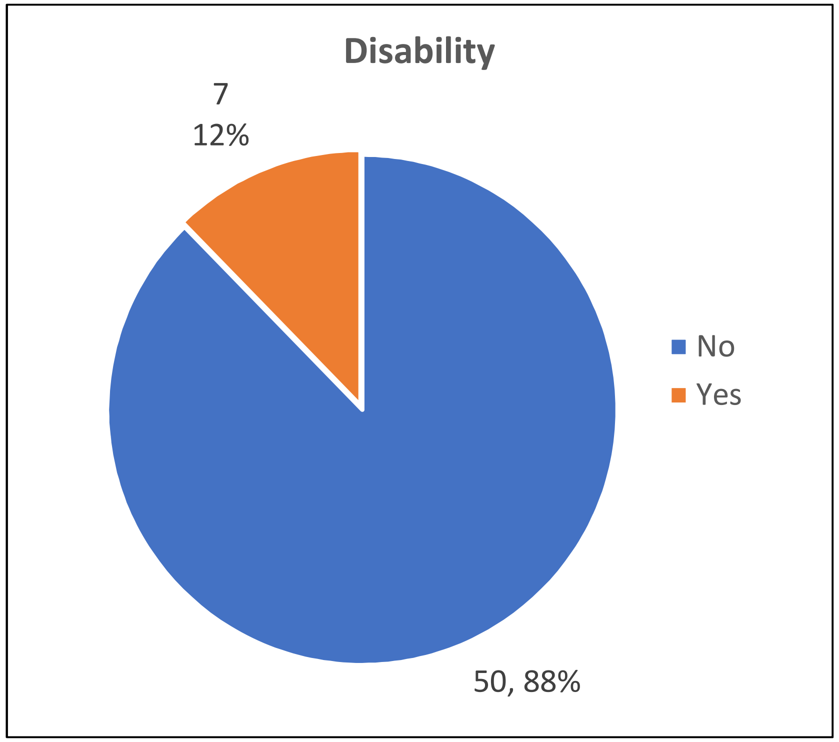


Rider Survey Results
Self Identification

I identify my gender as…	Age	Person with a Disability
Male ____	18-24 ____	Yes ____
Female ____	25-40 ____	No ____
Genderqueer/Non-Binary ____	41-64 ____	If yes, explain.
Prefer not to answer _____	65-79 ____	
Other _____	80+ ____	







Rider Survey Results
Loading Times and Mobility Aids

QUESTION

For Safety Operator or Survey Assistant to fill out

Time to load (min, sec):

Time to unload (min, sec):

Do you use any of the following mobility aids? (check all that apply)

____ Do not use any
____ Cane
____ Crutches
____ Walker
____ Manual wheelchair
____ Powered wheelchair
____ Scooter
____ White cane
____ Service animal
____ Other

If other, please explain: ____________

ANSWERS

- All loading and unloading completed within 60 sec, contrary to some of the ride hailing data*
    - No passenger required use of wheelchair ramp
    - One passenger used a cane
    - No passenger had mobility aids requiring securement

*This is due to how the ride hailing app calculated the load time. It uses the time between the safety operator hitting "Arrived" and "Picked Up Passenger", which could include interacting with the passenger outside of the vehicle before loading.

QUESTION

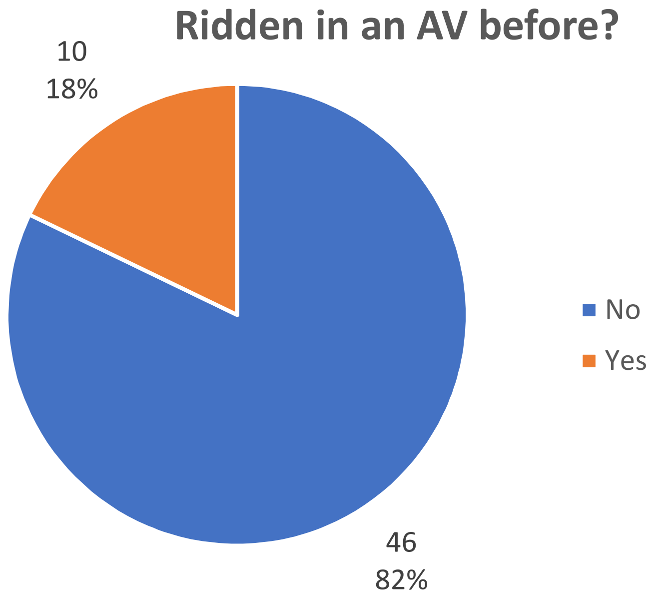
1. **Have you ever ridden on an automated vehicle?**

Yes ______

No ______

If yes, explain.

ANSWERS



Of the 10 passengers who reported "yes"

- 2 Tesla Autopilot
- NAVYA
- Uber
- MIA Airport Shuttle
- Discovery World
- Las Vegas Freemont St Chamber of Commerce
- Mcity
- "University vehicle (similar)"

QUESTION

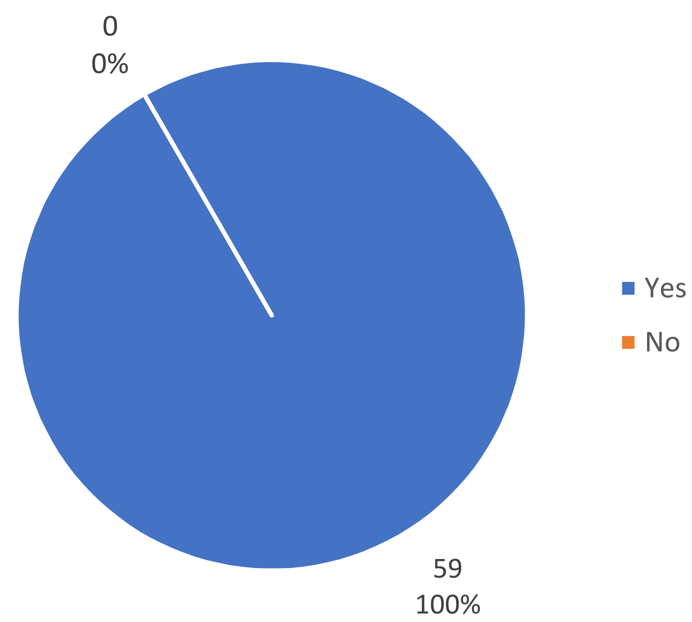
2. Did you have any difficulty boarding the vehicle?

Yes ______

No ______

ANSWERS

Difficulty Boarding Vehicle?



- No passengers used mobility devices requiring wheelchair ramp
- One passenger would have preferred to use ramp if equipped with handrail

QUESTION

3. Did you use the access ramp to board the vehicle?

Yes ______

No ______

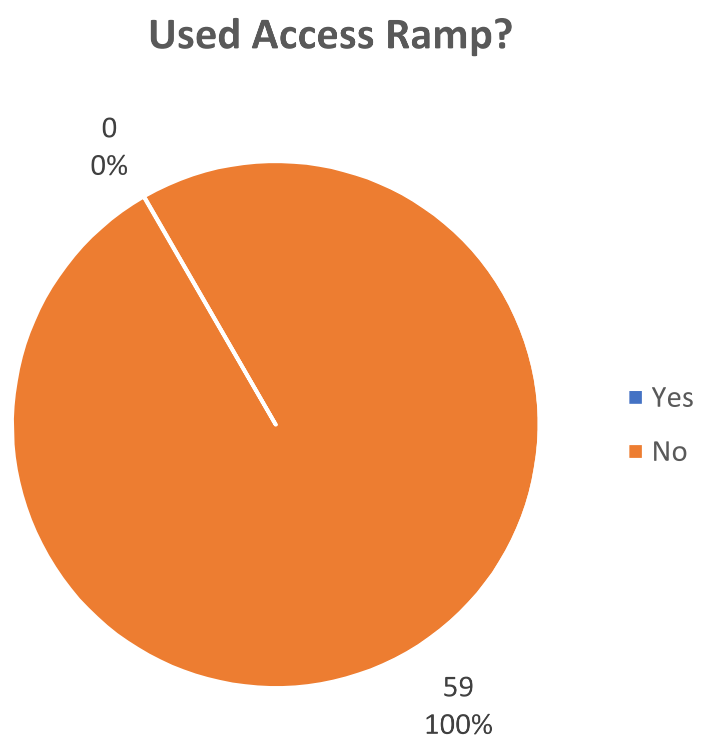
If yes:

Why did you use the ramp?

Did it help with onboarding/unloading?

Provide any other feedback regarding the ramp

ANSWERS



- No passengers used mobility devices requiring wheelchair ramp

QUESTION

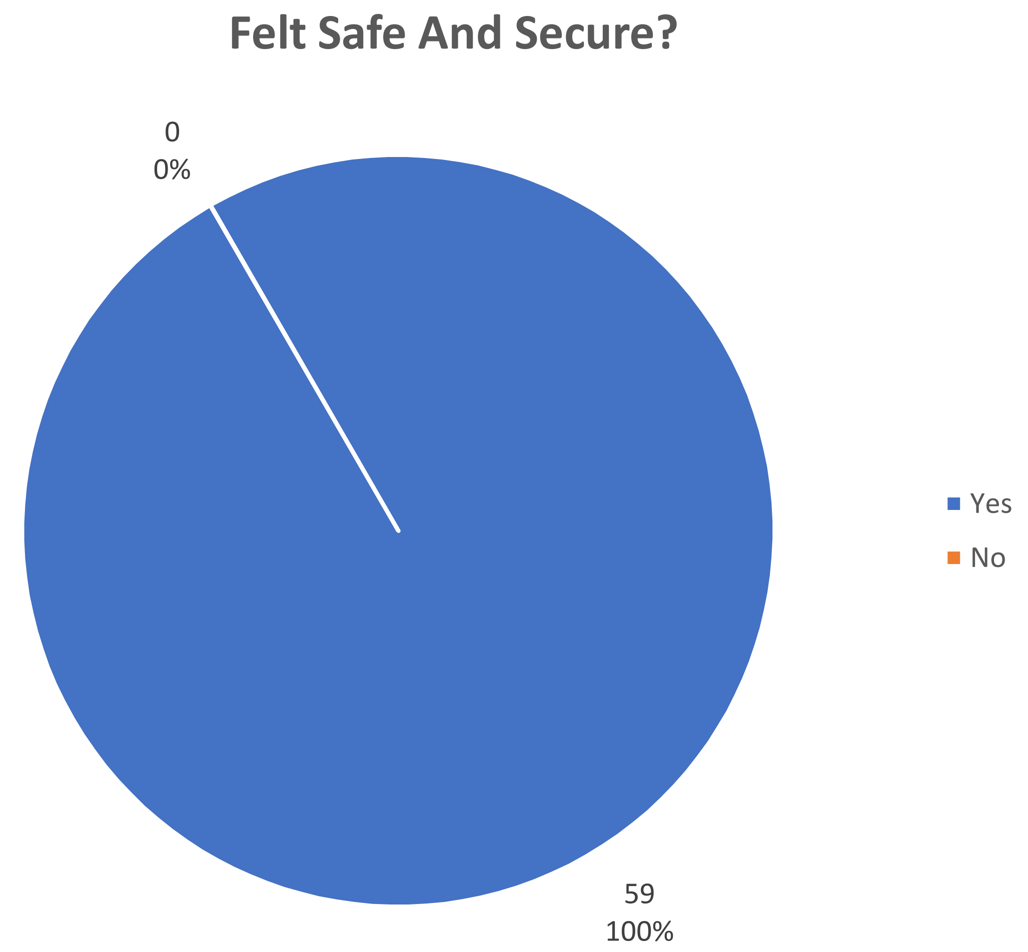
4. Did you feel safe and secure during your ride?

Yes ______

No ______

If no, explain.

ANSWERS



QUESTION

5. Was any part of the trip on the vehicle confusing for you?

Yes ______

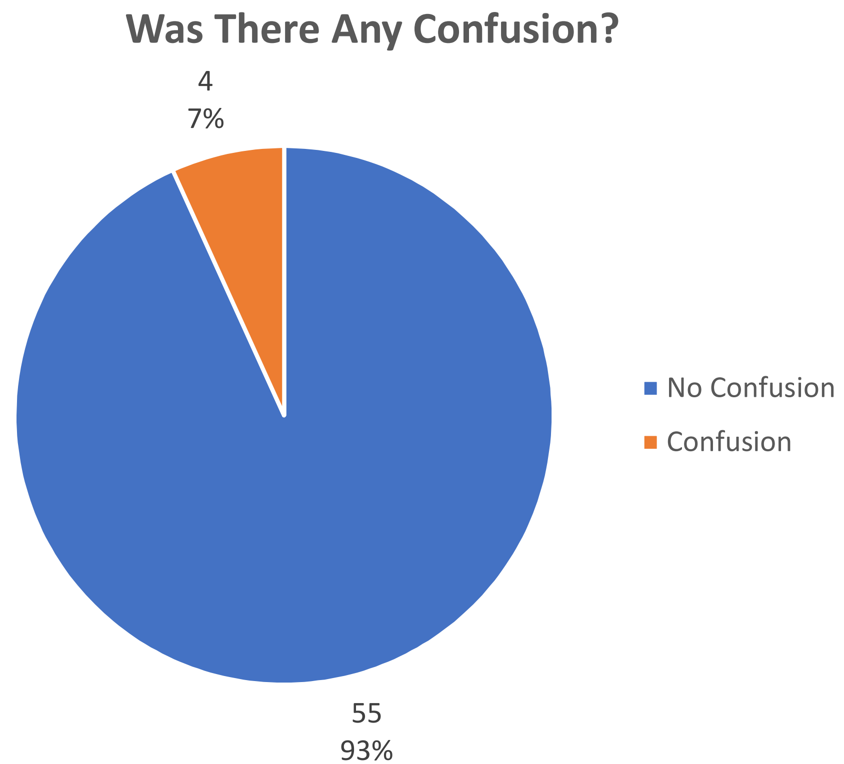
No ______

If yes, what specifically was confusing?

What was the result of the confusion?

How could the confusion have been avoided?

ANSWERS



- 4 passengers out of 59 surveyed reported confusion
  - 2 – Texting/ride hailing process difficulty
  - 1 – Vehicle stopped without pedestrian presence
  - 1 – “How can people be so close to the vehicle”

QUESTION

6. Was the onboard safety operator helpful?

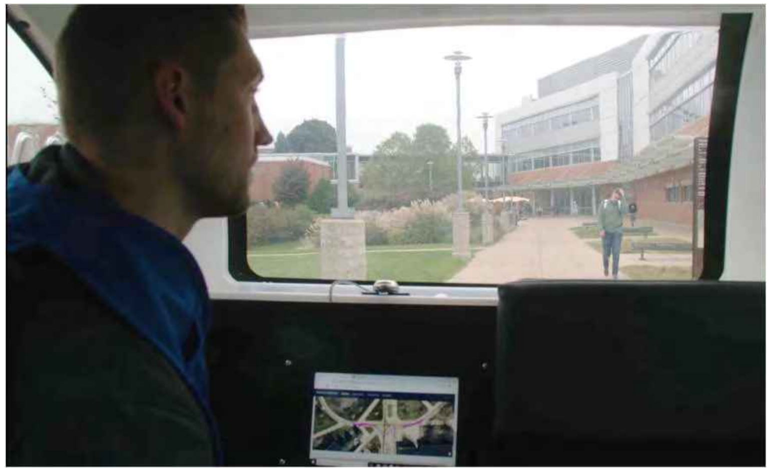
Yes ______

No ______

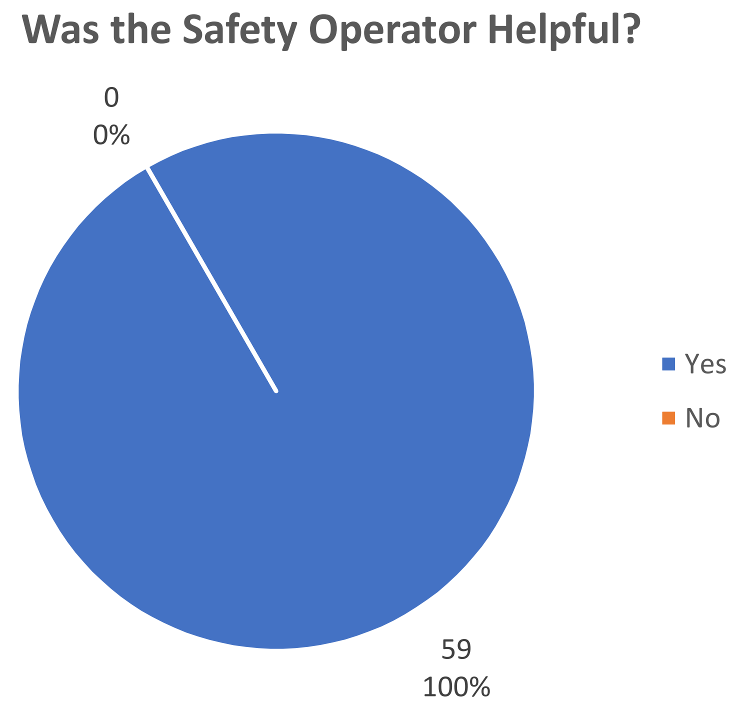
If yes, how did the safety operator provide assistance?

If not, explain what the operator could have done to make the trip go better for you.

How did the safety operator make you feel more secure?



ANSWERS



- "Very informative/Provided info"
- "Explained the research"
- "Explained the technology used"
- "Explained how vehicle avoids pedestrians"
- "Gives a human presence"
- "Holds the emergency stop"

QUESTION

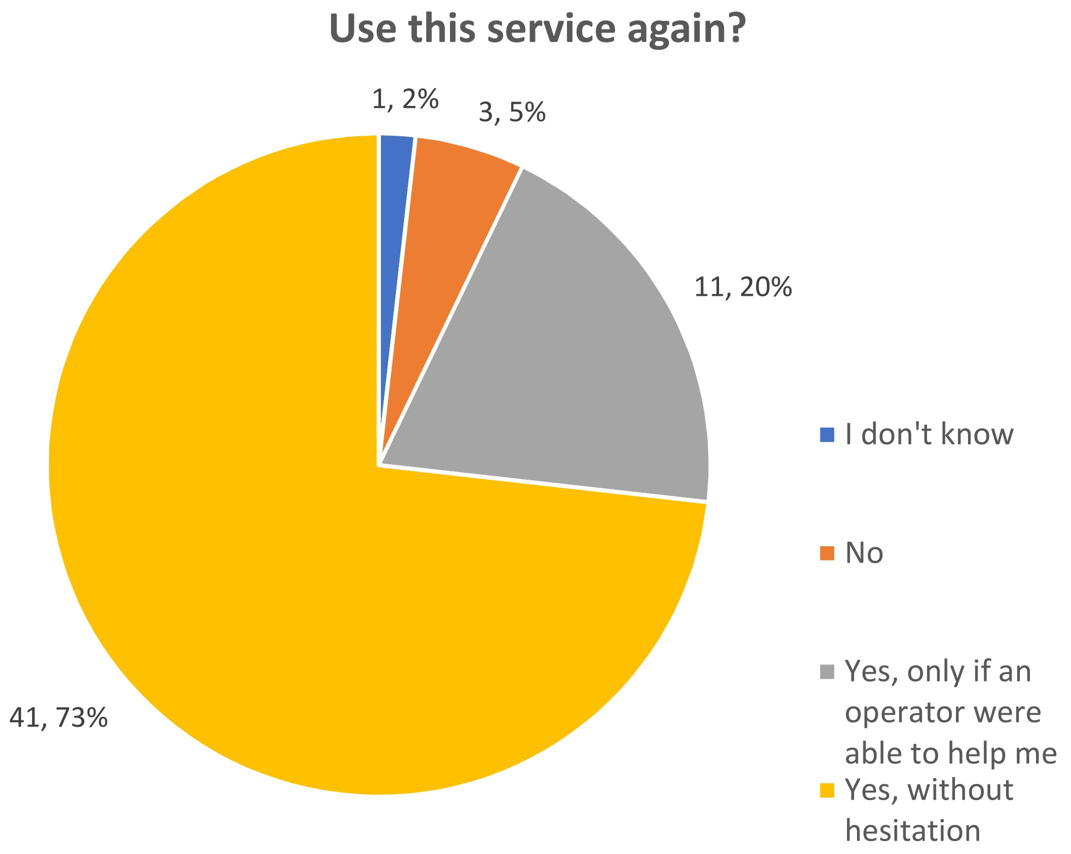
7. Would you use this type of mobility service again?

Yes, without hesitation _____
Yes, only if an operator were able to help me _____

No, I would not be interested in riding this shuttle _____
I don't know.

If no, please explain: _____

ANSWERS



All 3 "No" results explained they "do not need the vehicle for mobility"

QUESTION

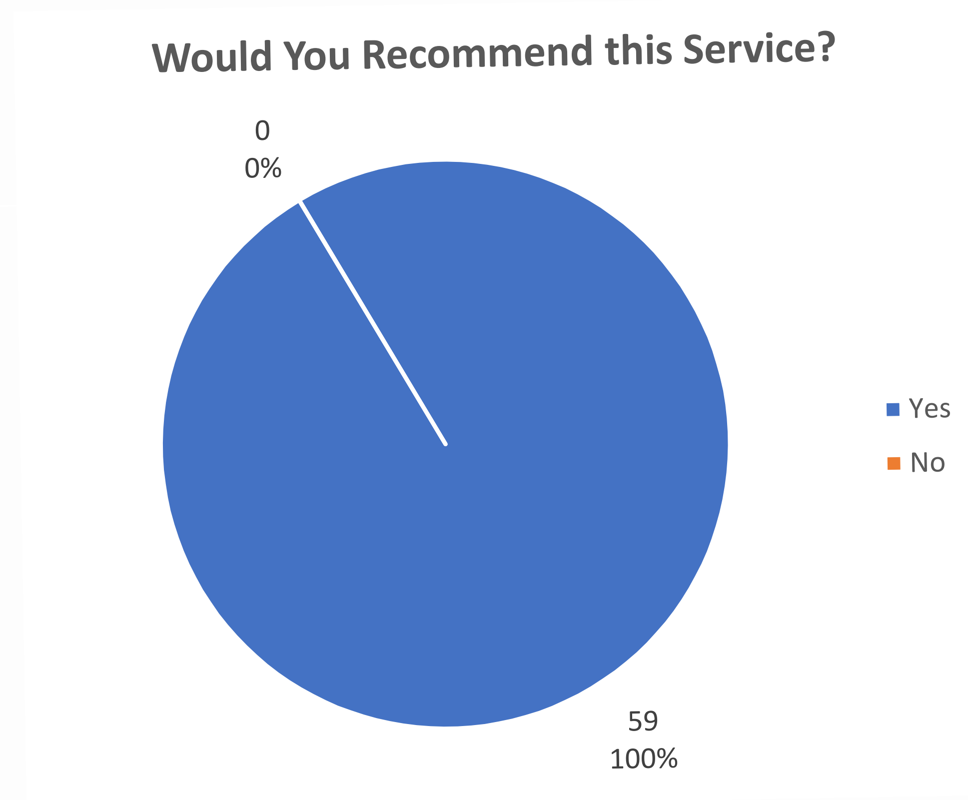
8. **Would you recommend this type of mobility service to a friend?**

   Yes ______

   No ______

   Why or why not?

ANSWERS



- "Especially to people with disabilities"
- "Would be great in bad weather"

Rider Survey Results
Mobility Device Securement

QUESTION

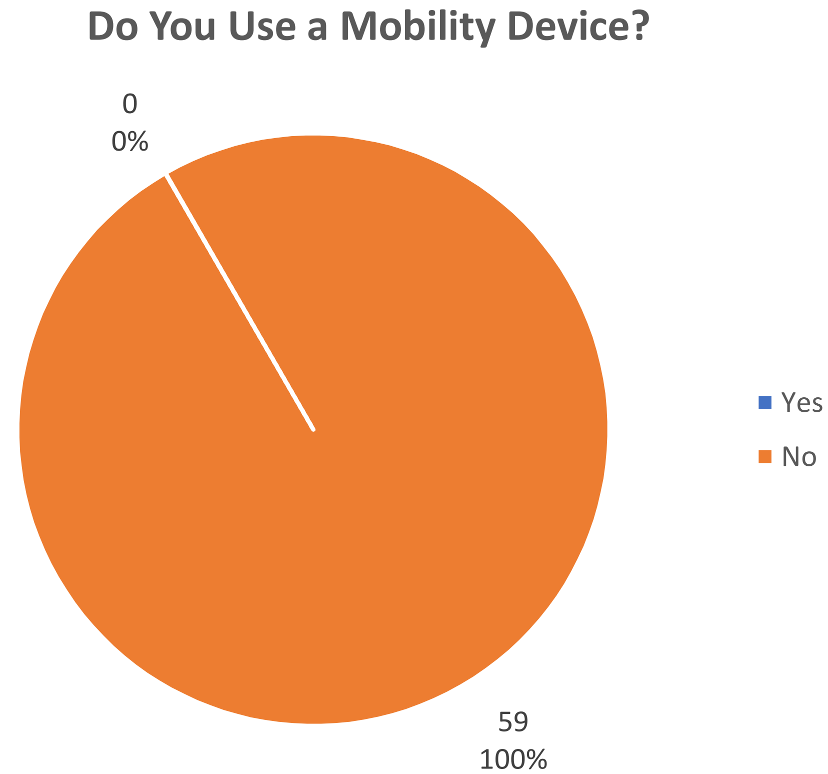
9. **If you use a mobility device such as a wheelchair, scooter, etc., were you assisted with getting your device secured?**

   Yes ______
   No ______

   Were you comfortable with the securement process?
   Yes ______
   No ______

   What did you like or dislike about the securement process?

ANSWERS



- No passengers used mobility devices requiring securement

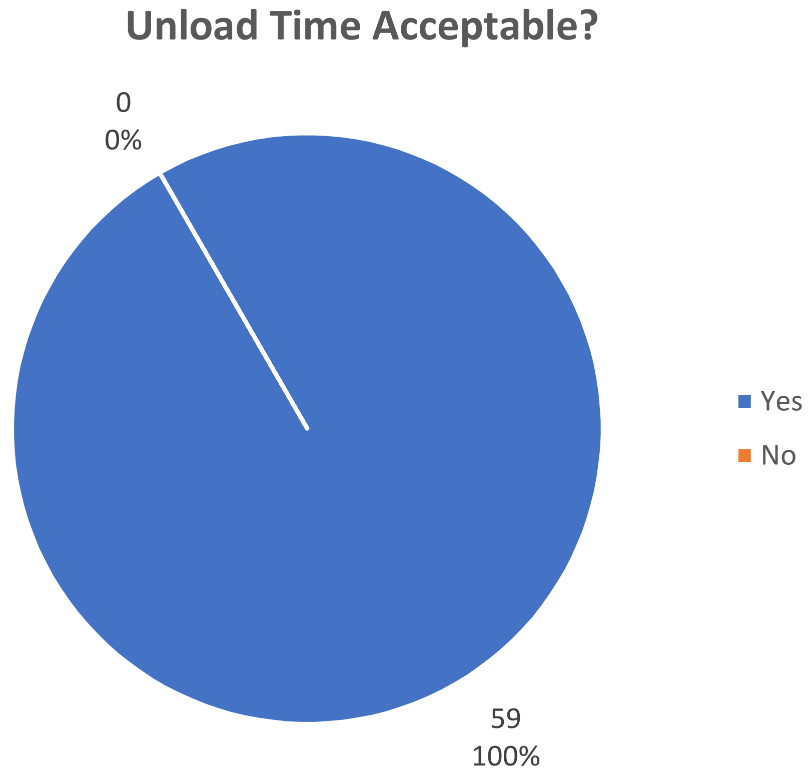
QUESTION

10. Was the time required to load/unload acceptable?

Yes ______

No ______

ANSWERS



- No passengers used mobility devices requiring securement

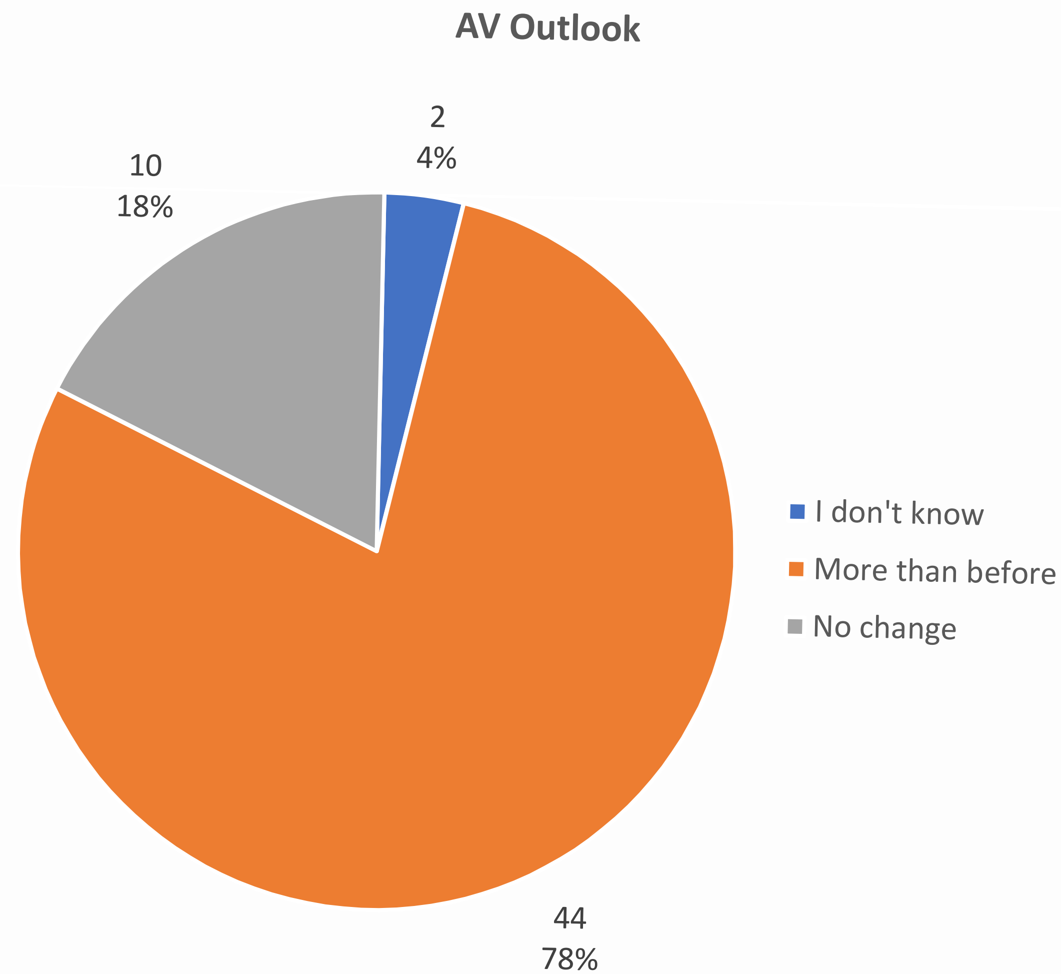
Rider Survey Results
Autonomous Vehicles

QUESTION

11. **Has your outlook on autonomous vehicles changed as a result of interacting with this particular shuttle?**

Less interested than before
No change
More interested than before
I don't know.

ANSWERS



QUESTION

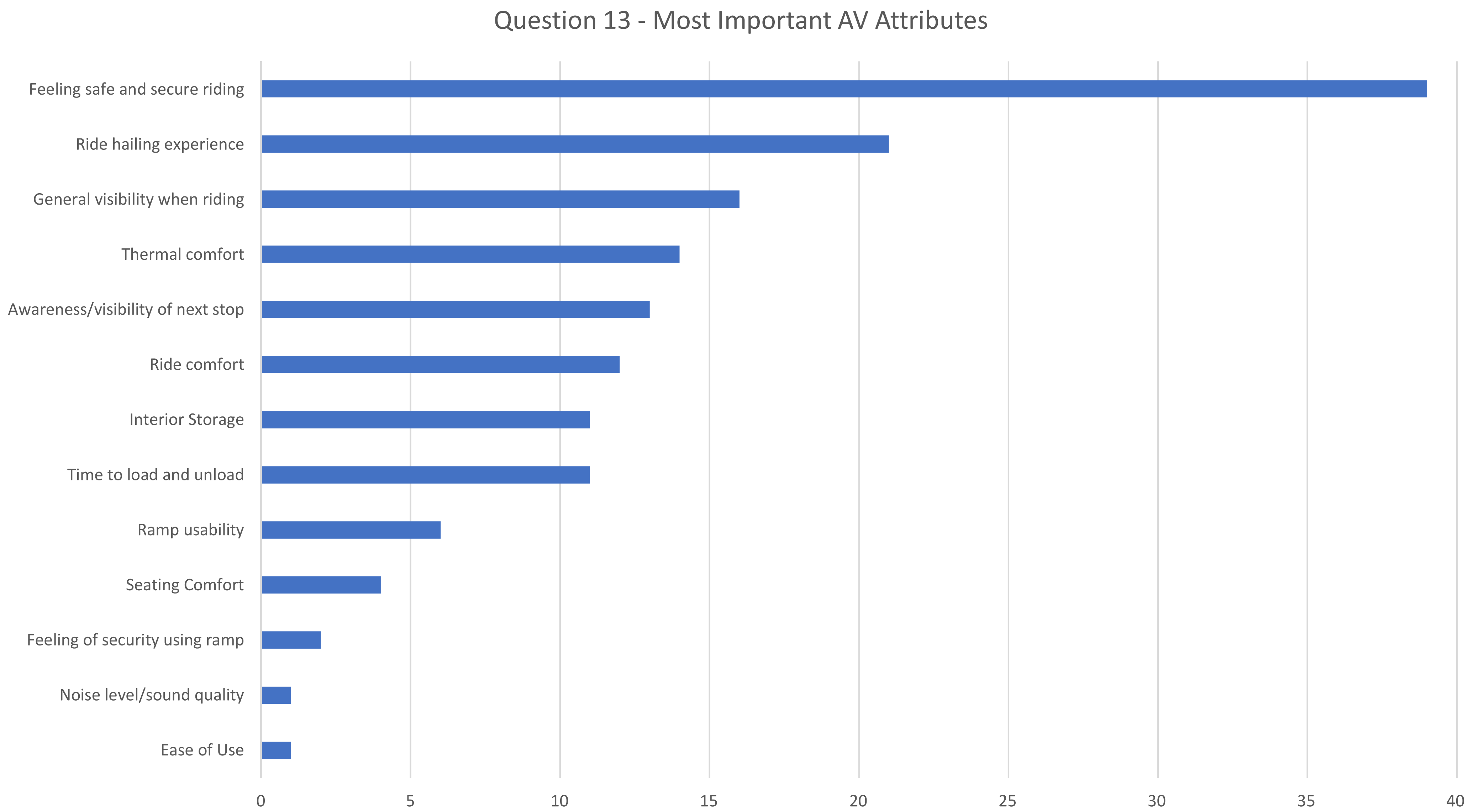
12. Do you have any other suggestions for improving your experience or comments you would like to provide on using this type of transportation?

ANSWERS

- Suggestions by Frequency
    - Faster
    - Larger Capacity
    - Reservation System
    - Program Awareness

    - Estimated Time of Arrival
    - Entertainment
    - Location Tracker
    - Front Camera View
    - Audible Warning for Stops
    - Easier to Find Stops
    - Automated Lift
    - Communication to Passengers
    - Communication to Pedestrians
    - Stops Off of Current Route
    - Ability to Navigate Steps
    - Increase Interior Space to Accommodate Double Bass (verbal, not on written survey)

Rider Survey Results
Most Important Attributes



Rider Survey Results
Key Takeaways

- For the overwhelming majority or riders (82%), this pilot provided their first ride in an autonomous vehicle

- 100% of riders
  - Had no difficulty boarding
  - Found the loading/unloading times acceptable
  - Felt safe and secure during their trip
  - Would not hesitate to use the service again
  - Would recommend this service to a friend

  Note: Although 7 of the 59 riders had disabilities, none of the riders used a wheeled mobility aid

- 4 out of 59 riders experienced some confusion during their trip
  - 2 related to ride hailing
  - 2 related to vehicle interaction with pedestrians

- 78% of riders expressed an increased interest in automated vehicles as a result of their experience in this pilot

- Feeling safe and secure was the highest-ranked vehicle attribute

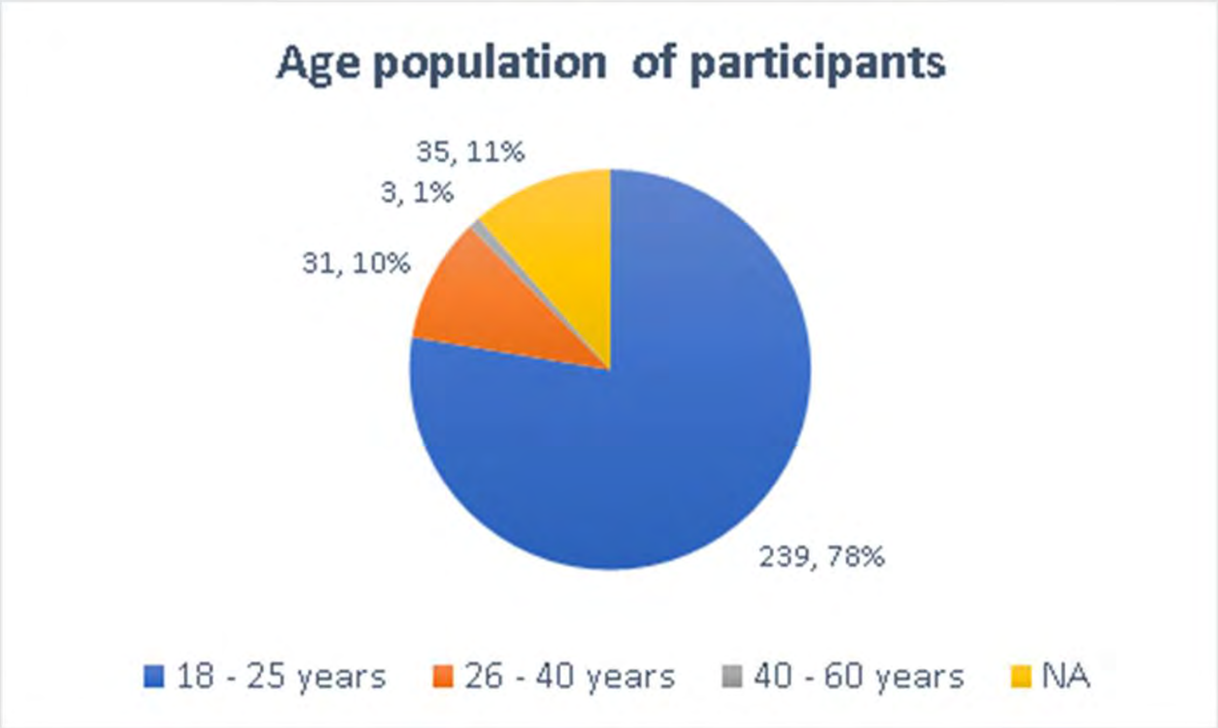
WMU Pedestrian Survey Results

Overview

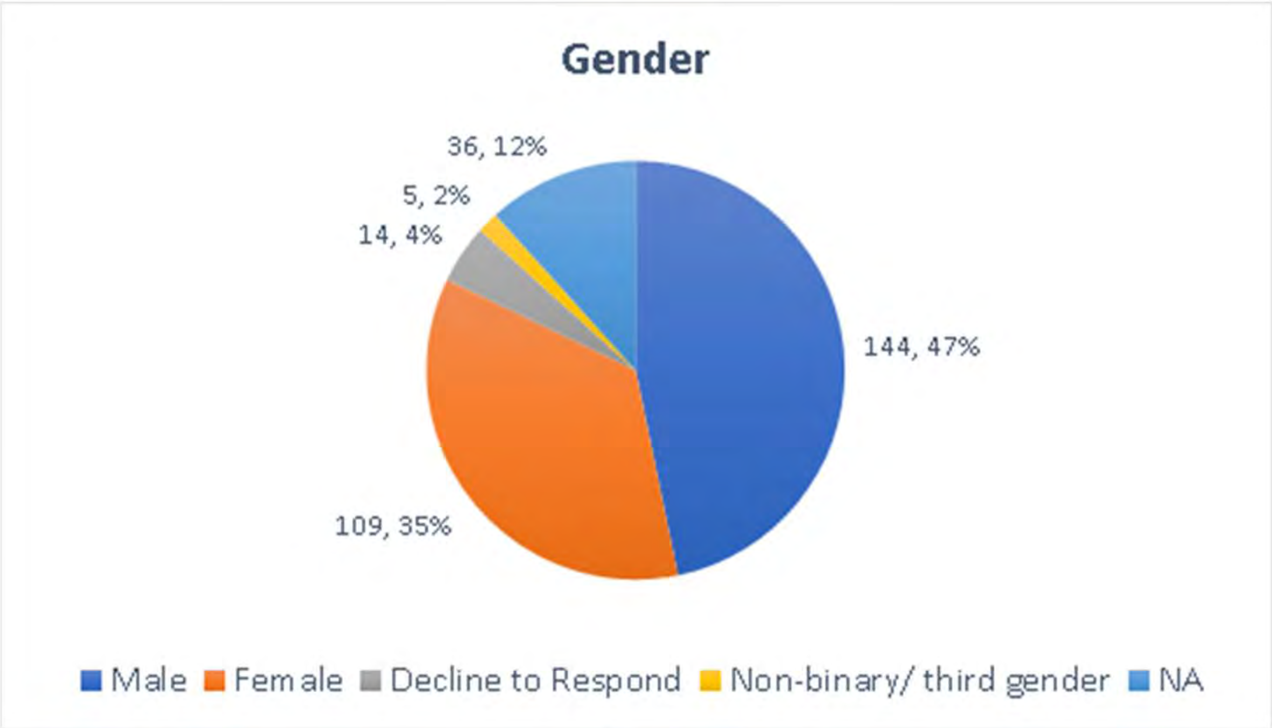
- Joint effort between the WMU Civil Engineering Department and the WMU Mechanical and Aerospace Engineering Department
- 15 questions
- Administered via email to freshman, sophomore, and junior WMU students
- 308 participants

College of Engineering and Applied Sciences
WESTERN MICHIGAN UNIVERSITY

What is your age group?



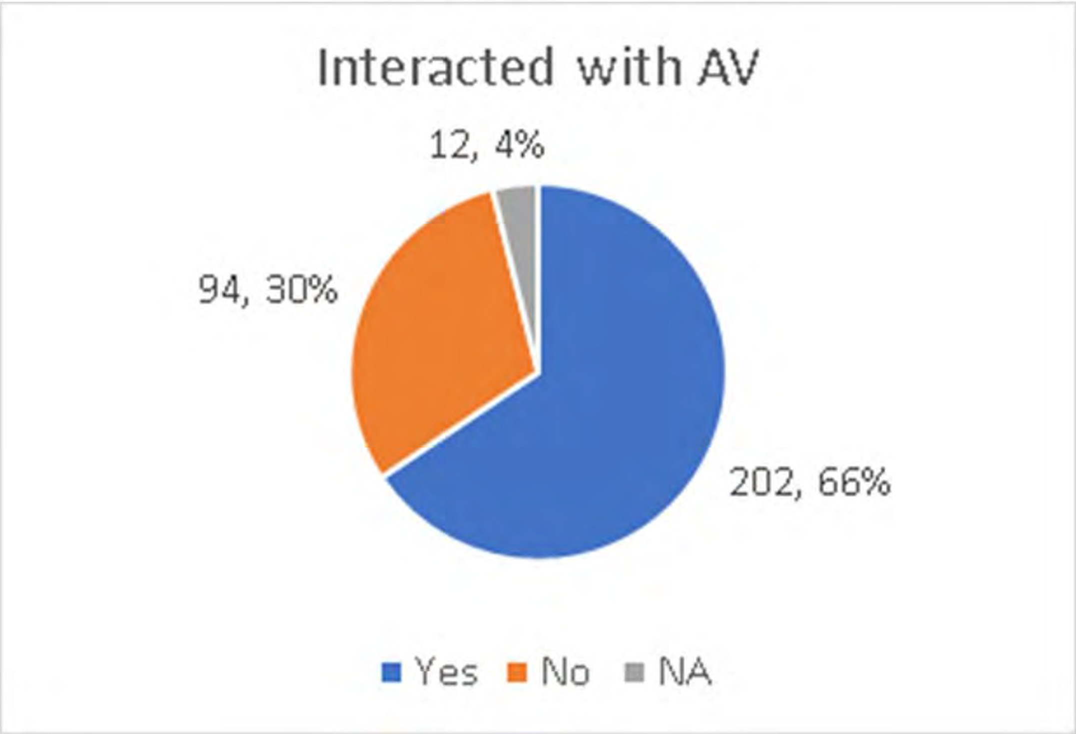
What is your gender?



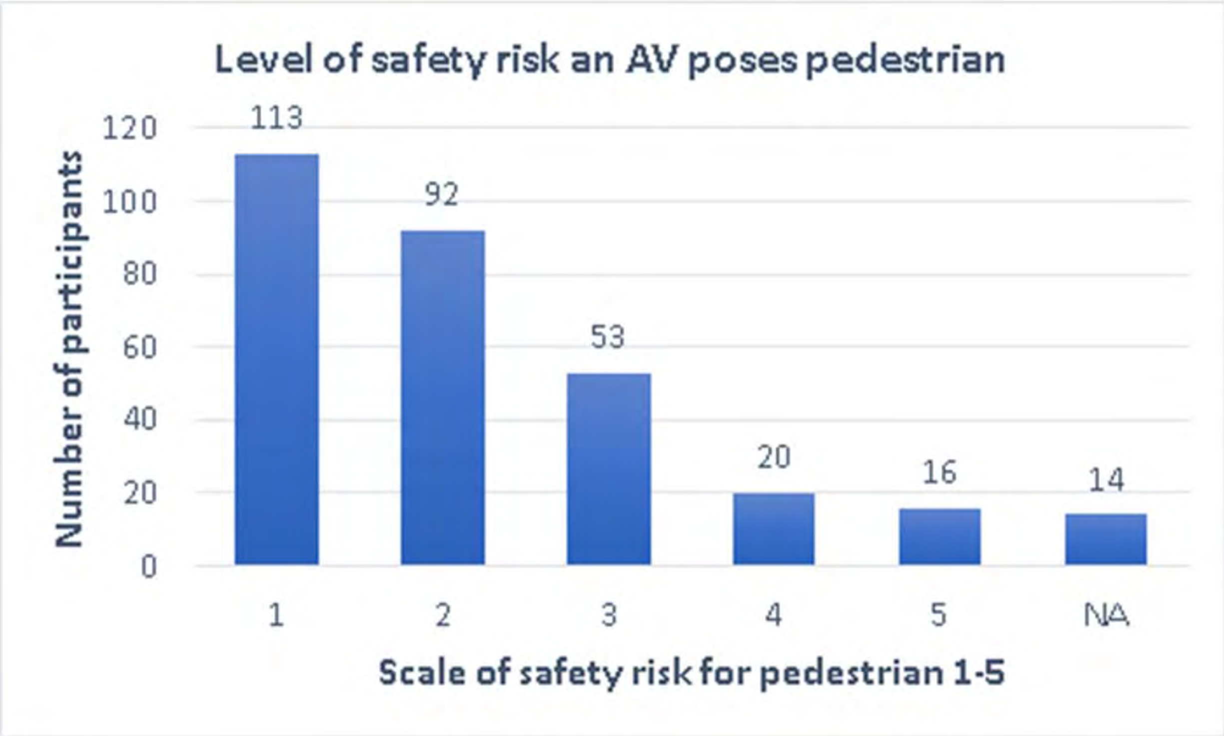
Note: NA means the survey participant did not respond to the question

WMU Pedestrian Survey Results
Pedestrians That Interacted with AV and Their Experienced Risk

Did you witness or interact with the autonomous vehicle on the WMU campus?

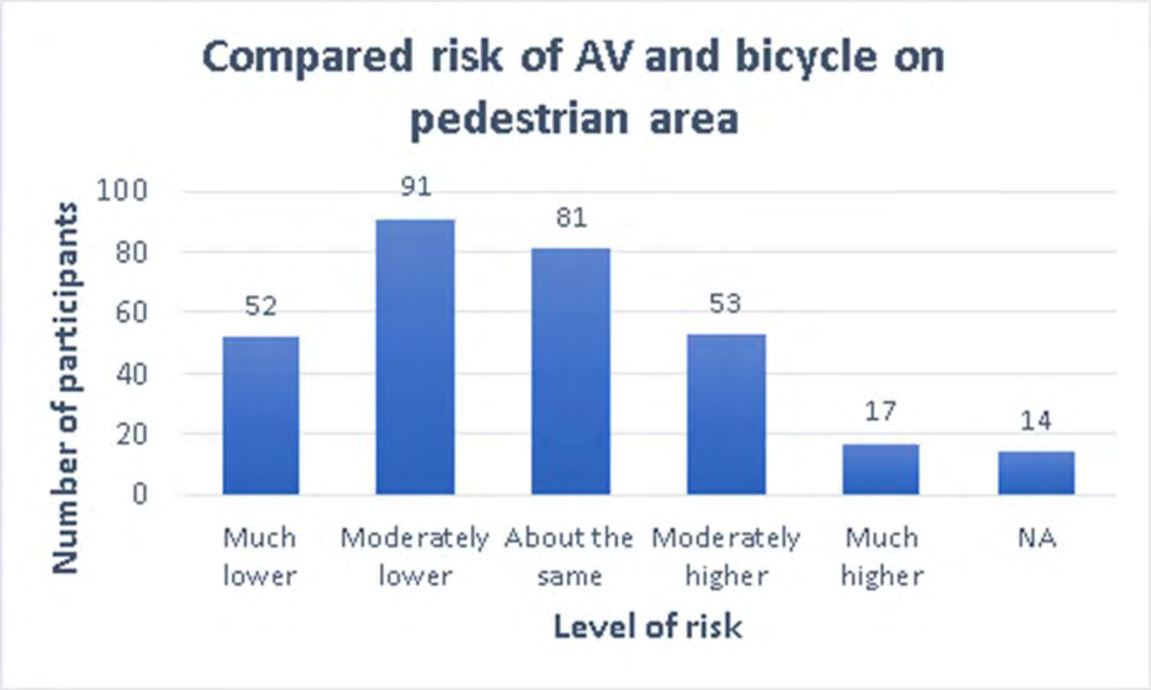


On a scale of 1-5, where 1 represents not at all and 5 represent very high, what level of safety risk does an autonomous vehicle on pedestrian walkways on campus pose to you?



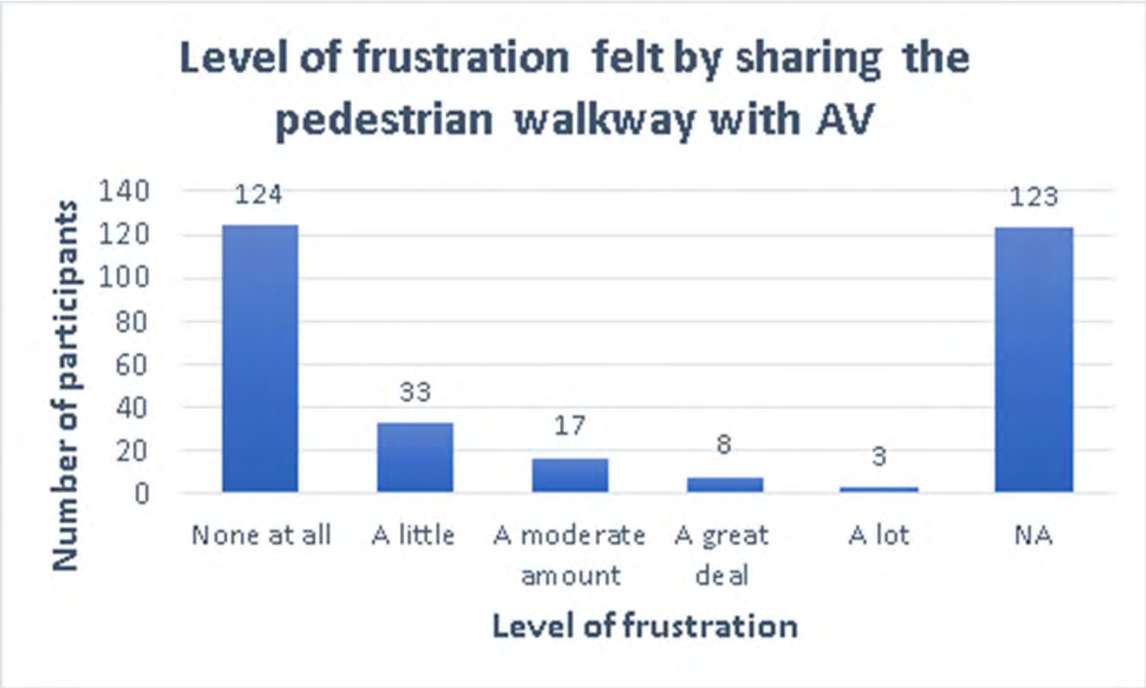
Risk Posed by Shuttle

How do you compare the risk posed by the autonomous vehicle operating on pedestrian walkway compared to a bicycle operating on a pedestrian walkway?

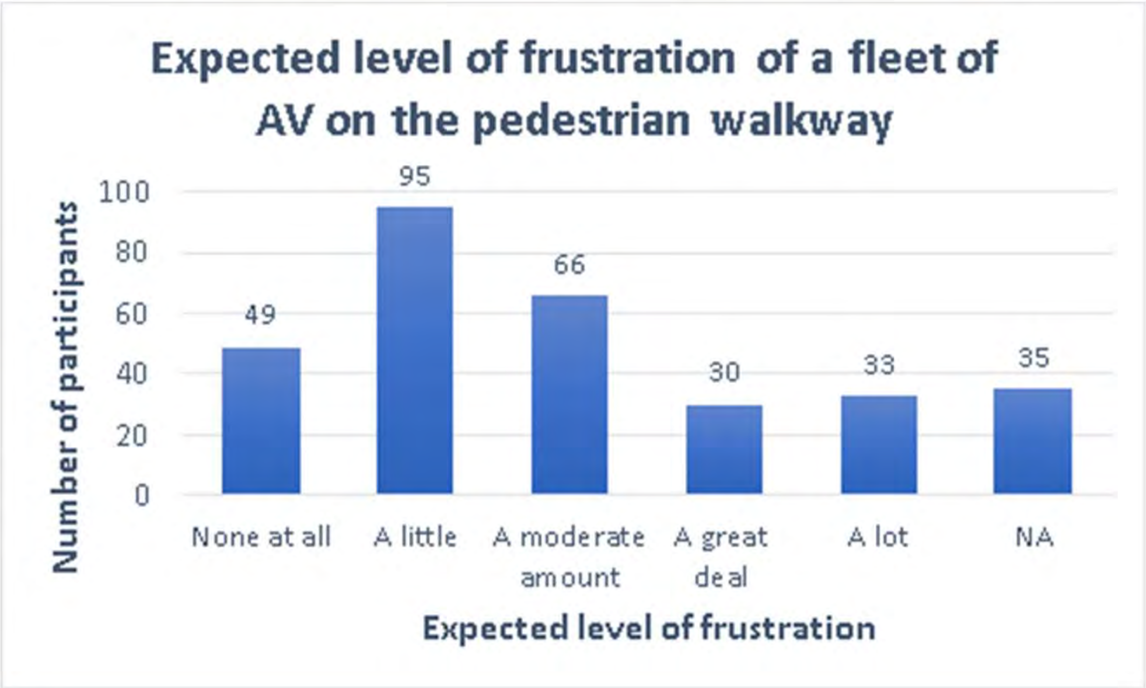


WMU Pedestrian Survey Results
Experienced and Expected Frustration from Students

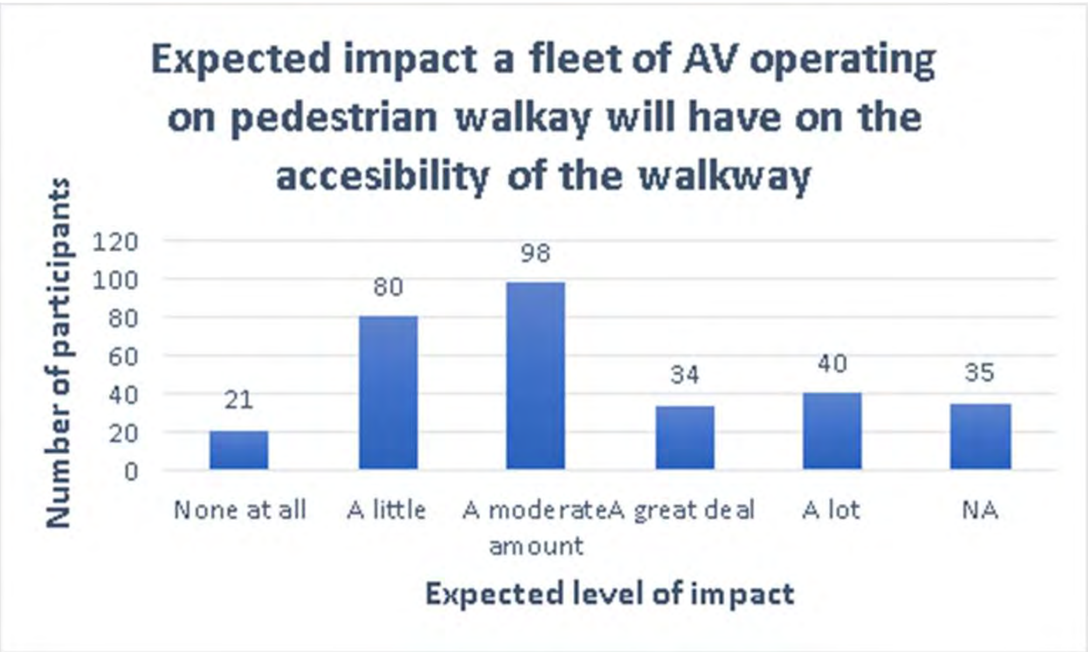
How much frustration did you experience sharing the pedestrian walkway on campus with this shuttle?



How much frustration do you expect to experience sharing the pedestrian walkway on campus with a fleet of autonomous shuttles on campus?



How much impact do you expect a fleet of autonomous vehicles operating on the pedestrian walkway will have on your accessibility of the walkway?



How much risk do you expect a fleet of autonomous vehicles operating on the pedestrian walkway will cause to pedestrians like yourself on the walkway?

WMU Pedestrian Survey Results
Comments from Students

Please share your thoughts on how you feel regarding potentially having a fleet of such autonomous vehicles operating on campus.

- “If they don't obstruct pedestrians from walking it is a valid idea”
- “I think it is a fantastic idea which may greatly benefit some WMU students. From what I've seen it's not too fast and poses little risk to pedestrians. And is only a little annoying to walk around if it's blocking you path to class (but not a big deal)”
- “It'd be nice if they could salt walkways for us”
- “It depends on what you consider a fleet. Pedestrian pathways should primarily for pedestrians, and these vehicles are relatively large so I could see too many of them being a detriment. I also couldn't see the cost being justified, especially if its passed onto students”
- “I think it will be beneficial for those with accessibility issues”
- “I think this isn't a good idea because getting to and from classes is hard enough with the walkways but with vehicles it will be even harder and more annoying”
- “I feel as if it could potentially block the flow of pedestrians as well as possibly scare some people although they would have a major impact for those with mobility disabilities”
- “If there are people walking, riding skateboards or bikes using the walkways along with the car, it might become an issue because the vehicle is kind of wide and in some places the walkways where it was driving you ended up walking in the grass”

WMU Pedestrian Survey Results
Key Takeaways

- The overwhelming majority of pedestrians that interacted with the autonomous shuttle felt that it posed little or no risk to pedestrians, and most of them felt that the shuttle posed less risk to pedestrians than a bicycle

- Students believe this type of service is very beneficial for individuals with disabilities

- Students generally have a positive view of deploying an autonomous shuttle on campus, as long as there is minimal obstruction on the pedestrian walkway

- 85% of the students experienced little or no frustration while sharing the walkway with the autonomous shuttle

- Many students expect a higher level of frustration and a larger impact on the walkway if a fleet of autonomous shuttles were deployed on campus given the size of the shuttle and the amount of students using the walkway at peak hours

Cost Benefit Analysis
Overview

Cost Benefit Analysis

1) Current Shuttle Alternatives
    a) Gather purchase, maintenance, and fuel costs
2) Statement of Assumptions used in analysis
3) Cost per mile comparison of current shuttles
    a) Including a table of Net Present Values
4) Ridership Analysis
    a) Low and High Ridership for fixed route analysis
    b) Low ridership for an On-Demand Service
5) EV price trends
6) Sensitivity analysis on delta cost for different deployment AV scenarios

Cost Benefit Analysis
Cost Model

Vehicle	Purchase	Maintenance ($/mile)	Fuel ($/mile)**	Passengers
Small EV	$100,000.00	$0.03	$0.03	4
Small ICE	$20,000.00	$0.03	$0.10	4
Small Hybrid	$30,000.00	$0.04	$0.08	4
Mid-size EV	$250,000.00	$0.10	$0.04	15
Mid-size ICE	$55,000.00	$0.33	$0.17	15
Full Bus EV	$350,000.00*	$0.18*	$0.17*	30
Full Bus ICE	$247,000.00*	$0.35*	$0.30*	30
Full Bus Hybrid	$275,000.00*	$0.44*	$0.24*	30

*Source: Lajunen, Antti. 2018
** Fuel Economy is included with this value

Cost Benefit Analysis
Cost Model

Key Assumptions	
Years of Operation	15
Miles/year	15,000
Operator Salary ($/year)	55,000
Autonomous Kit ($)	50,000*
Tele-ops ($)	5,000
AV Maintenance ($/mile)	0.01
Average Electric ($/kWh)	0.13
Average Unleaded ($/gal)	2.6
Average Diesel ($/gal)	3.05

*assumes a commercialized product, as opposed to a prototype system

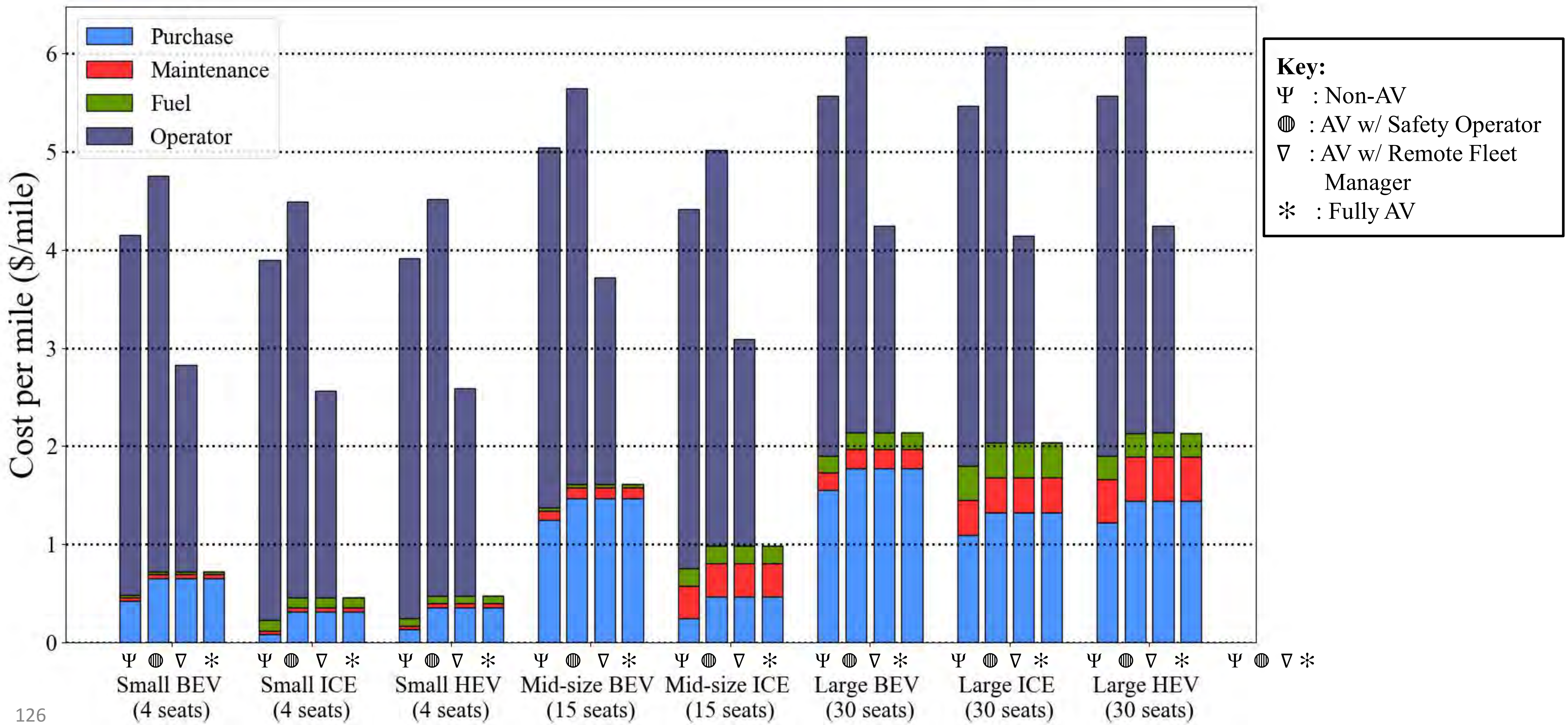
List of Sources

- Feng, Wei, and Miguel Figliozzi. 2013. "An Economic and Technological Analysis of the Key Factors Affecting the Competitiveness of Electric Commercial Vehicles: A Case Study from the USA Market." *Transportation Research Part C: Emerging Technologies* 26 (January): 135–45.
- "King County Metro Battery Electric Bus Demonstration: Preliminary Project Results, U.S. Department of Transportation, Federal Transit Administration." n.d. https://afdc.energy.gov/files/u/publication/king_county_be_bus_preliminary.pdf.
- Lajunen, Antti. 2018. "Lifecycle Costs and Charging Requirements of Electric Buses with Different Charging Methods." *Journal of Cleaner Production* 172 (January): 56–67.
- Moultak, Marissa, Nic Lutsey, and Dale Hall. 2017. "Transitioning to Zero-Emission Heavy-Duty Freight Vehicles." *Int. Counc. Clean Transp.* https://www.theicct.org/sites/default/files/publications/Zero-emission-freight-trucks_ICCT-white-paper_26092017_vF.pdf.
- Wadud, Zia. 2017. "Fully Automated Vehicles: A Cost of Ownership Analysis to Inform Early Adoption." *Transportation Research Part A: Policy and Practice* 101 (July): 163–76.
- Yoon, Taekwan, and Christopher R. Cherry. 2018. "Migrating towards Using Electric Vehicles in Campus-Proposed Methods for Fleet Optimization." *Sustainability: Science Practice and Policy* 10 (2): 285.
- "497181a.pdf." n.d. https://www.nature.com/articles/497181a.pdf.

Additional Assumptions:

- All purchase prices are considered with today's market of AV, ICE, and HEV prices
- These are upper level purchase costs, (i.e. how much it would cost to purchase from a manufacturer)
- Vehicle value depreciates to $0 after timeframe
- For the Fleet Manager case, there is one Fleet Manager that monitors two shuttles and can intervene if the shuttle must be driven manually
- Driver Salaries:
  - Non-AV Operator: $55,000
  - Safety Operator for AV: $60,500
  - Remote Fleet Manager: $63,250

Cost Benefit Analysis
Cost Per Mile



Cost Benefit Analysis
Time Value of Money Calculations

		NPV	% lower from Ψ			NPV	% lower from Ψ
Small EV	Ψ	659175.28		Small ICE	Ψ	727561.64	
	◍	754518.58	-14.46%		◍	822904.94	-13.10%
	∇	516466.24	21.65%		∇	584852.6	19.61%
	✻	225742.25	65.75%		✻	324128.6	55.45%
Small Hybrid	Ψ	693042.78		Mid-size EV	Ψ	983103.76	
	◍	788386.06	-13.76%		◍	1078447.07	-9.70%
	∇	550333.72	20.59%		∇	840394.7	14.52%
	✻	289609.73	58.21%		✻	579670.73	41.04%
Mid-size ICE	Ψ	1448276.05		Large EV	Ψ	1447790.69	
	◍	1543619.35	-6.58%		◍	1543133.99	-6.59%
	∇	1305567.01	9.85%		∇	1305081.65	9.86%
	✻	1044843.02	27.86%		✻	1044357.66	27.87%
Large ICE	Ψ	2006320.17		Large Hybrid	Ψ	1989801.29	
	◍	2101663.48	-4.75%		◍	2085144.59	-4.79%
	∇	1863611.13	7.11%		∇	1847092.25	7.17%
	✻	1602887.14	20.11%		✻	1586368.26	20.28%

Key:
Ψ : Non-AV
◍ : AV w/ Safety Operator
∇ : AV w/ Remote Fleet Manager
✻ : Fully AV

Cost Benefit Analysis
Assumptions

Ridership Evaluation

Scenario	Start Time	Stop Time	Route Distance (miles)	Average riders/day	Average trips/hour	Average riders/trip
A - High Ridership	**7:00 AM**	**12:00 PM**	**3**	**1000**	**2**	**29.4**
B - Low Ridership	**8:00 AM**	**4:00 PM**	**1.5**	**100**	**4**	**3.1**
C - On-Demand Service	**12:00 AM**	**11:59 PM**	**0.5 (average)**	**300**	**10**	**2.5**

- Scenario A statistics were taken from WMU’s current shuttle service. https://wmich.edu/broncotransit
- Scenario B statistics were determined for similar environment the pilot was deployed, except using a fixed-route.
- Scenario C statistics are for an on-demand service.

Assumptions

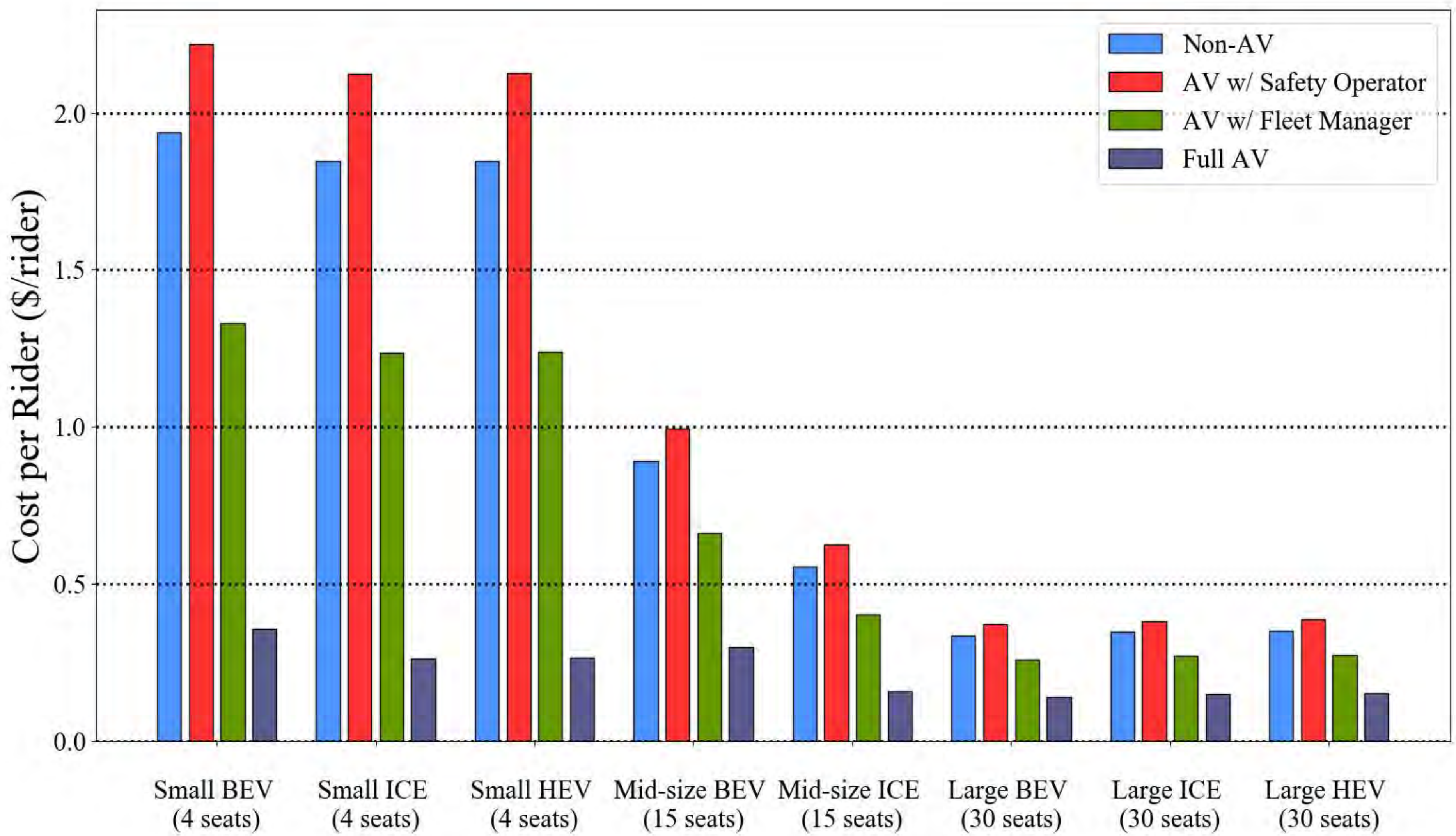
- No revenue from riders is collected
- Additional Vehicles purchased to keep up with average ridership

Cost Benefit Analysis

High Ridership Evaluation

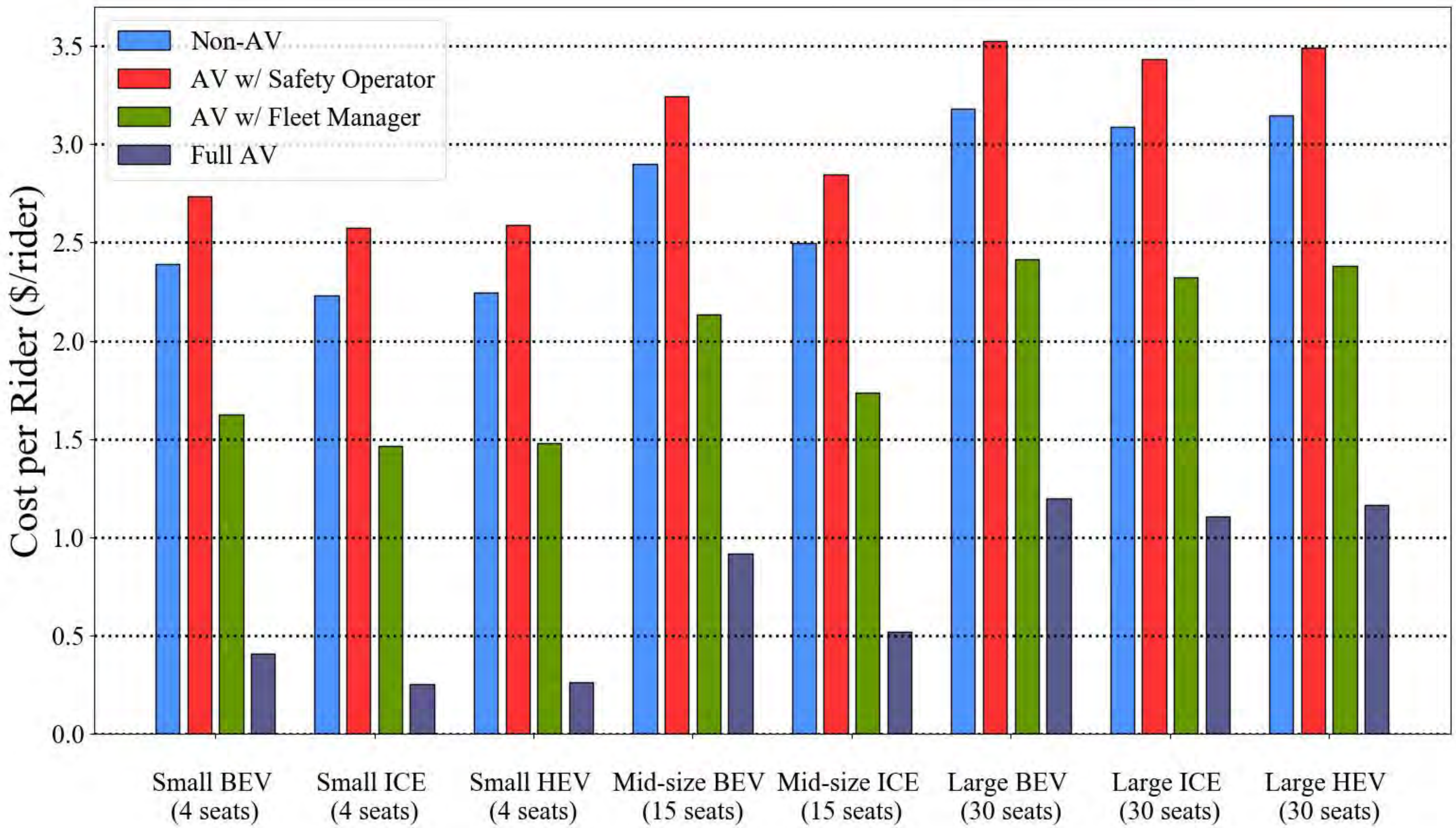
Scenario A - High Ridership

- Small shuttles are unrealistic for high ridership environments
- 6 small shuttles were needed to keep up with rider demand



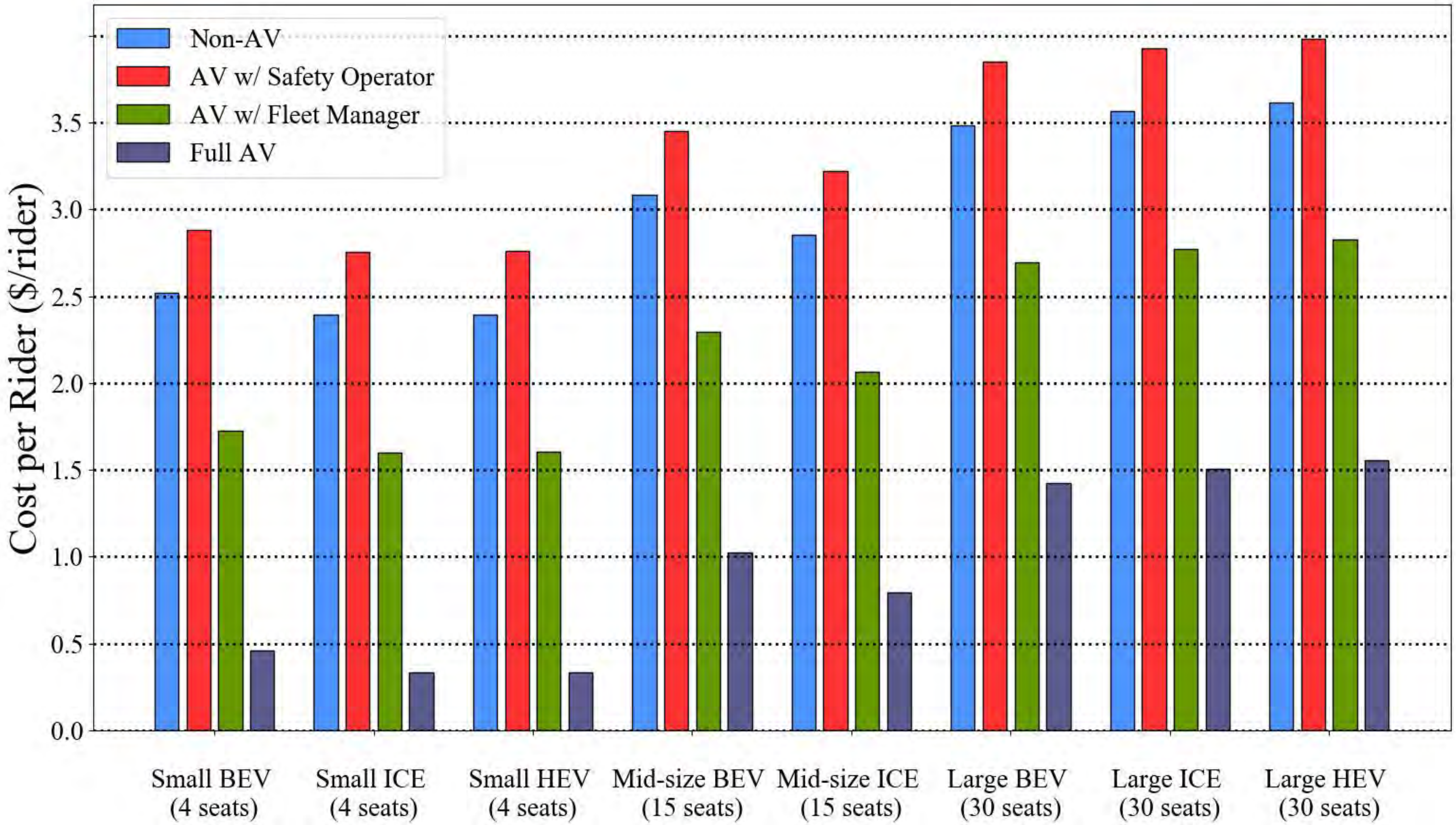
Scenario B - Low Ridership

- Smaller shuttles are ideal for low ridership campuses
- Low Ridership scenarios cause a large increase in cost per rider

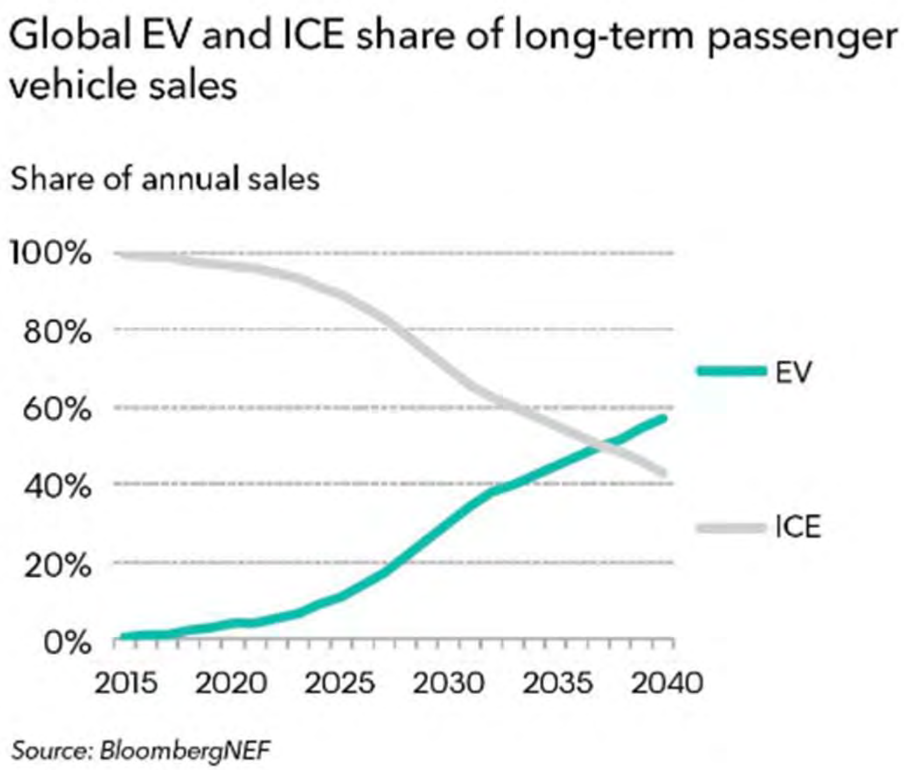


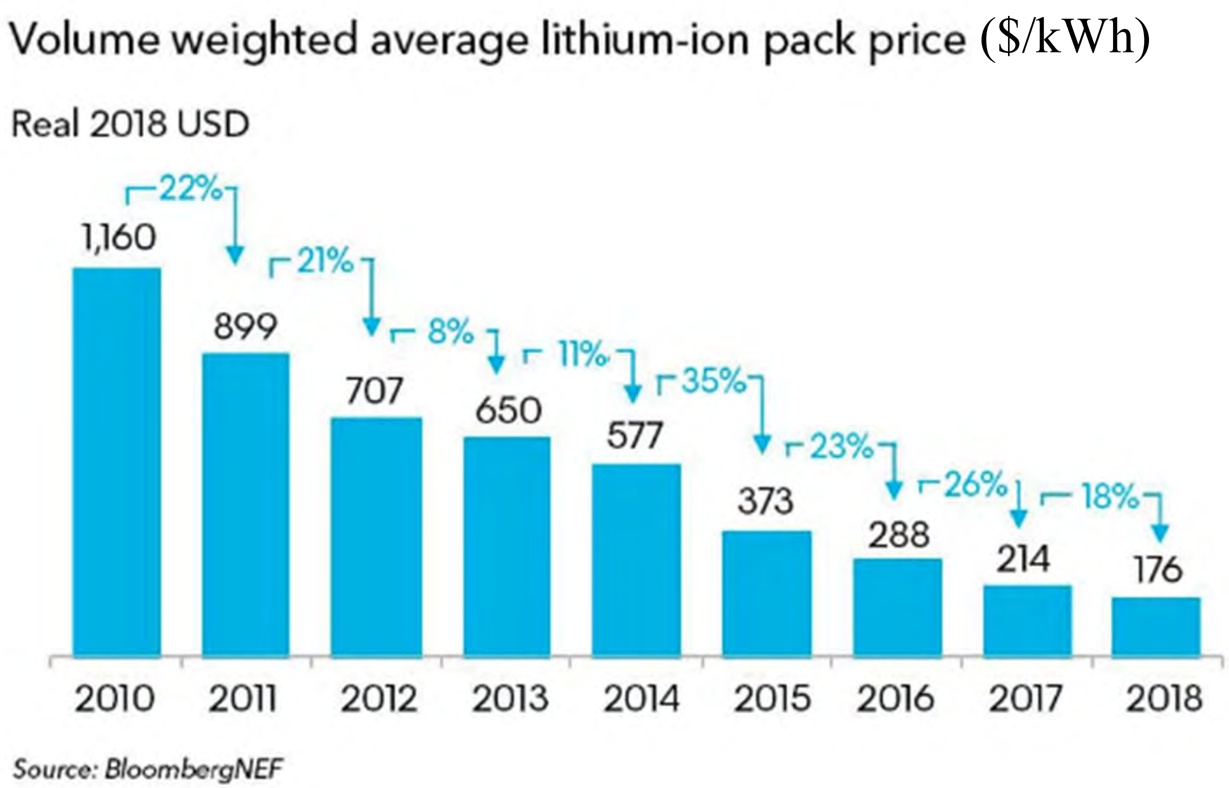
Scenario C - On Demand

- On-Demand provides lowest cost



Cost Benefit Analysis
EV Price Trends





See link to report: https://about.bnef.com/electric-vehicle-outlook/

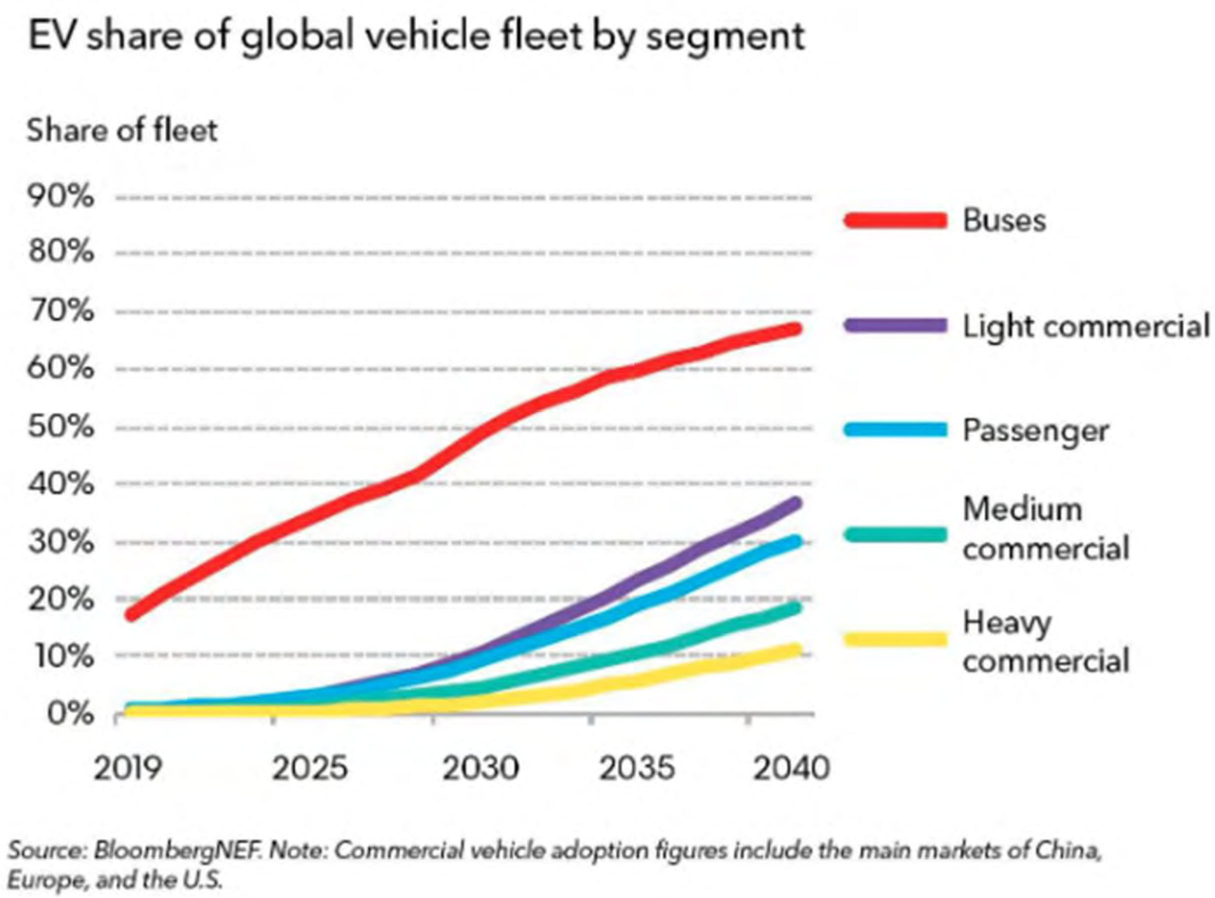
Cost Benefit Analysis
EV Demand Per Segment

Important Notes:

- Expecting EVs and ICE price parity by mid 2020s (from previous plots)

Takeaway:

- EVs should be the focus



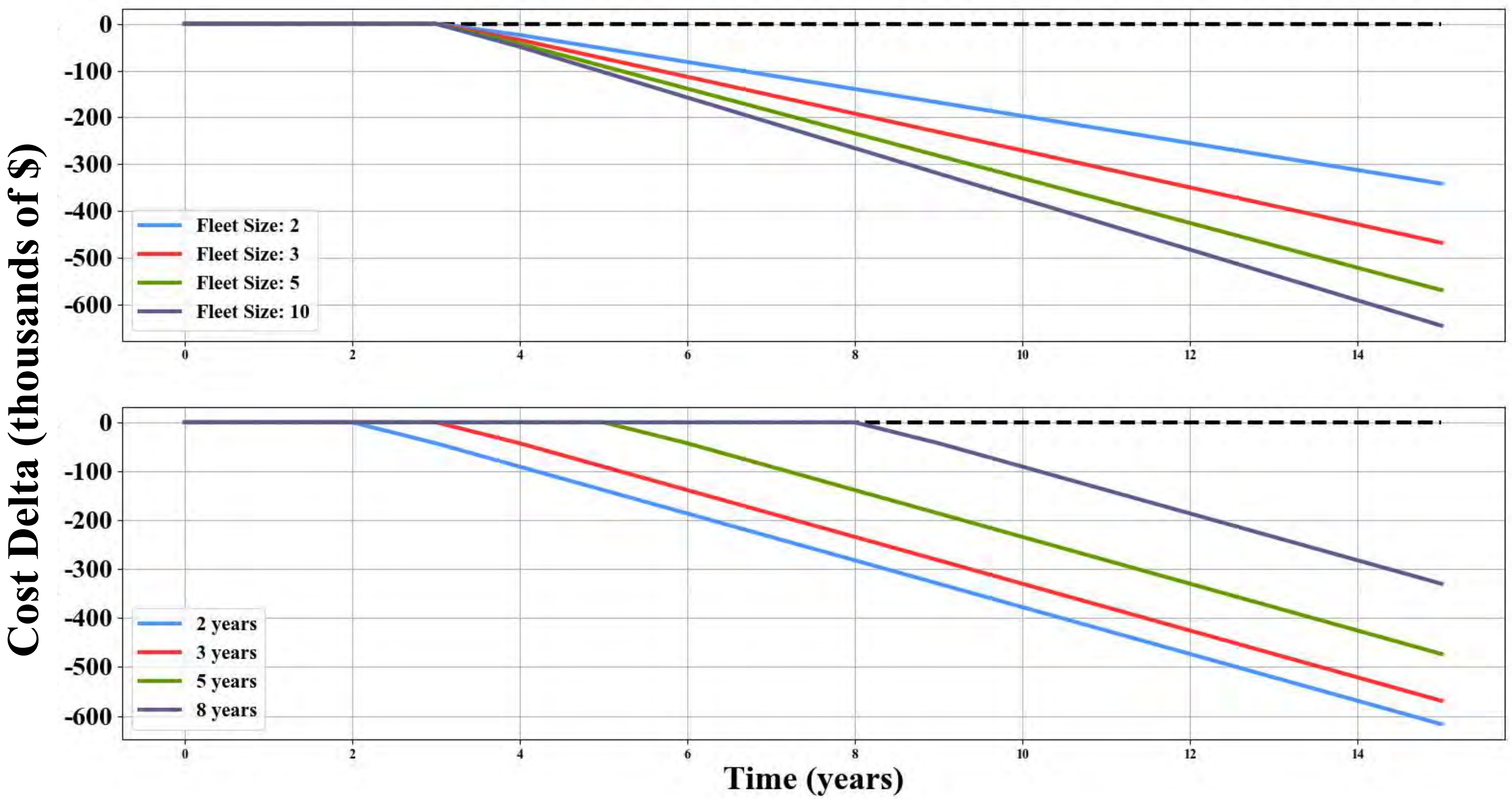
Vehicle model used for following plot:
(representing an EV)

Purchase costs:	$45,000
Maintenance:	$0.035/mile*
Fuel Cost:	$0.05/mile**

Assumptions:
a) Time = 15 years
b) Miles/year = 15,000

* "Costs.pdf." n.d. https://avt.inl.gov/sites/default/files/pdf/fsev/costs.pdf.
** Berman, Brad. n.d. "Total Cost of Ownership of an Electric Car." PluginCars.com. Accessed November 27, 2019. https://www.plugincars.com/eight-factors-determining-total-cost-ownership-electric-car-127528.html.

Deployment Alternatives Cost Difference Plots



- Baseline (dashed black line) represents autonomous BEV with a safety operator
- "Total cost" is the delta cost per vehicle, with one fleet manager for the fleet

Assumptions

- Top plot transitions from multiple safety operators to one fleet manager after 3 years
- Bottom plot is assumed to have a fleet manager for a 5-vehicle fleet

Key Lessons Learned
Accessibility

- The maximum ramp slope allowed by ADA accessibility specifications for transportation vehicles is too steep for many wheelchair users
  - ADA allows a slope of 1:4 for a ramp that deploys to ground level
  - The NAMV-MI team recommends a maximum ramp slope of 1:8

- The minimum 600 lbs. design load for access ramps included in the ADA Accessibility Standards is not adequate for many individuals in power wheelchairs

- Positive reaction from study group participants, despite weight and space constraints
  - Might reflect on what persons with disabilities have to deal with on a regular basis

- The challenges associated with this project reinforce the idea that designing accessibility into a product from the beginning is preferable to retrofitting a product for accessibility
  - Vehicle of a similar size could allow a much larger sample of mobility devices to be compatible
  - Early integration of a ramp allows for a simpler design that could be automated in the future
  - Retrofitting is costly and less effective than original design opportunities and may inhibit usability and integration of desired elements
  - Additional studies with user groups representing a wide range of disabilities are necessary to develop functional requirements prior to vehicle design

Key Lessons Learned
Automation

- Riders view safety as critical, but other priorities can be of equal or higher importance, especially to riders with disabilities
  - During the WMU pilot, the overwhelming majority of riders identified "feeling safe and secure while riding" as the highest priority attribute for an autonomous shuttle
    - Majority of riders at WMU had no disabilities
  - In the static accessibility analysis in Ann Arbor, participants with disabilities ranked cost, wait time, and time to plan a ride higher than safety when asked, "List the 3 most important factors you consider when deciding which mode of transportation to take"

- During the static accessibility analysis in Ann Arbor, 40% of participants indicated that they would only use the MMC shuttle if somebody was available to assist them; this reinforces the need for automated ramps/lifts and wheelchair securement systems when no safety operator is present

- It is challenging for an autonomous vehicle to navigate a high-traffic pedestrian area without excessive slowing or stopping; refining vehicle response to pedestrians in an effort to reduce travel time, while maintaining safety, is an important consideration for future development
  - In general, riders wanted vehicle to go faster but most pedestrians felt comfortable with the speed

- Industry standardization would facilitate integration of ADS on various vehicle platforms, increasing the potential for innovation

Key Lessons Learned
Other

- Targeted marketing upfront to spread awareness of the service may have been beneficial to recruit more riders
- Vehicle needs to operate in all weather conditions
- HVAC would be required for seasonal operation
- Service needs to be synchronized with the rider need
    - A service between center campus and other areas (dorms, etc.) would be more beneficial than a loop on center campus
    - Compare trip time without shuttle service vs. trip time (including wait time) with shuttle service
    - Other strategies could be investigated, such as continuous loop vs. on-demand
    - Understand needs of all potential riders, including those with disabilities

Significant Successes

- Public demonstration and pilot of a purpose-built low-speed automated vehicle
- Highlighted the importance of considering the needs of people with disabilities in the design and operation of automated vehicles
- Built public and industry knowledge and awareness around the development of purpose-built automated vehicles
- Added to the body of knowledge that University of Michigan is compiling related to ergonomic requirements of vehicles to address the needs of travelers with disabilities
- Developed Western Michigan University cost benefit analysis tool that can be used in future projects
- Generated increased interest in autonomous vehicles (confirmed by rider surveys)
- Generated rider and pedestrian survey data that can be referenced for future projects

Potential Follow-on Activities

- UM research papers
  - Seeking publication of accessibility and usability study data
  - Developing a human factors methodology for evaluating the accessibility and usability of shared autonomous vehicles

- WMU research
  - Seeking publication of the pedestrian survey data
  - Seeking to publish a general cost model in an upcoming autonomous vehicle conference
  - Through the Urban International Design Contest (UIDC), apply learnings from the NAMV-MI Michigan Mobility Challenge project to the site of the Battle Creek VA Medical Center
    - Work with public transportation to show connectivity to the city
    - Lower emissions using a fully electric autonomous shuttle
    - Improve transit around the hospital
    - Better accessibility to disabled veterans
    - Increase operational hours

Potential Follow-on Activities Continued

- Spread awareness of project, including lessons learned and inclusion of accessibility elements
    - Chris Andrews of PME presented at the Podcar City Conference in San Jose, CA 11/5
    - Matt Lesh of Comet Mobility presented at the Florida Autonomous Vehicle Symposium 11/21
    - Presentation being planned for several American Society for Civil Engineers (ASCE) events in 2020

- Potential vehicle enhancements
    - All weather operation, including HVAC
    - Emit sound for pedestrian awareness
    - Ramp improvements (automation, load capacity)
    - Increased payload

Next Steps

- Leverage MMC results and learnings to inform development of future accessible, purpose-built, transit vehicles
- Position vehicles for potential future pilots within USDOT ecosystem
- Work with industry operators to position vehicles for potential private pilots
- Publish research papers on MMC pilot and experience
- Identify potential funding opportunities to continue research on WMU campus or other localities in Michigan or elsewhere

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