

Self-Driving Electric Vehicles for Smart and Sustainable Mobility: Evaluation and Feasibility Study for Educational and Medical Campuses

Final Report | Report Number 21-16 | April 2021



NYSERDA

**Department of
Transportation**

Self-Driving Electric Vehicles for Smart and Sustainable Mobility: Evaluation and Feasibility Study for Educational and Medical Campuses

Final Report

Prepared for:

New York State Energy Research and Development Authority

Robyn Marquis, Ph.D., Project Manager

and

New York State Department of Transportation

Ellwood Hanrahan, Project Manager

Prepared by:

University at Buffalo

Adel W. Sadek, Ph.D., Department of Civil, Structural and Environmental Engineering

Chunming Qiao, Ph.D., Department of Computer Science and Engineering

Roman Dmowski, Research Scientist and Project Manager

Yunpeng (Felix) Shi, Graduate Research Assistant

with

Wendel

Elizabeth C. Colvin, Senior Project Manager

Michael Leydecker, Associate Principal

David C. Duchscherer, Chairman Emeritus

Global Dynamic Group

Joah Sapphire, Managing Partner

John Wolff, Managing Director

Steve Madra, VP: Policy & Regulation

Niagara International Transportation Technology Coalition

Andrew Bartlett, Ph.D., Transportation Engineer

Niagara International Transportation Technology Coalition

Technical Report Documentation Page

1. Report No. C-17-01	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Self-Driving Electric Vehicles for Smart and Sustainable Mobility: Evaluation and Feasibility Study for Educational and Medical Campuses		5. Report Date April 2021	
7. Author(s) Adel W. Sadek, Chunming Qiao, Roman Dmowski, Yunpeng (Felix) Shi, Andrew Bartlett, Joah Sapphire, John Wolff, Steve Madra, Elizabeth C. Colvin, Michael Leydecker, and David C. Duchscherer		8. Performing Organization Report No. 21-16	
9. Performing Organization Name and Address University at Buffalo, 204 Ketter Hall, Buffalo, NY 14260 Wendel, 375 Essjay Road, Suite 200, Williamsville, NY 14221 Global Dynamic Group (GDG IoT), 40 Wall Street, 28th Floor, New York, NY 10005 Niagara International Transportation Tech Coalition, 93 Oak St, Buffalo, NY 14203		10. Work Unit No.	
12. Sponsoring Agency Name and Address New York State Energy Research and Development Authority (NYSERDA) 17 Columbia Circle Albany, NY 12203-6399 and NYS Department of Transportation 50 Wolf Road Albany, New York 12232		13. Type of Report and Period Covered Final Report	
15. Supplementary Notes Project funded in part with funds from the Federal Highway Administration.		14. Sponsoring Agency Code	
16. Abstract Automated Vehicles (AVs) have the potential to improve transportation safety, increase system capacity, enhance mobility, and solve the first- and last- mile problem associated with public transportation. This project has three inter-related objectives: (1) to evaluate the technical feasibility, safety and reliability of a low-speed, self-driving shuttle known as Olli; (2) to research the public policy changes needed to allow for AVs to be tested and driven on New York State public roads; and (3) to conduct an evaluation of the costs and benefits of using AV technology on a realistic case study involving the Buffalo-Niagara Medical Campus (BNMC) in downtown Buffalo. The study tested Olli on the University at Buffalo (UB) Proving Grounds for Connected and Automated Vehicles (CAVs), using a set of twelve testing scenarios. Riders of Olli were surveyed and the results from these surveys, along with the results from other surveys conducted in the Buffalo-Niagara region, were analyzed to determine the factors that contribute to public acceptance of AV technologies in an effort to address them. The study also developed a new set of four principles, which we called the "Buffalo Principles," to facilitate taking the legal and regulatory action required for the sustainable testing and deployment of AVs. Finally, the project conducted a simulation study and a business case analysis of a scenario involving developing a small fleet of the self-driving shuttle Olli to serve the first- and last- mile segments of trips undertaken by a subset of BNMC employees.			
17. Key Words Automated Vehicles; Self-driving, low-speed shuttles; Automated Vehicle Testing; Public Acceptance; Discrete-choice Modeling; Transport Public Policy; Simulation Modeling	18. Distribution Statement Unrestricted		
19. Security Classif. (of this report) Unclassified	20. Security Class. (of this page) Unclassified	21. No. of Pages 230	22. Price

Notice

This report was prepared by the University at Buffalo, Wendel, Global Dynamic Group (GDG IoT), and the Niagara International Transportation Technology Coalition (NITTEC), in the course of performing work contracted for and sponsored by the New York State Energy Research and Development Authority (NYSERDA) and the New York State Department of Transportation (hereafter the "Sponsors"). The opinions expressed in this report do not necessarily reflect those of the Sponsors or the State of New York, and reference to any specific product, service, process, or method does not constitute an implied or expressed recommendation or endorsement of it. Further, the Sponsors, the State of New York, and the contractor make no warranties or representations, expressed or implied, as to the fitness for particular purpose or merchantability of any product, apparatus, or service, or the usefulness, completeness, or accuracy of any processes, methods, or other information contained, described, disclosed, or referred to in this report. The Sponsors, the State of New York, and the contractor make no representation that the use of any product, apparatus, process, method, or other information will not infringe privately owned rights and will assume no liability for any loss, injury, or damage resulting from, or occurring in connection with, the use of information contained, described, disclosed, or referred to in this report.

NYSERDA makes every effort to provide accurate information about copyright owners and related matters in the reports we publish. Contractors are responsible for determining and satisfying copyright or other use restrictions regarding the content of the reports that they write, in compliance with NYSEDA's policies and federal law. If you are the copyright owner and believe a NYSEDA report has not properly attributed your work to you or has used it without permission, please email print@nyserda.ny.gov

Information contained in this document, such as web page addresses, are current at the time of publication.

DOT Disclaimer

This report was funded in part through grant(s) from the Federal Highway Administration, United States Department of Transportation, under the State Planning and Research Program, Section 505 of Title 23, U.S. Code. The contents of this report do not necessarily reflect the official views or policy of the United States Department of Transportation, the Federal Highway Administration or the New York State Department of Transportation. This report does not constitute a standard, specification, regulation, product endorsement, or an endorsement of manufacturers.

Preferred Citation

New York State Energy Research and Development Authority (NYSERDA) and New York State Department of Transportation (NYSDOT). 2021. “Self-Driving Electric Vehicles for Smart and Sustainable Mobility: Evaluation and Feasibility Study for Educational and Medical Campuses.” NYSERDA Report Number 21-16. Prepared by A.W. Sadek, C. Qiao, A. Bartlett, J. Sapphire, E.C. Colvin, M. Leydecker, and D.C. Duchscherer. nyscrda.ny.gov/publications

Abstract

The last few years have witnessed an unprecedented interest in automated vehicles (AVs) as a means to address many of the challenges affecting current transportation systems. AVs have the potential to improve transportation safety, increase system capacity, enhance mobility, and solve the first- and last-mile problem associated with public transportation. This project has three interrelated objectives. The first objective is to evaluate the technical feasibility, safety, and reliability of using AV technology, and in particular a low-speed, self-driving shuttle known as Olli, to provide a self-driving vehicle capable of transporting passengers safely and reliably. The second objective is to research the public policy changes needed for AVs to be tested and driven on New York State public roads. Finally, the third objective is to conduct a detailed evaluation of the costs and benefits of using AV technology on a realistic case study involving the Buffalo-Niagara Medical Campus (BNMC) in downtown Buffalo.

To achieve the first objective of the research, the study tested Olli on the University at Buffalo (UB) Proving Grounds for Connected and Automated Vehicles (CAVs) located at UB North Campus in Amherst, NY. This was accomplished using a set of twelve testing scenarios designed for testing various aspects of Olli's driving behavior and maneuvering. The study also surveyed Olli's riders during the numerous demonstrations performed as a part of the study, and used the results from these surveys, along with the results from other surveys conducted in the Buffalo-Niagara region, to determine the factors that contribute to public acceptance of AV technologies in an effort to address those factors.

With respect to the second objective, the study developed a new set of four principles, that we have defined as the "Buffalo Principles," designed to facilitate taking the legal and regulatory action required for the sustainable testing and deployment of AVs. The study also developed suggested language for drafting permanent legislation for New York State regarding testing and deployment of AVs. Finally, for the third objective, the project conducted a simulation study and a business case analysis involving a small fleet of the self-driving shuttle Olli to serve the first- and last-mile segments of trips undertaken by a subset of BNMC employees. The case study analyzed the financial viability of Olli deployment under three deployment approaches: (1) a public plan, (2) a private plan, and (3) a public-private partnership.

Keywords

Automated Vehicles; Self-driving, low-speed shuttles; Automated Vehicle Testing; Public Acceptance; Discrete-choice Modeling; Transport Public Policy; Simulation Modeling; Business case analysis

Acknowledgments

Throughout this project, the research team worked very closely with a number of local and regional transportation organizations, whose cooperation was critical to the success of the work. In that regard, we would like to extend special thanks to: (1) Athena Hutchins, Executive Director of the Niagara International Transportation Technology Coalition (NITTEC); (2) Lisa Kenney, Smart Mobility Advisor to the Greater Buffalo Niagara Regional Transportation Council (GBNRTC); and (3) Bill Smith and Jamie Hamann-Burney, Director of Planning with the Buffalo-Niagara Medical Campus (BNMC).

The help of several University at Buffalo personnel was also instrumental in accomplishing the objectives of the research and is very much appreciated. These include: (1) Chris Austin, Director of UB Parking and Transportation Services; (2) John Kisker; (3) William McDonnell Chief Financial Officer with UB School of Engineering and Applied Sciences (SEAS) at that time; (4) Sujata Rawal, SEAS Assistant Dean and Director of Facilities, Planning and Management; (5) Sean Brodfuehrer with UB Facilities and Planning; (6) Craig Hooftallen, with UB Purchasing. The research team would also like to thank Chris Brown, First Transit General Manager at the time, whose help in securing a parking spot for Olli is very much appreciated. Finally, we extend a special thanks to Michael Brown and Eric Thorn, with Southwest Research Institute (SwRI), who generously shared with us their in-depth knowledge and experience with Automated Vehicle development and testing.

Table of Contents

Technical Report Documentation Page	ii
Notice	iii
DOT Disclaimer	iii
Preferred Citation	iv
Abstract	v
Keywords	v
Acknowledgments	vi
List of Figures	xii
List of Tables	xiv
Acronyms and Abbreviations	xiv
Summary	S-1
1 Introduction	1
1.1 Low-Speed, Self-Driving Shuttles	2
1.2 Purpose and Scope.....	4
1.3 Report Organization	5
2 Olli and UB CAV Proving Grounds	6
2.1 Acquiring UB’s Self-Driving Shuttle, Olli.....	6
2.1.1 Olli’s Operational Agreement	7
2.1.2 Olli’s Delivery and Deployment	7
2.1.3 Steward Training	9
2.1.4 UB CAV Proving Grounds.....	10
2.1.5 Olli’s Official Kick-Off Event at Fourth Annual TransInfo Symposium	11
2.1.6 Olli’s Data and Storage	12
2.1.7 Data Visualization.....	12
3 Safety Testing of Olli on University of Buffalo Proving Grounds	14
3.1 Olli’s Safety Test Set Design	14
3.2 Safety Testing Data Collection and Pre-Processing	16
3.3 Safety Tests Results and Discussion.....	16
3.3.1 Preliminary Comparisons of Olli’s Operating Characteristics	17
3.3.1.1 Distributions of Olli’s Speed and Acceleration	17
3.3.1.2 Speed and Acceleration Profiles Comparison	19
3.3.1.3 Stopping Distance Comparison.....	23

3.3.2	Test 1 and 2: Left/Right Turn Performance.....	24
3.3.3	Test 3 and 4: Four-Way Stop Test with and without Conflicts	26
3.3.4	Test 5: Shuttle Stop Test	27
3.3.5	Test 6 and 7: Stationary/Moving Pedestrian Identification Test.....	28
3.3.5.1	Stationary Pedestrians Test.....	29
3.3.5.2	Parallel Moving Pedestrians Test.....	29
3.3.5.3	Crossing Pedestrians Test.....	30
3.3.6	Test 8 and 9: Vehicle Following/Leading Test	30
3.3.7	Test 10: Passing Vehicle Test.....	32
3.3.8	Test 11: Object Detection Test.....	32
3.3.8.1	Front Detection Test	33
3.3.8.2	The Side Detection Test	33
3.3.9	Test 12: Static Vehicle Obstruction Test.....	35
3.3.10	Additional Physical Testing of Olli in Inclement Weather.....	36
3.3.11	Olli Power Test.....	38
3.4	Summary of the Findings from Olli's Safety Testing	39
4	Public Acceptance of Olli and AVs	41
4.1	Research Tasks in Assessing Public Acceptance of AV	42
4.2	Olli's Demonstrations	42
4.3	Olli's Riders Survey	44
4.4	NITTEC Web Survey, 2016	45
4.5	GBNRTC AV Forum, 2019	46
4.6	Surveys Analysis Methodology	47
4.6.1	Before and After Comparison for Olli and AV Forum Surveys.....	47
4.6.2	Binary Choice Analysis for 2016 Web Survey.....	48
4.6.3	Ordered Choice Analysis for AV Survey	49
4.7	Results.....	50
4.7.1	Task 1—NITTEC Web Survey Analysis, 2016.....	50
4.7.1.1	Survey Summary.....	50
4.7.1.2	Binary Choice Results	51
4.7.2	Task 2—Olli Ridership Survey Analysis	53
4.7.2.1	Survey Summary.....	53
4.7.2.2	Before and After Comparison	55
4.7.3	Task 3—2019 AV Forum Analysis.....	56
4.7.3.1	Forum Summary.....	56

4.7.3.2	Ordered Choice Analysis of AV Forum Results	58
4.7.3.3	Before and After Comparison	61
4.7.4	Task 4—Web Survey versus AV Forum Comparison	62
4.7.4.1	Difference Comparison	62
4.7.5	Task 5—Olli versus AV Forum Comparison	64
4.7.5.1	Difference Comparison	64
4.8	Conclusions and Recommendations	67
4.8.1	Addressing Public Concerns Regarding AVs from 2016 Survey (Task 1).....	67
4.8.2	Olli Ridership Before and After (Task 2).....	68
4.8.3	Impact of the AV Forum (Task 3)	68
4.8.3.1	Forum Results.....	68
4.8.3.2	Ordered Choice Analysis	68
4.8.3.3	Before and After Comparison	69
4.8.4	Comparison of Forum Participants to 2016 Survey and Olli Riders (Tasks 4 and 5).....	69
4.8.5	Overall Recommendations.....	69
5	AV and Public Policy Research	70
5.1	Introduction	70
5.1.1	Initial AV Deployments and Legislation	70
5.1.2	New York State AV Legislation Activities Prior to Current Project	72
5.1.3	State AV Legislation	74
5.1.4	United States Department of Transportation AV Guidance	74
5.1.5	Federal Motor Vehicle Safety Standards	76
5.1.6	FMVSS Exemptions.....	77
5.1.7	Buffalo Principles.....	80
5.1.8	Suggested Language for New York State.....	81
5.1.9	System-Controlled Vehicles	82
5.2	State AV Legislation	82
5.2.1	Alabama	83
5.2.2	Arizona.....	83
5.2.3	Arkansas	83
5.2.4	California	84
5.2.5	Colorado.....	86
5.2.6	Connecticut	86
5.2.7	Delaware	86
5.2.8	Florida	86

5.2.9	Georgia	87
5.2.10	Hawaii	87
5.2.11	Idaho	87
5.2.12	Illinois	87
5.2.13	Indiana	88
5.2.14	Kentucky	88
5.2.15	Maine	88
5.2.16	Massachusetts	88
5.2.17	Minnesota.....	88
5.2.18	Nebraska.....	89
5.2.19	Nevada.....	89
5.2.20	North Carolina	89
5.2.21	North Dakota	89
5.2.22	Ohio	90
5.2.23	South Carolina.....	90
5.2.24	Tennessee	90
5.2.25	Texas	90
5.2.26	Utah	91
5.2.27	Vermont.....	91
5.2.28	Washington	91
5.2.29	Wisconsin.....	91
5.2.30	New York State.....	91
5.3	U.S. DOT AV Guidance.....	94
5.3.1	AV 1.0 Federal Automated Vehicles Policy: Accelerating the Next Revolution in Roadway Safety.....	94
5.3.2	AV 2.0 Automated Driving Systems (ADS): A Vision for Safety 2.0.....	98
5.3.3	AV 3.0 Preparing for the Future of Transportation: Automated Vehicles 3.0.....	101
5.3.4	AV 4.0 Automated Vehicles 4.0 Ensuring American Leadership in Automated Vehicle Technologies	106
5.4	Federal Motor Vehicle Safety Standards.....	111
5.4.1	Increasing Vehicle Safety Resulted from Greater Vehicle Safety Regulation	111
5.4.2	The Human-at-the-Wheel Paradigm Inherent in FMVSS	113
5.4.3	§ 571.101 Standard No. 101; Controls and Displays	114
5.4.4	§ 571.102 Standard No. 102: Transmission Shift Position Sequence, Starter Interlock, and Transmission Braking Effect.....	115
5.4.5	§ 571.103 Standard No. 103: Windshield Defrosting and Defogging Systems	116

5.4.6	§ 571.108 Standard No. 108: Lamps, Reflective Devices, And Associated Equipment..	116
5.4.7	§ 571.111 Standard No. 111: Rear Visibility	117
5.4.8	§ 571.124 Standard No. 124: Accelerator Control Systems	118
5.4.9	49 CFR § 571.500 - Standard No. 500: Low Speed Vehicles.....	119
5.4.10	Current FMVSS Impede Advancement of AV Technology	120
5.5	FMVSS Exemptions	123
5.5.1	NHTSA Exemptions From FMVSS.....	123
5.5.2	Expedited NHTSA Exemption Process.....	125
5.5.3	EasyMile Example	128
5.5.4	Mcity and NAVYA Example.....	130
5.5.5	Nuro Example.....	133
5.5.6	Conclusion	136
5.6	Buffalo Principles	137
5.6.1	Buffalo Principle Number 1: Testing on Private Roads	139
5.6.2	Buffalo Principle Number 2: Test Using Slow Speeds.....	142
5.6.3	Buffalo Principle Number 3: Record Data	144
5.6.4	Buffalo Principle Number 4: Use of Integrated Simulation.....	149
5.6.5	The Nuro Deployment Affirms the Efficacy of the Buffalo Principles.....	150
5.6.6	Conclusion: The Buffalo Principles Provide a Sustainable Basis for AV Deployments...	153
5.7	Suggested Language for New York State	154
5.7.1	The Introduction of AV Legislative in NYS.....	156
5.8	System-Controlled Vehicles.....	161
5.8.1	Human-Centric Industry Definitions Are Incomplete	162
5.8.2	System-Controlled Vehicles Versus Human-Controlled Vehicles	164
5.8.3	Inadequate Federal Guidance.....	166
5.8.4	Limited International AV Technology Advancements	172
5.8.5	Underwriters Laboratories Publishes First AV Standard	173
5.9	Conclusion	175
5.9.1	Summary of Findings.....	175
5.9.2	New Regulatory Regime	179
6	Buffalo Niagara Medical Campus Case Study	181
6.1	Introduction	181
6.2	Estimate Mobility Needs and Demand	182
6.3	Design Network and Routes for Serving BNMC Mobility Needs	185
6.4	BNMC Case Study Simulation Model.....	188

6.4.1	Demand for the Simulated Case Study	188
6.4.2	Simulation Model Assumptions	190
6.4.3	Simulation Model Parameters	191
6.4.4	Simulation Result Analysis.....	192
6.5	BNMC Business Case Analysis	194
7	References	197
	Appendix A. NYS AV Testing and AV Legislation.....	A-1
	Appendix B. Annual Report by NYS Commissioner of DMV.....	B-1

List of Figures

Figure 1.	The Self-Driving Shuttle, Olli	3
Figure 2.	UB’s Visit to Robotics Research, Inc. of Maryland	6
Figure 3.	UB CAV Proving Grounds	8
Figure 4.	Statler Food Commissary Building (RTK Station Location).....	8
Figure 5.	LM Training of UB Research Assistants	9
Figure 6.	UB Stewards Issued their AV Driverless License from Local Motors	9
Figure 7.	UB North Campus CAV Proving Grounds	10
Figure 8.	UB Olli’s Official Kick-Off Event on August 9, 2018	11
Figure 9.	Visualizing the Output from Olli’s Localization Algorithm	13
Figure 10.	Olli’s Test Track on UB CAV Proving Grounds	15
Figure 11.	The Self-Driving Shuttle’s Speed and Acceleration Distribution: Speed Distribution	17
Figure 12.	The Self-Driving Shuttle’s Speed and Acceleration Distribution: Speed Distribution and Acceleration Distribution	18
Figure 13.	Stopping Speed Profile.....	20
Figure 14.	Stopping Acceleration Profiles.....	21
Figure 15.	Aggregate Speed and Acceleration Profiles: Aggregate Speed Profiles	22
Figure 16.	Aggregate Speed and Acceleration Profiles: Aggregate Acceleration Profiles.....	22
Figure 17.	Pedestrian Identification Test Setup	28
Figure 18.	Parallel-Moving Pedestrians Test Setup	29
Figure 19.	Olli’s Onboard Monitor during Front Detection Test.....	33
Figure 20.	Olli’s Onboard Monitor during Front Detection Test.....	34
Figure 21.	Static Vehicle Obstruction Test Setup	35
Figure 22.	The Presence and Heights of Snowbanks on the Sides of the Service Road	37
Figure 23.	Olli’s Permanent Stop as a Result of the Presence of Snowbanks	37
Figure 24.	Power Consumption—Olli Not Accelerating, Heat Off, and with Five Occupants.....	39
Figure 25.	QR Code for Taking Olli’s Ride Survey	44
Figure 26.	Various Screens of Olli’s Ride Survey	45
Figure 27.	Responses to: I felt safe during the ride	53

Figure 28. Responses to: I needed to pay close attention to the movement of Olli for my own safety	54
Figure 29. Responses to: The ride was comfortable.....	54
Figure 30. Responses to: The ride was no different than a human-driven shuttle bus.....	55
Figure 31. Shifts in Response to: I am confident that we will have fully automated vehicles on the road in the near future.....	55
Figure 32. Responses to: I am familiar with the topic of driverless mobility	63
Figure 33. Responses to: I would ride in a self-driving vehicle	63
Figure 34. Responses to: I think that driverless vehicles will replace human-driven vehicles in the future.....	65
Figure 35. Responses to: I am familiar with the topic of Driverless Mobility.....	65
Figure 36. Responses to I think that driverless vehicles will replace human-driven vehicles in the future.....	66
Figure 37. Responses to: I feel that driverless vehicles are generally safe.....	66
Figure 38. Buffalo Niagara Medical Campus	181
Figure 39. BNMC Case Study GIS.....	183
Figure 40. BNMC Employee Home Addresses.....	184
Figure 41. BNMC Proposed Route Structure	187
Figure 42. Locations of Olli's Stations	189
Figure 43. Normal Distribution.....	190
Figure 44. Two-Dimensional Screenshot of the Simulation Model Output	193
Figure 45. Three-Dimensional Screenshot of the Simulation Model Output.....	193
Figure 46. Proposed Olli Parking, Charging, and Maintenance Facility	195

List of Tables

Table 1. Olli Test Summaries	14
Table 2. Self-Driving Shuttle X Data and Measures	16
Table 3. The Self-Driving Shuttle’s Speed and Acceleration Comparisons.....	18
Table 4: Stopping Distance Comparison	23
Table 5. Stopping Distance Comparison T-test Results	24
Table 6: Left-Turn and Right-Turn Performance.....	25
Table 7. Four-Way Stop Test Performance	26
Table 8: Shuttle Stop Test Performance in Dry Weather.....	27
Table 9: Shuttle Stop Test Performance in Rainy Weather.....	27
Table 10. Shuttle’s Reaction to Stationary Pedestrians.....	29
Table 11. Results of Parallel-Moving Pedestrians Test	30
Table 12. Crossing Pedestrian Test Results	30
Table 13. Vehicle Following and Leading Test Performance	31
Table 14. Static Vehicle Obstruction Test Results.....	35
Table 15. Data Recorded During Olli Power Test.....	38
Table 16. Web Survey Modelling Variables.....	49
Table 17. AV Forum Survey Modelling Variables	50
Table 18. 2016 NITTEC Web Survey Results	51
Table 19. AV Use and Cost Binary Choice Models	52
Table 20. AV Forum Responses to Driverless Mobility Topics	57
Table 21. AV Forum Effectiveness Results	58
Table 22. AV Forum Modelling Results	59
Table 23. AV Forum Before and After Results.....	61
Table 24. Web Survey versus AV Forum Results.....	63
Table 25. Olli Ridership Survey versus AV Forum Results.....	64
Table 26. BNMC Employee Distribution across Buildings	188
Table 27. Travel Demand from North Parking Garage to BNMC Buildings.....	189
Table 28. Origin-Destination Matrix for the Olli’s Loop.....	190

Acronyms and Abbreviations

A	Ampere
AAMVA	American Association of Motor Vehicle Administrators
ADAS	Advanced Driver Assistance Systems
ADS	Automated Driving System
ANPR	Advance Notice of Proposed Rulemaking
ASU	Arizona State University
ATN	Automated Transit Networks
AV	Autonomous Vehicle (also Automated Vehicle)
AVRI	Autonomous Vehicle Readiness Index

BAAM	Big Area Additive Manufacturing
BNMC	Buffalo Niagara Medication Campus
CAV	Connected and Automated Vehicle
CAVE	Connected and Automated Vehicle Enclosure
CBD	Central Business District
CFR	United States Code of Federal Regulations
CFT	Center for Tomorrow
CISE	Computer and Information Science and Engineering
CSPO	Consortium for Science, Policy & Outcomes
DARPA	Defense Advanced Research Projects Agency
DDT	Dynamic Driving Task
DMV	Department of Motor Vehicles
DxW	Drive-by-Wire
FMVSS	Federal Motor Vehicle Safety Standards
Ft	Feet
GBNRTC	Greater Buffalo Niagara Regional Transportation Council
GDG IoT	Global Dynamic Group, LLC
GPS	Global Positioning System
GM	General Motors, Inc.
HAV	Highly Automated Vehicle
HMI	Human Machine Interface
ISO	International Standards Organization
LIDAR	Light Detection and Ranging
LM	Local Motors
LSV	Low-Speed Vehicle
MARTI	Mobile Autonomous Robotics Technology Initiative
MPH	Miles Per Hour
MPO	Metropolitan Planning Organization
MPR ²	McFadden Pseudo R ²
M&S	Modeling and Simulation
MUTCD	Manual on Uniform Traffic Control Devices
NCSL	National Conference of State Legislatures
NHTSA	National Highway Traffic and Safety Administration
NITTEC	Niagara International Transportation Technology Coalition
NSF	National Science Foundation
NSTI	National Summer Transportation Institute
NYS	New York State
NYSDOT	New York State Department of Transportation
NYSERDA	New York State Energy Research and Development Authority

ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
OEDR	Object and Event Detection and Response
pcap	Packet Capture
PON	Project Opportunity Number
PRT	Personal Rapid Transit
PTASP	Public Transportation Agency Safety Plan
RADAR	Radio Detection and Ranging
RDDF	Route Definition Data File
RLL	Restricted Log Likelihood
RR	Robotics Research
RTK	Real-time Kinematic
SAE	Society of Automotive Engineers
SCV	System-Controlled Vehicle
SDO	Standards Development Organizations
SDV	Self-Driving Vehicle
SwRI	Southwest Research Institute
STP	Standards Technical Panel
SUNY	State University of New York
TransInfo	Transportation Informatics
UB	University at Buffalo
UL	Underwriters Laboratory
U-M	University of Michigan
U.S. DOT	U.S. Department of Transportation
UTRC	University Transportation Research Center
UVC	Uniform Vehicle Code
v	volts
VMT	Vehicle Miles Traveled
VSSA	Voluntary Safety Self-Assessment
ZEAV	Zero-Emission Autonomous Vehicle (manufactured by General Motors)

Summary

In recent years, there has been an unprecedented interest in automated vehicles (AVs), as evidenced by the number of companies striving to develop automated and self-driving capabilities. This includes both major automotive companies, major technology companies, and several tech start-ups. It is also evidenced by the number of research studies and scientific conferences dedicated to the topic, on one hand, and real-world demonstrations and pilots of the technology on the other. AVs have potential to revolutionize transportation, resulting in a major paradigm shift in the way we travel and move our goods. Among their purported benefits are: (1) improved safety, (2) decreased traffic congestion and increased system capacity, (3) enhanced human productivity, (4) improved mobility for children and the elderly, (5) enabling innovative ideas for shared mobility, (6) solving the first- and last-mile problem associated with public transportation, and (7) reducing private car ownership. The benefits of vehicle automation related to improving the efficiency of shared mobility services and public transportation constituted the focus of this project.

This project has three interrelated objectives. The first objective is to evaluate the technical feasibility, safety, and reliability of using AV technology, and in particular a low-speed, self-driving shuttle known as Olli, to provide for a self-driving vehicle capable of transporting passengers safely and reliably. The second objective is to research the public policy changes needed to allow AVs to be tested and driven on New York State public roads. Finally, the third objective is to conduct a detailed evaluation of the costs and benefits of using AV technology on a realistic case study involving the Buffalo-Niagara Medical Campus (BNMC) in downtown Buffalo.

S.1 Safety Testing of Olli on University at Buffalo Proving Grounds

To achieve the first objective of the research, the study tested the Olli bus on the University at Buffalo (UB) Proving Grounds for Connected and Automated Vehicles (CAVs) located at UB North Campus in Amherst, NY. This was accomplished using a set of twelve testing scenarios designed for testing various aspects of Olli's driving behavior and maneuvering. The key findings regarding safety and reliability testing of Olli are summarized below.

- Olli was able to complete left- and right-turning maneuvers safely and no manual intervention was needed.
- While making a turn, the shuttle was able to accurately, and in a timely fashion, detect any conflicting vehicle or obstruction ahead on its route and to stop by itself.

- The duration for Olli to complete a turn is a function of the presence or absence of conflicting traffic or any perceived conflict.
- Olli was able to cross a four-way intersection normally without conflicts. In addition, the shuttle would not pass the intersection if there were vehicles present at conflicting directional stop signs, even if those vehicles were stationary.
- Olli did not seem to be applying the common traffic rule at four-way stops, which states that the vehicle that arrives first gets to go through the intersection first. Rather, Olli prioritizes safety and only moves when it perceives that there are no other conflicting vehicles at the intersection.
- Olli appears to successfully detect obstacles/pedestrian suddenly appearing in its path and to react in a safe manner by bringing the shuttle to a full stop, even when the distance between Olli and the obstacle negligible.
- Olli is not oversensitive and does not over-react to the presence of pedestrians on the sidewalk, as long as they are stationary or moving parallel to its path (hence no conflict).
- Olli was able to detect any potential hazardous situation, and managed to take safe actions, arising from a conflict between Olli and a pedestrian.
- Olli was able to follow a front vehicle driving ahead of it, and to maintain a desirable speed. It also maintained a desirable speed when there were vehicles following.
- During the cases, when another vehicle overtook (i.e., passed) Olli, the shuttle generally maintained travel at its design speed. The only exception was when the human driven vehicle merged back in the original lane too early, leaving a space headway of less than approximately 12 meters (39 ft) between it and Olli. In that case, the shuttle would apply a sudden brake, to maintain the safe distance, and would then resume traveling at a desirable or design speed.
- The shuttle when parked was able to detect all objects located to the front of the vehicle, within a range equal to at least 20 meters (66 ft).
- Olli appears unable to distinguish between a pedestrian and a parked vehicle when the distance between the pedestrian and the parked vehicle is less than 1 meter.
- Olli seems to have a detection blind spot located on the side of the shuttle at the midpoint, where the passenger doors are located.
- Olli managed to detect a stationary vehicle, located in front of a human-driven vehicle (i.e., Olli is the third vehicle in line in such a setup), after the human-driven vehicle had changed lanes. The shuttle also managed to bring itself to a stop, in a reasonably smooth manner, to avoid collision.
- The current version of perception and recognition algorithm used for Olli, appears to be unable to distinguish between piles of snow located at the sides of the road, and a real hazard or obstacle that it needs to avoid. Because of this, Olli stopped frequently when snow was piled to the side of the road.

S.2 Public Acceptance of Olli and Automated Vehicles

The study also surveyed Olli's riders during the numerous demonstrations performed as a part of the study. The survey included a set of questions designed to solicit the views of riders regarding AV's safety, reliability, and adoption. Participants in the survey were asked to answer those questions twice, before riding Olli as well as after the ride. In addition to analyzing the results from the surveys completed by Olli's riders during the project, the research team leveraged two other AV-related surveys which were recently conducted in the Buffalo-Niagara region. The first survey was a 2016 web survey, open to the travelling public of the Western New York Region. The second survey was performed for a group who participated in an all-day forum, organized by the Greater Buffalo Niagara Regional Transportation Council (GBNRTC) to learn more about autonomous mobility in August 2019. The insights gained from analyzing those surveys are summarized below.

S.2.1. Addressing Public Concerns Regarding Automated Vehicles from a 2016 Survey

- The majority of those surveyed are uncomfortable with AVs, with only 39% stating they would ride in one and 26% saying they would prefer them to a standard vehicle.
- A significant majority of those surveyed cited issues with control and liability, with many stating they would need to be able to take over control of the vehicle (85%), or be free of any legal (81%) or monetary (73%) consequences of an accident in an AV.
- Those who stated they understood the benefits of AVs were more likely to say they would ride in, own, and prefer an AV, while those who stated they enjoyed driving were less likely to agree with all three statements. Responders who enjoyed driving were also more likely to say they needed the ability to take control of an AV and be concerned with legal and monetary liability.
- In general, those who were recently ticketed for driving violations were more accepting of AVs and less concerned about control and liability issues.
- Those with longer commutes were more open to AV usage and unlikely to be concerned with liability, but also showed a need for optional manual control.
- Older users, as well as those with higher incomes, tended to be averse to AV usage and ownership; older individuals were also more likely to be concerned with control and liability, while those with higher incomes were less likely to have these associated concerns.
- Race, education, and type of employment were not found to have a significant impact on how individuals responded to any of these statements.

S.2.2. Change in Attitude toward Automated Vehicles after Riding Olli—Insight from Olli Surveys

- Following the interactive experience with the autonomous shuttle, participants were found to be more likely to agree with the statement: "I am confident that we will have fully AVs on the road in the near future."

- The responses most highly correlated with this increase in confidence were from participants who felt comfortable and safe during the ride.

S.2.3. Insight from Automated Vehicle Forum Surveys and the Impact of the Forum on Participants

In relation to the ability of the forum to influence participants' knowledge and opinions on the topics discussed, responses showed that a majority felt the event was effective in all regards. A particularly strong majority felt that their participation:

- Provided them with different perspectives and expanded their own opinions on driverless mobility (92%).
- Significantly increased their knowledge about driverless mobility (86%).
- Significantly influenced their knowledge about information collected to operate driverless mobility systems (79%).
- Motivated them to follow the development of driverless mobility (79%).

Additional key findings, derived from the ordered choice models developed based on the AV forum survey results, included the following:

- Overall, it proved important to not only ensure participants understood the information and tasks, but also to develop an understanding of how the results could be used. Participants who agreed that this was true were more likely to state their knowledge and opinions of driverless mobility, and stated that topics were improved by the event.
- Ensuring that participants felt the (1) information was unbiased, (2) discussion was uncompromised, and (3) findings would influence decision makers was also vital as those who felt these assurances not only believed that their knowledge and opinions were impacted, but were also more likely to state that they understood other perspectives on the topics discussed.

Following participation in the event:

- Participants felt more familiar and were more concerned with driverless mobility, relative to other technological issues.
- Participants understood issues, arguments, and perspectives related to driverless mobility.
- Participants have sufficient information to make judgments about driverless mobility and feel they know what should be done about transportation issues in their region.
- No significant change was observed in participants' confidence that AVs will replace human-driven vehicles in the future or participants' willingness to ride in a driverless vehicle.

S.2.4. Change in Public Attitudes toward AV Over Time

The study also compared the results from the 2016 web survey to the results from the Olli surveys and the AV forum surveys performed in 2019. This comparison revealed the following:

- On average, forum participants were more familiar with driverless mobility and more willing to ride in an AV than those who completed the 2016 survey.
- The average response from riders indicated they felt AVs were safer than their forum counterparts even though the riders were much less familiar with driverless mobility.

S.2.5. Overall Recommendations Based on Insight from AV Surveys

- Providing the public with a clear understanding of AVs in terms of safety and operations is key to gaining trust in the technology.
- A forum such as described here is an effective tool in improving public knowledge of AVs.
- Future forums should ensure that the information provided is not only clear, but also fair and unbiased to better meet the event’s goals; ensuring that discussions are uncompromised and that participants feel their input is valued are also important.
- While useful in improving public understanding, the forum alone was not effective in convincing participants that AVs are a safe alternative to a human-driven vehicle. To convince the public, interaction with a functioning AV such as the Olli is significantly more effective.

S.3 AV and Public Policy Research

To best inform this project, the research team first reviewed recent State legislation from 20 states and executive orders from 10 Governors that have authorized testing of AV technology. Next, the team reviewed efforts at the Federal level to support AV technology most relevant to the project. Since September 2016, the United States Department of Transportation (U.S. DOT) has published four non-binding voluntary guidance documents on AV technology, all of which were carefully reviewed and analyzed in this project. The team then examined the potential for Olli to be granted an exemption for the purposes of enabling its testing on public roads by reviewing applicable exemption cases by the National Highway Traffic Safety Administration (NHTSA). The team found the exemption process offers insufficient regulatory relief. Specifically, few have been granted, the process is onerous and time-consuming, each exemption is only temporary in nature, and each retain safety requirements that reinforce the “human-at-the-wheel” assumptions inherent in Federal Motor Vehicle Safety Standards (FMVSS).

Based on the above analysis, the study developed a new set of principles, that the team has defined as the “Buffalo Principles,” designed to facilitate taking the legal and regulatory action required for the sustainable testing and deployment of AVs. The Buffalo Principles are comprised of four tenets. The first is testing on private roads. The value of this principle is evident by the impact of the two real-world demonstrations of an AV built by Southwest Research Institute (SwRI), held on June 9, 2016 in Saratoga Springs, NY and on June 24, 2016 in Buffalo, NY for public policy makers. These two

demonstrations could not have occurred unless they were conducted in parking lots at both locations since parking lots are deemed private property and exempt from Federal, State, and Local law. The second tenet of the Buffalo Principles is testing using slow speeds, because one may safely assume that AVs at slow speeds are as safe as traditional vehicles. The third tenet of the Buffalo Principles is to record data and the fourth is the use of integrated simulation. The study also developed suggested language for a document drafting permanent legislation for New York State to allow testing and deployment of AVs.

S.4 Buffalo Niagara Medical Campus Case Study

Finally, to address the third objective of the project, the Buffalo Niagara Medical Campus (BNMC) was used as a case study to assess the feasibility of Olli to provide “last mile” service from a financial standpoint, as well as for evaluating the likely benefits in terms of cost savings and reduced parking demand, fuel savings, and emissions reductions. BNMC is a rapidly growing consortium of world-class health care, life sciences, medical education institutions, and spin-off companies located in the City of Buffalo.

Evaluating the feasibility, costs, and benefits of Olli for BNMC encompassed the following sub-tasks: (1) assess the mobility needs and service objectives of the medical complex in close collaboration with its principal stakeholders, (2) design the network and routes for Olli to effectively serve BNMC, (3) design the mode of operations for the Olli bus and determine vehicle frequency, and (4) derive performance measures from model results, and estimate cost and benefits of operations. The project also conducted a simulation study and a business case analysis of a scenario involving the development of a small fleet of self-driving Olli shuttles to serve the first- and last-mile segments of trips undertaken by a subset of BNMC employees. The case study analyzed the financial viability of Olli deployment under three possible approaches: (1) a public plan, (2) a private plan, and (3) a public-private partnership. For a public plan, the total annual cost would be around \$1,365,000/year, which would be borne by BNMC or some other public entity. Under a private plan and based on a ridership of 270,000 trips per year the break-even cost per rider would be \$5.05/trip or with a modest profit, \$5.50/trip. Finally, for a public-private partnership, whereby the public entity is responsible for the capital cost and the private entity is responsible for the operating costs, the cost per trip would be approximately \$1.75.

1 Introduction

In the recent few years, there has been an unprecedented interest in automated or self-driving vehicles, as evidenced by the number of companies striving to develop automated and self-driving capabilities. This includes both major automotive companies (e.g., Tesla, Ford, General Motors, BMW, Daimler, Nissan, Volvo, and Hyundai, to name a few), as well as major technology companies (e.g., Google, Uber, CISCO and Amazon). It is also evidenced by the number of research studies, research papers, and scientific conferences dedicated to the topic—on one hand, and real-world demonstrations and on the other hand, pilots of the technology (e.g., the self-driving Uber in Pittsburgh, Pennsylvania).

Self-driving vehicles (also known as connected and automated vehicles of CAV) have potential to revolutionize transportation, resulting in a major paradigm shift in the way we travel and move our goods.

Among the purported benefits of the technology are: (1) improved safety (by reducing crashes caused by driver error and/or incapacitation), (2) decreased traffic congestion and increased capacity (by reducing headways for example), (3) increased human productivity (the time drivers currently spend in driving could be used for other purposes with automated vehicles), (4) improved mobility for children and the elderly, (5) enabling innovative ideas for shared mobility, (6) solving the first- and last-mile problem associated with public transportation, and (7) reduced private car ownership. The benefits of vehicle automation related to improving the efficiency of shared mobility services and public transportation constitute the focus of this project.

In fact, the idea of using automation in public transportation has been around for several years, if not decades. The term, Automated Transit Networks (ATN), was coined to refer to systems utilizing a fleet of robotically controlled, driverless vehicles of moderate capacity (two to 10 people) that delivers fully automated, on-demand, nonstop transportation service, typically on exclusive guideways. The ATN concept was initially captured in a 1970's demonstration project in Morgantown, WV. The ATN concept embedded in this 1970s demonstration project, however, remained unviable for commercial operations from a fiscal standpoint, due mainly to immature, and thus prohibitively expensive, control technology until 2000.

Since 2000, several companies have invested significant capital to create modern ATN systems. Numerous planning studies have been conducted since 2000 based on the premise that ATN are constructible, covering a range of operating parameters. One such study was the subject of a previous

study funded by the New York State Energy Research and Development Authority (NYSERDA) for the Ithaca, NY area. The Ithaca study “assessed how Personal Rapid Transit or PRT [a form of ATN], together with Transit Oriented Development, will enhance the quality of life and promote economic development in New York’s small and mid-sized cities.” The study concluded that PRT held energy and environmental, quality of life, safety, and economic benefits, and also provided a qualitative comparison with existing modes. However, the study also cited three potential challenges: (1) PRT was still an emerging technology at the time the study was conducted (2009 and 2010), (2) suitability for peak demand due to unvalidated achievable headways, and (3) the visual impact of dedicated, elevated guideways.

Automated vehicles (AVs) offer all the advantages of PRT and ATN, without some of the limitations mentioned above. For example, AVs do not need expensive, elevated guideways for their operations, can be easily integrated in the current transportation system and urban fabric, and are not limited to any track. With these advantages, AVs can provide for a efficient shared mobility system, serve as a feeder for more traditional public transportation systems, and reduce the need for private car ownership.

1.1 Low-Speed, Self-Driving Shuttles

Low-speed, self-driving shuttles are a type of an AV design that has been proposed to implement the ideas mentioned above. Specifically, they are designed to provide a shared mobility system that can serve as a feeder for public transit, address the first- and last-mile challenge of traditional bus systems, and reduce private car ownership. The shuttles are typically electric, have a low speed (e.g., maximum of 25 mph) to ensure safety, and operate within a geo-fenced environment (which is less complicated for an AV compared to an open-driving environment).

In September 2018, Volpe National Transportation Systems Center completed a research study for the United States Department of Transportation (U.S. DOT) which reviewed the state-of-the-practice of low-speed automated shuttles worldwide (Cregger et al., 2018). The Volpe study found that there was a significant interest in low-speed automated shuttles by several stakeholders and that there were, at the time of the writing in 2018, several pilots underway both in the United States and around the world. The study also showed that current low-speed, automated shuttles were still undergoing frequent updates to both their hardware and software, and thus they should still be considered prototypes, which often have limited capabilities and require significant intervention from an onboard human operator. The study

also pointed out that, from a business model standpoint, removing the onboard human operator may be required before self-driving shuttles are able to compete, from a financial viability perspective, with their human-driven counterparts. Finally, the study states that the task of evaluating self-driving shuttles remains a challenging one, and that many of the current demonstrations and pilots lacked clearly defined goals, appropriate performance metrics, and baseline data.

A good example of a low-speed, self-driving shuttle, is the Olli shuttle developed by Local Motors (Figure 1), a start-up mobility company headquartered in the Phoenix, AZ metro area, and which was the focus of evaluation and testing in the current project. Olli is a self-driving, electric vehicle designed specifically to support shared transportation systems. The vehicle typically has a capacity of between eight to 10 passengers, and utilizes a suite of sensors, including Lidar, radar, and cameras to monitor the driving environment. For driving control, the current version of Olli utilizes the AutoDrive™ software developed by Robotics Research, Inc.

Figure 1. The Self-Driving Shuttle, Olli



The control software utilizes a 3D map of the environment, which is first created by driving Olli manually around the environment in which Olli is to be deployed and using its suite of sensors to develop the map. This map is then stored onboard the vehicle and used for localization. The control algorithm is made of several layers. The high-level layer interprets the data from the sensor and plans the route. The low-level

layer is for controlling acceleration and braking. Finally, a safety layer is included to deal with emergency situations. Olli has a top speed of 25 mph. Finally, it is worth mentioning that Local Motors uses 3D printing technology to manufacture the vehicle, which adds a sustainability angle to the manufacturing process. Specifically, Local Motors uses the Big Area Additive Manufacturing (BAAM) system, which is capable of printing composite materials at high rates, reaching 80 pounds per hour.

1.2 Purpose and Scope

This project has three interrelated objectives. The first objective is to evaluate the technical feasibility, safety, and reliability of using AV technology, and in particular, the Olli bus, to provide for a self-driving vehicle capable of transporting passengers safely and reliably. The second objective is to research the public policy changes needed to allow AVs to be tested and driven on New York State public roads. Until today, AVs were not allowed on NYS roads, although they are allowed in other states such as California, Nevada, and Florida. Finally, the third objective is to conduct a detailed evaluation of the costs and benefits of using AV technology on a realistic case study involving the Buffalo-Niagara Medical Campus (BNMC) in downtown Buffalo.

For the first objective and given that it is not possible yet to test AVs on public roads in NYS, the study tested the Olli bus on the North Campus of the University at Buffalo (UB) in Amherst, NY. All experimentation was conducted on UB Proving Grounds for Connected and Automated Vehicles (CAVs) located at UB North Campus in Amherst, NY. The proving grounds is made up of private roads, that are used exclusively by the vehicles of students, faculty, staff, and authorized visitors, and in a manner that is not open to the public. These roads thus fall under the Vehicle and Traffic Law's (VTL) definition of "private roads."

With respect to the second objective, recognizing that new technology has the potential to transform the motor vehicle industry, National Highway Traffic Safety Administration (NHTSA) made one of its first official actions in this area when it released on May 30, 2013 a "Preliminary Statement of Policy Concerning Automated Vehicles." This statement defined vehicle automation as having five levels, from Level 0 (which refers to human drivers being in complete and sole control of the vehicle at all times) to Level 4 (where the vehicle performs all safety-critical driving functions and monitor roadway conditions for the entire trip). Recently, NHTSA adopted the definition of the Society of Automotive Engineers (SAE) for automation, which was first issued on January 16, 2014, where 6 levels are defined, from SAE Level 0 (a human driver does everything) to SAE Level 5 (the automated system can perform all driving tasks, under all conditions). Using the SAE levels of automation, U.S. DOT draws a distinction between

Levels 0–2 and 3–5 based on whether the human operator or the automated system is primarily responsible for monitoring the driving environment. As a result, U.S. DOT has created a new term entitled “highly automated vehicle” (HAV) which represents SAE Levels 3–5. We expect that it will be U.S. Federal legislation, policy, and regulations related to HAVs that will have the greatest impact on defining the testing and deployment of driverless bus technology in Western New York. Therefore, our policy research will primarily focus on HAVs.

For the third objective, the team will use BNMC as our case for assessing the feasibility of Olli from a financial standpoint, as well as for evaluating its likely benefits. BNMC is a rapidly growing consortium of world-class health care, life sciences, medical education institutions and spin-off companies located in the City of Buffalo. In the last few years, the campus has witnessed dramatic growth both in terms of employment and new construction. BNMC is envisioned by many to bring around a total transformation of the Buffalo downtown area, changing it into a welcoming and thriving place for people to work, shop, eat, and live. Given this, BNMC leadership has been placing great emphasis on sustainable transportation principles and has been pursuing a number of ridesharing and cycling programs to reduce dependency on the single-occupancy private vehicle and improve transportation sustainability.

1.3 Report Organization

In addition to this introductory section, the report is divided into the following sections. Section 2 describes the process of acquiring the self-driving shuttle, Olli, and the setting up of the testbed on UB’s North Campus, referred to as UB Connected and Automated Vehicles (CAV) Proving Grounds. Section 3 then discusses the safety testing of Olli on UB CAV Proving Grounds and presents the results from these tests. The focus of section 4 is on assessing public acceptance of AVs, based on the analysis of the results from surveys conducted during the course of the project of riders of Olli, as well as survey results conducted in Western New York for the same purpose. Section 5 is dedicated to discussing the public policy changes needed to allow AVs to be tested and driven on the State’s public roads. The BNMC case study is finally presented in section 6. And finally, concluding remarks and suggestions for future research are offered in section 7.

2 Olli and UB CAV Proving Grounds

This section will describe the process of acquiring UB’s self-driving shuttle, Olli, which was tested and evaluated in this project, and the steps taken to deploy the vehicle on UB North Campus grounds. It will also describe the testbed established at UB for testing and evaluating Olli and other CAVs.

2.1 Acquiring UB’s Self-Driving Shuttle, Olli

The first task in this project was to acquire the self-driving shuttle, Olli, for the purposes of testing and evaluating its safety and reliability. As soon as the project had started in August 2017, the research team began working with Local Motors on the details of delivering the Olli bus to the University. UB was assigned to vehicle #5 (the fifth Olli bus to be manufactured by Local Motors in 2018), and an expected delivery date of May 2018 was set. During that period, UB also scheduled a visit to Robotics Research LLC of Maryland on April 4, 2018. During the visit, Robotics Research demonstrated the vehicle’s capabilities and engaged in technical discussions with the UB team regarding the vehicle’s capabilities and operating parameters (Figure 2).

Figure 2. UB’s Visit to Robotics Research, Inc. of Maryland



The UB research team worked with UB Parking and Transportation, as well as with UB facilities, to secure an appropriate sheltered place for the storage of the vehicle once delivered. An interim place for the purposes of this project was secured, with plans for a longer-term solution that involves building a Connected and Automated Vehicle Enclosure (CAVE) on UB CAV Proving Grounds in the future. The interim location was at First Transit facilities on Millersport Highway in Amherst, NY, where UB

fleet of buses are parked. The place has power and internet connection and is accessible until midnight during the summer and 24 hours in the winter. The use of First Transit facilities, however, necessitated towing Olli from the First Transit location to UB Proving Grounds each time testing was to be conducted, since as mentioned previously, Olli, with no steering wheel, is not permitted yet to be driven on public roads in the State. The construction of the planned CAVE will help alleviate this problem.

2.1.1 Olli's Operational Agreement

The research team then worked with Local Motors on an operations agreement, which governed the parameters of purchasing and use of Olli. The agreement highlighted some key points, which are summarized below:

- UB's Olli is defined as a level 4/5 Autonomous Shuttle capable of operating to that level in a fixed route, fixed stop manner in a controlled environment (base vehicle performance). The vehicle may be operated in inclement weather. UB's Olli has (1) three Lidar sensors, (2) five radar sensors, (3) six cameras, and (4) a GPS Location Device. Olli is also equipped with Nsight data recorder to allow for constant recording of Olli operations, and with communications platform responsible for monitoring Olli and camera systems.
- The Client (UB) will be responsible for all maintenance and service on the Olli. Olli must be in a safe and fully operational condition. Clients will provide all oil, tires, and other parts necessary to properly maintain Olli and will maintain detailed maintenance records. The interior and exterior of Olli must be maintained in a clean and sanitary condition. Sensors should have surfaces cleaned daily to prevent possible artifact issues with SDV systems.
- The client (UB) will have the obligation to inspect the Olli prior to operating it and to record results of such inspections in a per-operation checklist and inspection form provided by the manufacturer.
- The manufacturer (Local Motors) will obtain and maintain, continuously in effect at all times during the term, at its sole cost and expense, comprehensive general liability insurance coverage with coverage limits of not less than two million and no/100 dollars (\$2,000,000.00) per occurrence and five million and no/100 dollars (\$5,000,000.00) in aggregate, that insures against claims, damages, losses and liabilities arising from bodily injury, death and/or property damage, including any such claims, damages, losses or liabilities arising from or relating to the operations of manufacturer or any its subcontractors or the presence of the manufacturer.

2.1.2 Olli's Delivery and Deployment

UB's self-driving Olli was delivered to the University on June 25, 2018 by Local Motors. On the same day (Tuesday, June 25, 2018), Local Motors (LM) and Robotics Research (RR), Inc. started their mapping and scoping study of UB CAV Proving Grounds where Olli was to be deployed (Figure 3). The mapping and scoping study involved taking measurements, videos, and photographs of the area. In addition, LM and RR checked candidate locations for the Real-time Kinematic (RTK) correction

base station which were to be utilized in improving the accuracy of the measurements of Olli's GPS in real-time. The roof of the Statler Food Commissary building was chosen to place the RTK station (Figure 4). LM and RR then ran a data collection of all routes and verified mapping and autonomous routing in a night session.

Figure 3. UB CAV Proving Grounds



Figure 4. Statler Food Commissary Building (RTK Station Location)



2.1.3 Steward Training

The next step was for LM to train the Olli's onboard stewards (Figure 5). The responsibilities of those stewards include (1) monitoring Olli while in operation, (2) performing the daily Olli vehicle inspection reports, assuming manual control of Olli when required, (3) being able to perform emergency and non-emergency stop functions of Olli, and (4) report any safety concerns immediately to LM. The training of UB stewards took place during the period from June 27 to July 3. The training first focused on drive-by-wire (DxW) techniques to control Olli, on how to start the vehicle, how to apply emergency and non-emergency brakes, and how to initiate autonomous driving. At the conclusion of their training, UB stewards were issued AV Driverless Licenses from LM (Figure 6).

Figure 5. LM Training of UB Research Assistants



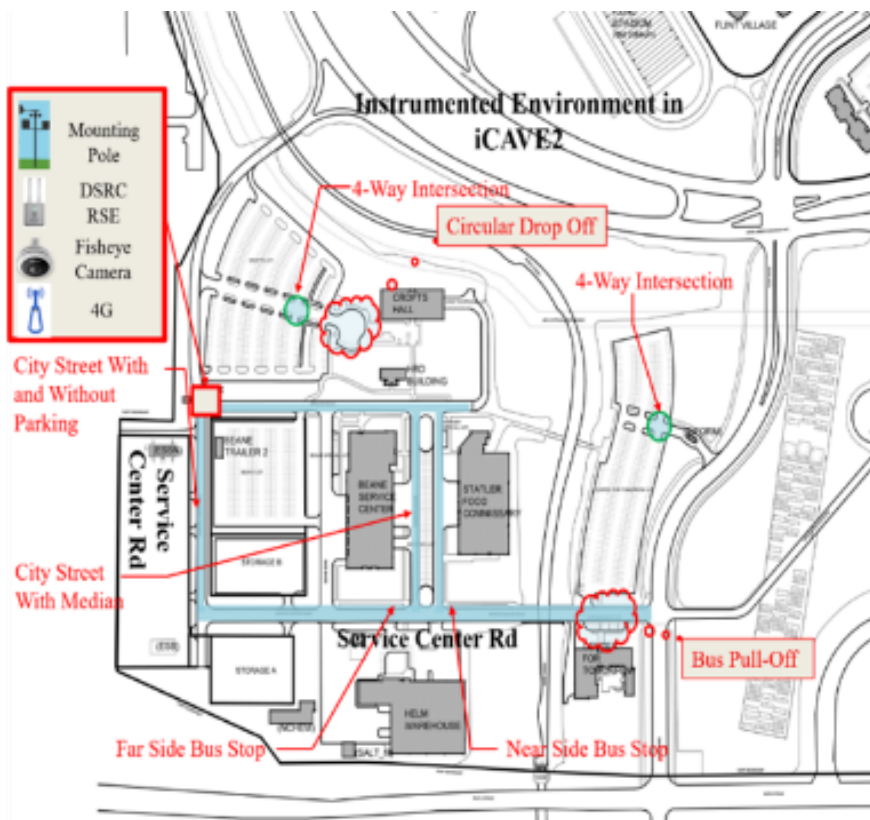
Figure 6. UB Stewards Issued their AV Driverless License from Local Motors



2.1.4 UB CAV Proving Grounds

In early 2017, UB sought the opinion of the State University of New York (SUNY) Counsel regarding the feasibility of testing AVs on its campus. The counsel has confirmed that the university has the legal authority to test AV on certain roads that have been determined to be private, and hence are not under the jurisdiction of DMV for testing approval. In addition to these private roads, the counsel confirmed the feasibility of AV testing in the University parking lots, which are defined separately in the law. Based on this, the university has designated a set of campus roads, which are used exclusively by the vehicles of students, faculty, and staff and authorized visitors and not open to the public, as constituting UB CAV Proving Grounds (see Figure 7).

Figure 7. UB North Campus CAV Proving Grounds



As can be seen, the proving grounds include several smart infrastructure elements as well as LiDAR, cameras and wireless Access Points and connected traffic signals. Moreover, the grounds were carefully designed to allow for testing various aspects of AV driving maneuvers, including navigation at a four-way intersection, circular drop-off, right- and left- turning maneuvers, and stopping at designated bus stops.

2.1.5 Olli's Official Kick-Off Event at Fourth Annual TransInfo Symposium

On August 9, 2018, the Transportation Informatics (TransInfo) University Transportation Center, headquartered at UB, held its fourth Annual Symposium on Transportation Informatics. Working with NYSERDA and NYSDOT, the research team leveraged this opportunity to launch the official kick-off of Olli's testing at UB (Figure 8). The event was well attended and included (1) officials from NYSERDA (Dr. Robyn Marquis) and from Region 5 NYSDOT (Mr. Dipak Shastri), UB Leadership, specifically UB's Vice President for Research (Dr. Venu Govindaraju), and the School of Engineering and Applied Sciences Dean (Dr. Liesl Folks), (2) Local Motors Vice President, Matthew Rivett and several other LM engineers, and (3) many other representatives from academia, government, and industry. The event included a technical demo of Olli self-driving on UB CAV Proving Grounds, a keynote lecture by Professor Alain Kornhauser of Princeton University, a national expert on autonomous driving, and a panel discussion on the challenges of AV testing and deployment moderated by Dr. Stephen Still.

Figure 8. UB Olli's Official Kick-Off Event on August 9, 2018

Shown are Matt Rivett (LM) at the podium, Dean Liesl Folks (UB), and Dr. Robyn Marquis (NYSERDA).



2.1.6 Olli's Data and Storage

UB research team worked with LM and RR to gain access to as much as data as possible from Olli to support the evaluation of the safety and reliability of Olli. This allowed the research team to access a rich data set, which included both raw as well as processed data. The data items made available to the team included the following:

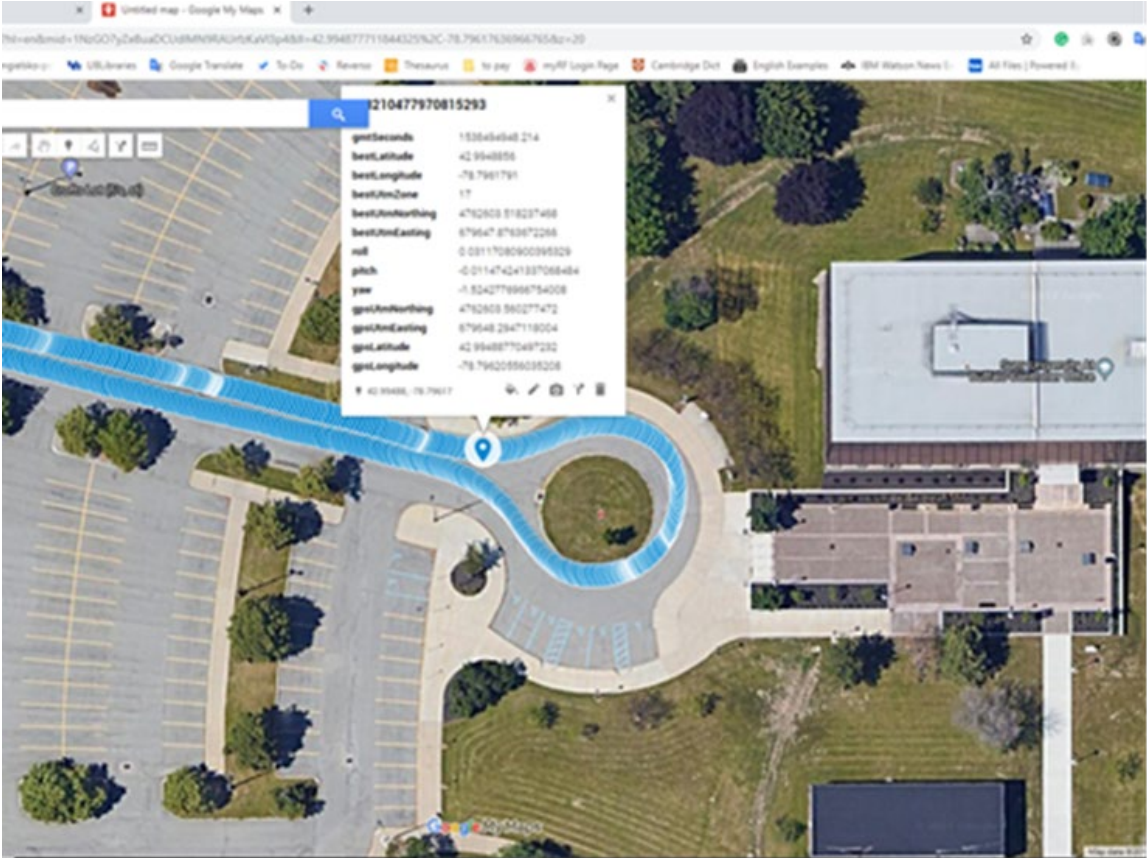
- Output data from all the Lidar and radar sensors on Olli
- Time-stamped vehicle position, roll, pitch, yaw, and velocity
- Offsets associated with the three different Lidars
- A tag indicating whether data is collected in manual or autonomous driving mode
- Olli decision/action data
- Coordinates of the route
- Coordinates for virtual stops
- Safety envelope coordinates
- Output of Olli's localization algorithm (where Olli thinks it is)
- Which "path"/route Olli decides to take (planning algorithm output)
- What vehicle control operations Olli decides to perform (i.e., acceleration/deceleration rate and output of its control algorithm)
- Time-stamped battery-level and battery consumption rate
- Time-stamped Olli's mobility info (acceleration/deceleration)

At the end of each testing day, the research team would copy the data from the shuttle's 1-TB hard disk, before uploading the data to LM and RR server. Following this, the hard disk would be wiped clean to allow for collecting additional data during the next testing day.

2.1.7 Data Visualization

During the course of the project, the UB research team developed methods for analyzing and visualizing the Olli recorded data. Specifically, methods were developed to allow for displaying the Velodyne Lidar data (using VeloView software), converting the Velodyne pcap file to a rosbag file, converting the camera pcaps to an mp4 file, and displaying the output from Olli's localization algorithms onto Google a map (see Figure 9).

Figure 9. Visualizing the Output from Olli's Localization Algorithm



3 Safety Testing of Olli on University of Buffalo Proving Grounds

This section will describe the tests designed and conducted to assess the safety and reliability of Olli under a variety of testing scenarios and in both good and inclement weather conditions.

3.1 Olli’s Safety Test Set Design

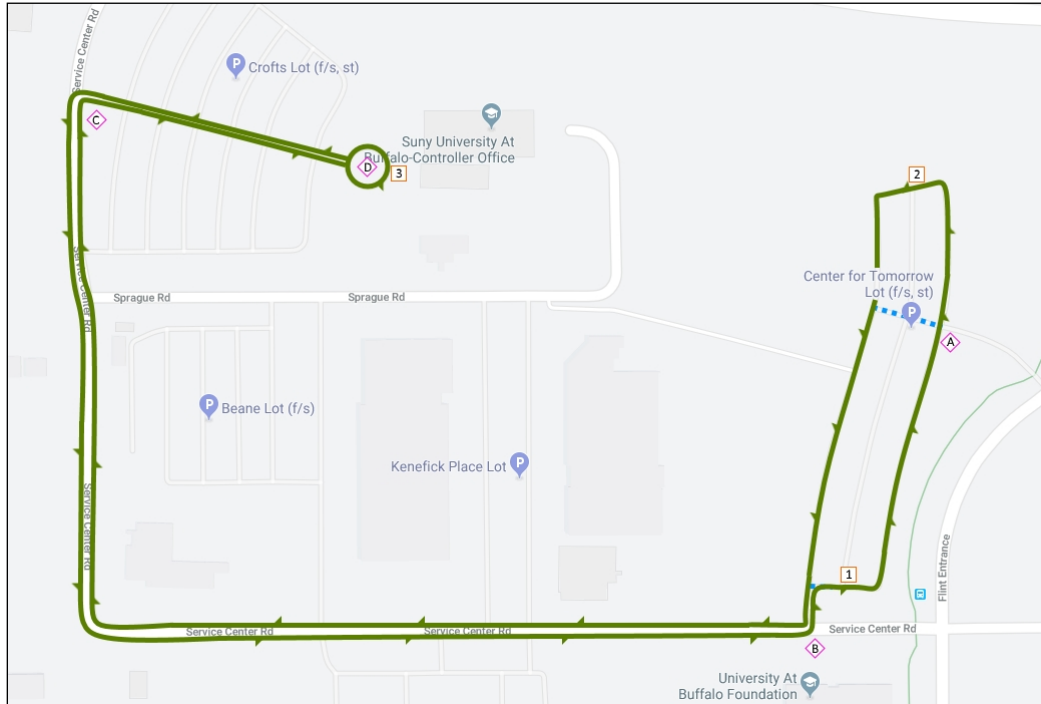
In designing the suite of tests for evaluating the safety and reliability of Olli in this project, the research team was guided by a recent study conducted by Southwest Research Institute (SwRI) for the National Highway Transportation Safety Authority (NHTSA). That study identified four dimensions of testing, namely (1) tactical, (2) design domain, (3) collision avoidance, and (4) failure cases. Based on this, the research team created a total of twelve tests (Table 1).

Table 1. Olli Test Summaries

No.	Test	Objective
1	Left Turn	Observe and measure how the shuttle behaves when making left turns
2	Right Turn	Observe and measure how the shuttle behaves when making right turns
3	Four-Way Stop (No Conflict)	Observe and measure how the shuttle behaves when navigating a four-way stop, without opposing traffic
4	Four-Way Stop (Conflict)	Observe and measure how the shuttle behaves when navigating a four-way stop, with opposing traffic
5	Shuttle Stop	Observe and measure how the shuttle behaves when approaching different types of designated shuttle stops
6	Stationary Pedestrian Identification	Observe and measure how the shuttle behaves when a stationary pedestrian interferes with its path
7	Moving Pedestrian Identification	Observe and measure how the shuttle behaves when a mobile pedestrian interferes with its path
8	Vehicle Following	Observe and measure how the shuttle behaves when following a human driven vehicle
9	Vehicle Leading	Observe and measure how the shuttle behaves when leading a human driven vehicle
10	Passing Vehicle	Observe and measure how the shuttle behaves when a human driven vehicle passes it
11	Object Detection	Observe and measure how well the shuttle detects the surrounding environment in stationary
12	Static Vehicle Obstruction	Observe and measure how the shuttle behaves when meeting a static vehicle obstruction
Data Type		Measures Collected
Raw Data		speed, acceleration, position, battery level
Processed Data		reaction time, detection rate, functional battery life
Observations		roadway/weather conditions, unexpected interactions

A subset of those tests was performed in dry and good weather conditions, and then repeated during inclement weather conditions. This was done to gauge the impact of inclement weather on the self-driving shuttle performance. Each test also identified the information collected, including raw data collected by the self-driving shuttle, processed measures calculated from that data, and qualitative observations made during the test (also listed in Table 1).

Figure 10. Olli's Test Track on UB CAV Proving Grounds



As previously mentioned, testing was conducted on UB CAV Proving Grounds on UB North Campus. A layout of the test track is provided in Figure 10. The green line represents the path followed by the self-driving shuttle, with the arrows indicating direction. The blue dashed lines represent alternative paths on which the shuttle is capable of operating. The numbered squares represent the three shuttle stops for the route. Additional points of interest along the route are marked with lettered diamonds, which represent (1) a four-way stop intersection (labelled with the letter A), (2) a right onto, or left turn off, a traveled road (labelled with the letter B), (3) a right off, or left turn onto, a traveled road (labelled with the letter C), and (4) a simulated roundabout (labelled D).

3.2 Safety Testing Data Collection and Pre-Processing

In addition to the recorded camera feeds, Olli’s onboard equipment records information on its position and movement every 0.2 seconds. The raw data collected in this way is limited in its immediate utility and requires some cleaning and processing. Additionally, different data types were collected independently and needed to be linked based on the associated time stamp. Table 2 lists the raw data collected and the corresponding calculated measure(s), if applicable.

Table 2. Self-Driving Shuttle X Data and Measures

Raw Data	Units	Calculated Measure	Units
GMT Time	Seconds	Time Stamp	Hour, minute, second
Latitude/Longitude	degrees	N/A	N/A
Speed	m/s	Speed	mph
Acceleration	m/s ²	N/A	N/A
Battery Level	%	Battery drain rate	%/second
Torque	N·m	N/A	N/A
Brake pressure	MPa	N/A	N/A
Autonomous Mode	Binary	N/A	N/A

3.3 Safety Tests Results and Discussion

For each of the twelve tests, some combination of the variables listed in Table 2 were measured. Additionally, qualitative observations were recorded on how the shuttle reacts to certain scenarios (e.g., detection and reaction time/distance to external stimuli). Whenever possible, attempts were made to determine how the shuttle’s behavior statistically differed from a human-driven vehicle, and how performance differed in inclement weather, using the statistical t-test or Z-test, according to the sample size. In addition to basic operating parameters such as speed and acceleration, the primary behavior compared in this way was Olli’s ability to detect and react to potentially dangerous scenarios. For Olli, this reaction primarily involved coming to a complete stop as safely as possible. Therefore, to understand how the behavior of the shuttle compares to that of a human driver, the stopping sight distance for a human driver was compared to that of the shuttle.

3.3.1 Preliminary Comparisons of Olli's Operating Characteristics

3.3.1.1 Distributions of Olli's Speed and Acceleration

For comparison, Figures 11 and 12 show the distributions of Olli's speed and acceleration when operated in autonomous mode as well as when manually controlled. As can be seen, in terms of speed, the shuttle seems to have a few specific speeds (6.7 mph in the parking lots, and 11.0 and 13.3 mph on the service road), instead of varying its speed within its full range. Additionally, the shuttle uses a limited range of acceleration, usually between -0.25 and 0.25 meter/second² (m/s^2). However, there is a local maximum acceleration near 0.45 m/s, indicating this is an acceleration the shuttle prefers to use when reaching its desired speed. Also, the left tail of the distribution extends further than the right, meaning the shuttle is able to decelerate at higher rates than it accelerates. This is further reflected by the maximum deceleration of nearly 2.5 m/s², while the maximum acceleration is just over 1.0 m/s².

Figure 11. The Self-Driving Shuttle's Speed and Acceleration Distribution: Speed Distribution

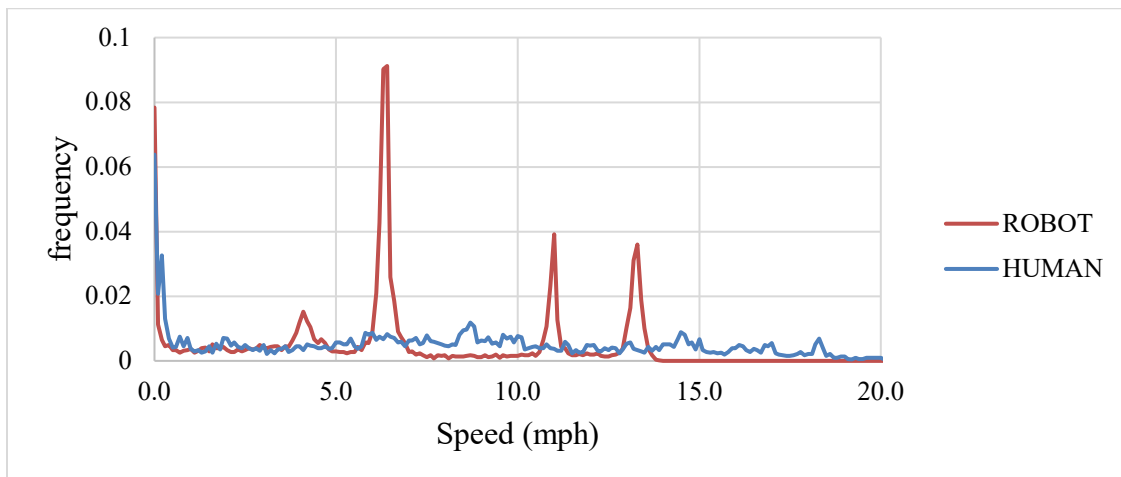


Figure 12. The Self-Driving Shuttle’s Speed and Acceleration Distribution: Speed Distribution and Acceleration Distribution

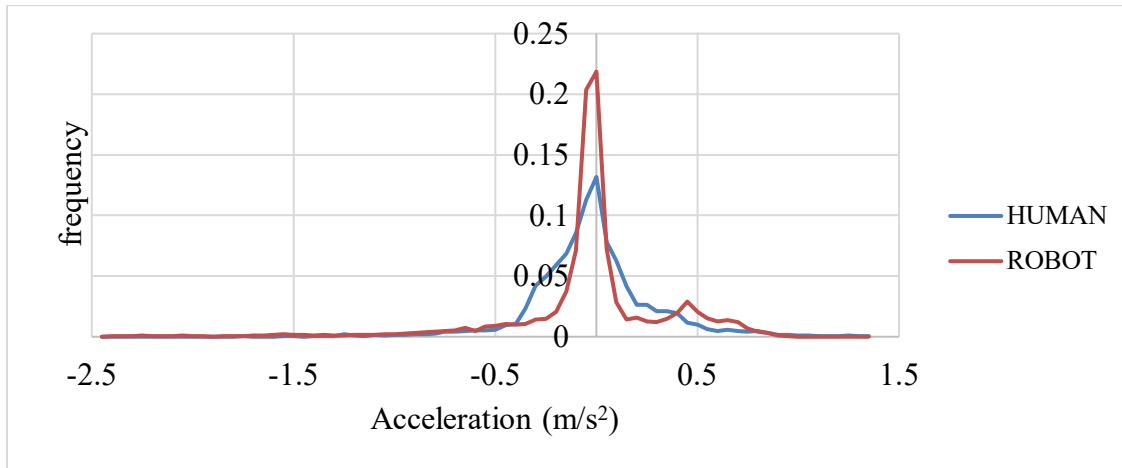


Table 3 presents the results of speed and acceleration Z-test comparing raining and clear conditions. As can be seen, there appears to be statistically significant difference between operations in the dry and rainy conditions. Specifically, in non-inclement weather, the shuttle’s speed was, on average, approximately 0.5 mph less, while its average acceleration was about 0.1 m/s² greater and average deceleration 0.15 m/s² less. The Z-tests performed proved each of these differences to be statistically significant, with certainty levels of >99.99%, 99.15%, and 97.60%, respectively.

The observation that the shuttle’s speed is greater during rain is initially counterintuitive, as it is often expected that human-driven vehicles operate at slower speeds during inclement weather. However, additional testing, under a wider range of inclement weather conditions, is needed before drawing any concrete conclusions. Moreover, the observation may be explained by the fact that the shuttle currently does not have any programmed behavior response to weather. On the other hand, the greater acceleration during clear weather and greater deceleration during inclement weather are more in line with traditional logic. Greater traction when roads are dry allows the shuttle to reach its desired speed in less time, while wet pavement requires harder braking to decelerate in a safe distance.

Table 3. The Self-Driving Shuttle’s Speed and Acceleration Comparisons

	Speed		Acceleration		Deceleration	
	Clear	Rain	Clear	Rain	Clear	Rain
Average	6.117	6.645	0.234	0.223	(0.233)	(0.247)
Standard Dev.	3.678	4.299	0.249	0.230	(0.348)	(0.374)
zd	9.834		2.399		1.984	
Level of Certainty	>99.99%		99.15%		97.60%	

3.3.1.2 Speed and Acceleration Profiles Comparison

Over several trials, the self-driving shuttle's ability to detect and react to stopping scenarios was monitored. This included both expected stops (i.e., stops that were already included in the shuttle's control logic and internal high-definition map), such as an upcoming turn or the end of a route, as well as unexpected stops in which the autonomous shuttle was presented with an obstacle, in accordance with experiment procedures. These tests were repeated for both clear and rain conditions.

Figure 13 displays the speed profiles of stops in all four of these cases, while Figure 14 show the acceleration profiles. The 0 of the time axis indicates the point where the shuttle began to decelerate. In addition, to identify the trends more clearly in each case, Figures 15 and 16 show the aggregate speed and acceleration profiles.

Figure 13. Stopping Speed Profile

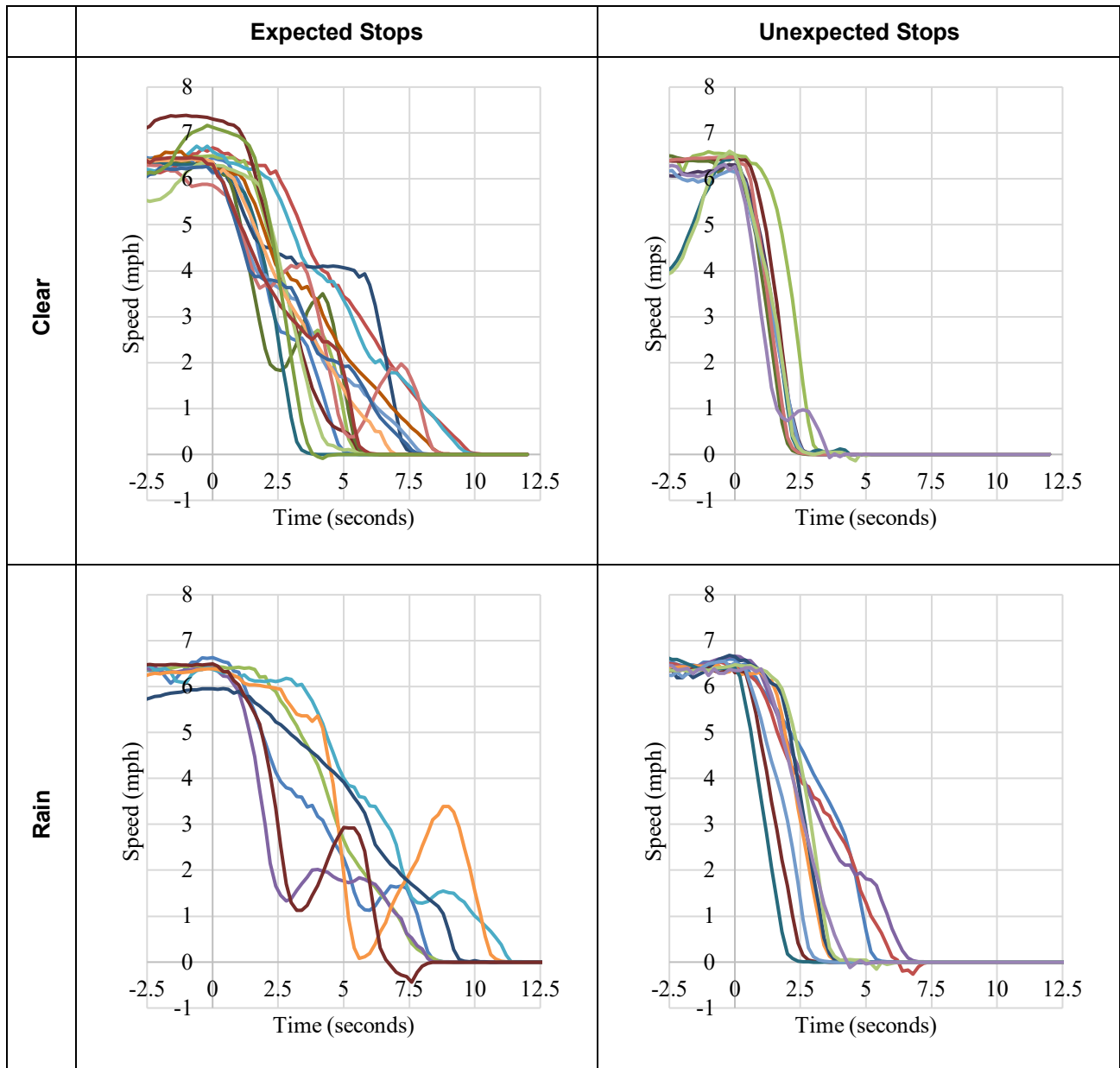


Figure 14. Stopping Acceleration Profiles

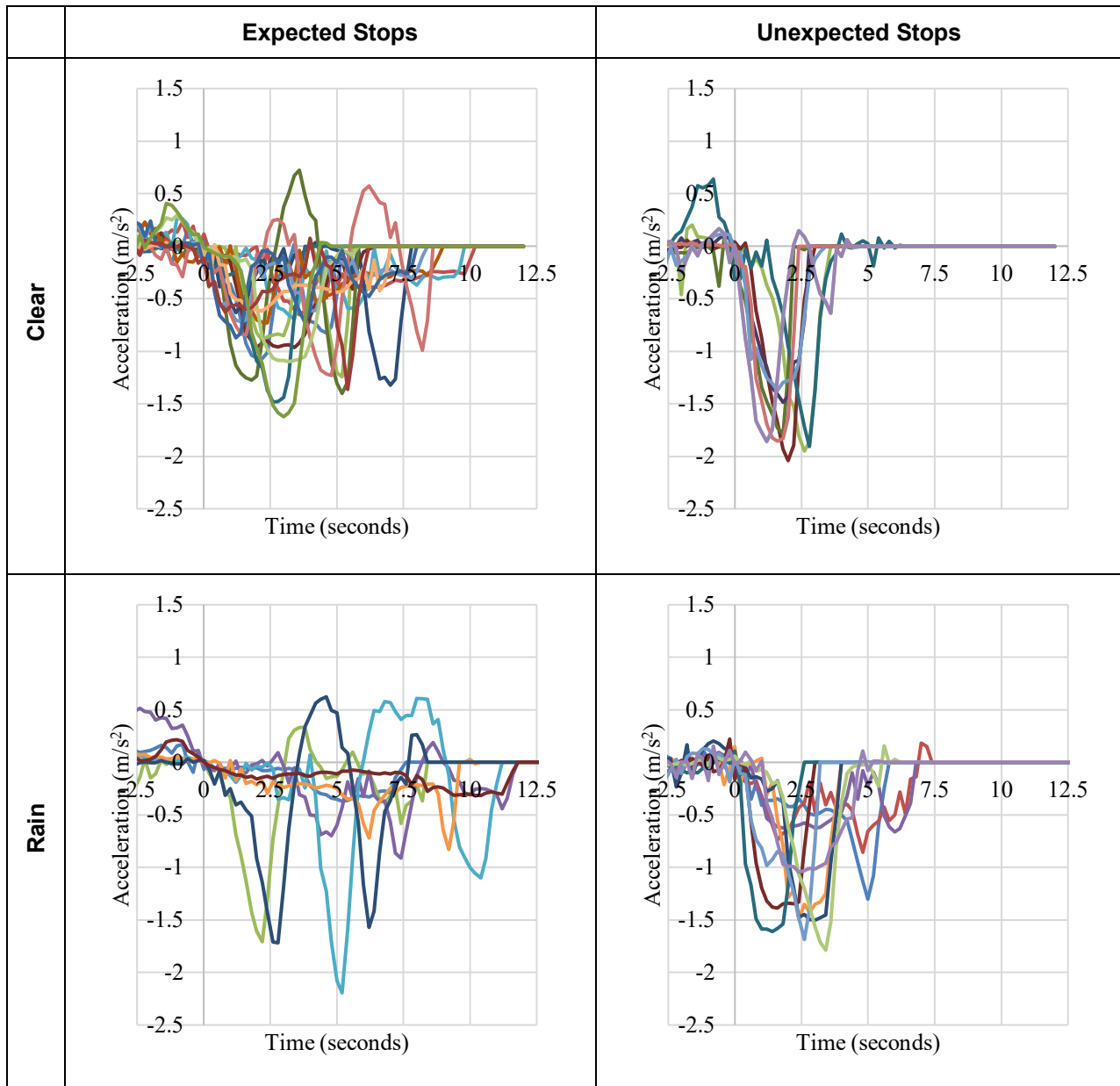


Figure 15. Aggregate Speed and Acceleration Profiles: Aggregate Speed Profiles

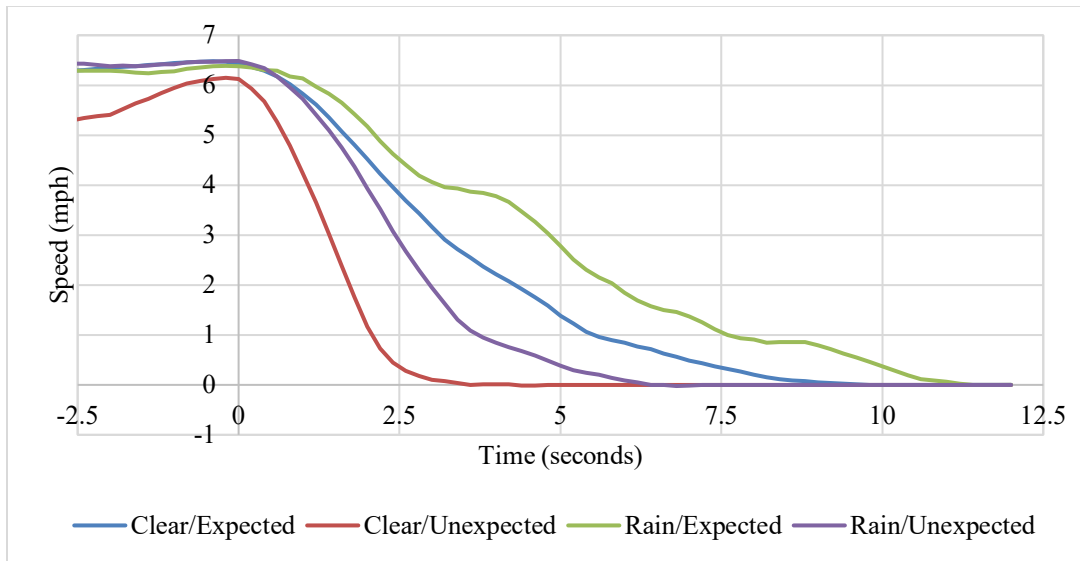
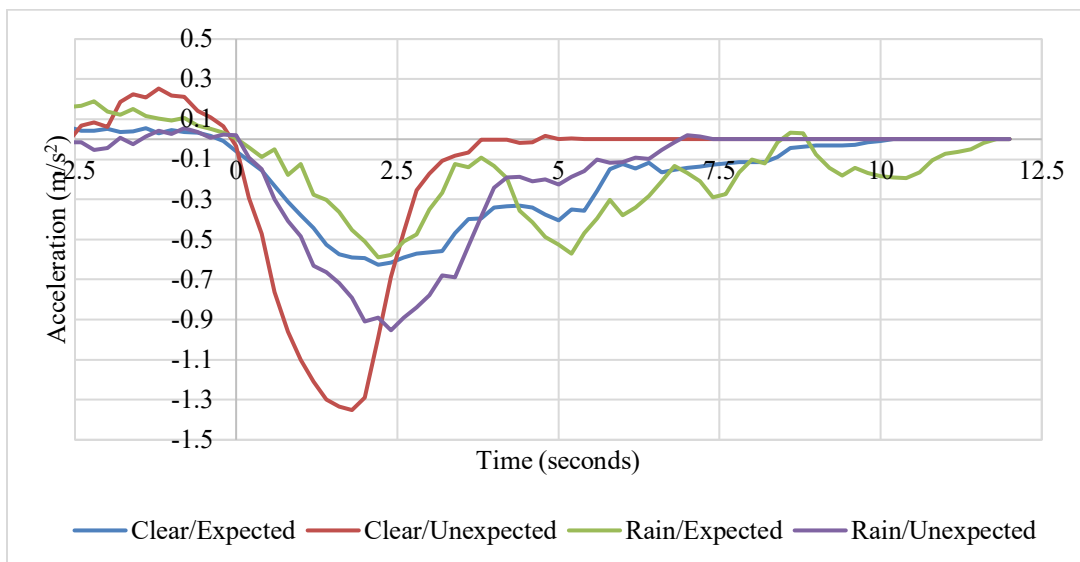


Figure 16. Aggregate Speed and Acceleration Profiles: Aggregate Acceleration Profiles



The stopping distance of the self-driving shuttle in different scenarios show that, on average, the shuttle utilizes a much greater distance during expected stops than unexpected stops. This is expected, as the shuttle can use its advance knowledge of expected stops to decelerate more gradually. In terms of inclement weather impact, the conditions during rain resulted in greater stopping distances for both expected and unexpected stops. This is also logical, as the decreased traction leads to longer periods of braking needed to come to a stop.

The speed and acceleration profiles provide a more detailed view of how the self-driving shuttle behaves in these situations. When coming to an expected stop during dry conditions, the shuttle makes a smoother stop of a longer period with a relatively little change in deceleration rate. Comparatively, an unexpected stop under the same conditions occurs over a much shorter period, with a rapid, but constant, change in deceleration rate. The observed results are much different when raining. While making an expected stop in these conditions, the self-driving shuttle still utilized a relatively long period, but the deceleration rate changed continuously while the stop was occurring with the vehicle even accelerating at some points. The unexpected stops made during rain usually featured a lesser maximum deceleration than during dry conditions but spread out over a longer period and with a less constant rate of change, resulting in greater distances traveled during the stop.

3.3.1.3 Stopping Distance Comparison

Additionally, the self-driving shuttle’s stopping ability was compared for clear and raining conditions to determine if inclement weather had a significant impact on its performance. For each trial, the stopping sight distance a human driver would need was also estimated, assuming a perception and reaction time of 2.5 seconds and a typical coefficient of friction. While the self-driving shuttle’s initial speed was usually near its base operating speed of approximately 3 m/s (6.71 mph), there was some variation. Therefore, when comparing the values collected in the trials, all results were normalized to an initial speed of 3 m/s.

Table 4: Stopping Distance Comparison

Weather Condition	Self-Driving Shuttle Average Stopping Distance (ft)		Equivalent Human-Driver Average Stopping Distance (ft)		Difference between Self-Driving Shuttle and Human Driver (ft)	
	Expected Stop	Unexpected Stop	Expected Stop	Unexpected Stop	Expected Stop	Unexpected Stop
Dry	35.6	17.2	28.8	28.5	+6.8 (+23.6%)	-11.3 (-39.6%)
Rain	55	26.9	37.4	37.6	+17.6 (+47.1%)	-10.7 (-28.5%)
All	40.2	21.2	30.8	32.3	+9.4 (+30.5%)	-11.1 (-34.4%)

The results are shown in Table 4, which shows the average stopping distance in these scenarios by the self-driving shuttle and a human driver, respectively. The Table also shows the differences between the two data sets as both numerical values and percentages (calculated relative to the human driver average stopping distance). According to the table, for example, the average stopping distance of the self-driving shuttle during dry weather and for unexpected stops is 11.3 feet less than that a human driver, which represents a reduction of 39.6% over a human driver.

The results also show that, the stopping distances during rainy conditions, for both the self-driving shuttle and the equivalent human driver and for both expected and unexpected stops were significantly longer compared to dry weather conditions. Additionally, when compared to an equivalent human driver, the self-driving shuttle was found to utilize greater distances for unexpected stops than a human-driven vehicle (23.6% greater in dry weather and 47.1% more in rainy conditions). Given that the self-driving shuttle has an advance knowledge of such cases, it appears to be trying to make the stop smooth by braking over a longer distance. For unexpected stops, the self-driving shuttle was able to stop more quickly and over a shorter distance compared to an equivalent human driver. Specifically, the stopping distance for the self-driving shuttle was 39.6% less than the stopping distance for an equivalent human driver in dry weather, and 28.5% less in rainy conditions. This is thanks to the fact that the self-driving shuttle’s perception and reaction time are negligible compared to a human driver.

Additionally, the t-test was used to determine the statistical significance of the difference in stopping distance in each scenario. These results are shown in Table 5. From these results, it can be stated with greater than 99.99% certainty that the self-driving shuttle travels less distance when stopping unexpectedly than a human driver does. Secondly, it can be stated with 99.7% certainty that the shuttle travels less distance when stopping unexpectedly in clear conditions than when there is significant rainfall. It should be noted that the human-driven vehicle in this comparison is modeled only by a theoretical formula. To provide a better comparison in the future, data from a real-world, human-driven vehicle should be collected.

Table 5. Stopping Distance Comparison T-test Results

Comparison	t-value	Level of Certainty
Self-Driving Shuttle versus Human Driver Unexpected Stops	6.719	>99.99%
Self-Driving Shuttle in Rain versus Clear Weather Unexpected Stops	3.027	99.70%

3.3.2 Test 1 and 2: Left/Right Turn Performance

As was mentioned in Table 1, the left and right turn performance tests (tests 1 and 2 in Table 1) were designed to measure the safety and efficiency of the self-driving shuttle’s left-turn and right-turn maneuvers. The tests were performed when the shuttle drove normally in autonomous mode. The turning time duration and surrounding environment were recorded. The results are shown below in Table 6.

Table 6: Left-Turn and Right-Turn Performance

Turns	Turning Type	Trip 1	Trip 2	Trip 3	Average
Left	Lot onto Major Road: Stop Sign	20 s	21 s	30 s	23.67 s
Left	Major Road into Lot: Free	15 s	5 s	5 s	8.33 s
Right	Lot onto Major Road: Stop Sign	22 s	20 s	17 s	19.67 s
Right	Major Road into Lot: Free	5 s	9 s	10 s	8 s

There were two types of turns for both left-turn and right-turn performance tests. First was turning from the parking lot onto the major road, where the shuttle stopped in front of a stop sign before turning. The second type was turning from the major road into the parking lot; in that case, the shuttle could make the turn freely as long as it had no conflicts with other vehicles or pedestrians. It is worth noting that the turning time recorded, represented the duration from the deceleration of the shuttle to the finishing of the turning process. Therefore, the time stopped in front of the stop sign was also included in the turning time recorded. This is the reason behind the variation of the turning time across the three cases shown in Table 6, since the time depended upon the presence or absence of conflicting vehicles.

The results show that, as expected, turning with stop signs took much longer than turning freely for both left and right turns. It makes sense since the shuttle will be brought to a complete stop at the stop signs, while at free turns, the shuttle will not stop completely if there is no vehicle interfering with the shuttle's route. Additionally, left turns took slightly longer than right turns in average when the additional time needed for completing a left turn compared to a right turn was about 4 seconds for turns with a stop sign and 0.33 second for turns without stop signs. The table also shows large variation between different tests/ trips. For example, in the free left turn tests (2nd row), trip 1 took 15 second which was three times longer than that of trip 2 and 3; this is because, as mentioned before, the time varied depending upon whether there were conflicting vehicles or not in each case.

Another observation to be made regarding Olli's turning maneuvering performance is that the shuttle tended to operate on the conservative side. For example, for the right turn from the major road into the lot, which is recorded in the last row of Table 6 and which is supposed to be a free turn, the shuttle tended to stop even if there was just another vehicle attempting to make a left-turn from the parking lot onto the major lot. In that case, of course, there is no real conflict between Olli and that other vehicle.

Overall, the main findings of the left-turn and right-turn performance tests can be summarized as follows:

- The time duration of turns was largely dependent upon the presence or absence of conflicting traffic or perceived conflicts around the shuttle.
- While making a turn, the shuttle was able to accurately and in a timely fashion detect any conflict vehicle or obstruction ahead on its route and stop by itself.
- The shuttle made no dangerous move while turning. No manual control was needed.

3.3.3 Test 3 and 4: Four-Way Stop Test with and without Conflicts

The purpose for the four-way stop tests was to measure the performance of the shuttle at four-way stop signs, especially when there were vehicles waiting in the conflicting directions. The testing location was in the parking lot right across from the Center for Tomorrow (CFT) building, where a four-way intersection was programmed in the shuttle’s route. First, the shuttle was driven by the intersection without any other vehicles. Then, vehicles were placed near the stop sign on the left or right of the shuttle’s direction to test the shuttle’s behavior. The results are shown in Table 7.

Table 7. Four-Way Stop Test Performance

Test Number	Conflicting Vehicle Direction	Distance from Shuttle to the Other Vehicle	Shuttle Pass the Intersection?	Number of Extra Stops Made before Passing
Test 1	None	N/A	Yes	0
Test 2	Left	20 m (66 ft)	Yes	0
Test 3	Left	15 m (49 ft)	Yes	1-2
Test 4	Left	12 m (39 ft)	No	N/A
Test 5	Right	12 m (39 ft)	Yes	0-1
Test 6	Right	10 m (33 ft)	No	N/A

Since the four-way intersection was programmed into the shuttle, there were no actual stop signs where the vehicles in conflicting direction parked. Thus, the measures taken were the distance from the shuttle to the corresponding vehicle. The results indicate that without conflicts, the shuttle passed the intersection normally without any stops. However, when there were conflicting direction vehicles present, the shuttle stopped, waiting for the conflicting vehicles to clear the intersection. Since the vehicles were stationary in our test, those vehicles never cleared the intersection, as far as Olli is concerned. In fact, as can be seen from Table 7, Olli stopped permanently, and did not clear the intersection when the distance between the shuttle and the conflicting vehicle was less than 12 meters (in case of a vehicle to the left of Olli) and when it was less than 10 meters (for a vehicle to the right of Olli), as can be seen in Tests number 4 and 6 shown in Table 7. When the distance between Olli and the conflicting vehicles was larger than

that, the shuttle tried to move forward, but stopped at least once before entering the intersection for safety reasons because the conflicting vehicles were close to the stop sign (this was the case for Tests 3 and 5). When the distance was large enough to indicate the conflicting vehicles were some distance away from the stop sign, the shuttle would pass the intersection without any stops (as in Tests 1 and 2).

In summary, the shuttle was able to cross the intersection normally without conflicts. In addition, the shuttle would not pass the intersection if there were vehicles present at conflicting direction stop signs, even if those vehicles never moved. It is worth noting that the shuttle would always give the priority to other vehicles at the stop sign, even if it arrived earlier than those other vehicles. In other words, Olli did not seem to be applying the common traffic rule at four-way stops, which states that the vehicle that arrives first gets to go through the intersection first. Rather, Olli prioritizes safety and would only move when it perceives that there are no other conflicting vehicles at the intersection.

3.3.4 Test 5: Shuttle Stop Test

This test was designed to evaluate the shuttle’s stop performance (other preliminary stopping and acceleration analyses were previously discussed in section 3.3.4). This test focused on the emergency stopping performance. In this test, the team created scenarios where Olli was normally driving on the Center For Tomorrow (CFT) parking lot, where its speed was typically around 3 meters/second (or 7 mph) and a person suddenly comes out from a parked vehicle in front and at a relatively short distance from Olli. The team observed how Olli behaved in both dry and rainy conditions. The results are shown in Table 8 (for dry conditions) and Table 9 (for rainy conditions).

Table 8: Shuttle Stop Test Performance in Dry Weather

Distance to Shuttle when Pedestrian Appears (Meters)	Shuttle’s Speed when Pedestrian Appear (Meters/Second)	Distance between Shuttle and Pedestrian when Stopped (Meters)
60	3.1	11.5
30	3.1	9.05
12	3.1	7.3

Table 9: Shuttle Stop Test Performance in Rainy Weather

Distance to Shuttle when Pedestrian Appear (Meters)	Shuttle’s Speed when Pedestrian Appear (Meters/Second)	Distance between Shuttle and Pedestrian when Stopped (Meters)
100	2.9	12.2
100	3.1	13.5
70	3.0	12.3

As can be seen, the shuttle managed to stop in all cases, and the buffer distance between the shuttle and the pedestrian, after fully stopping, varied between 7 and 13 meters (23 and 43 ft). The buffer distance was the smallest when the original distance to the shuttle, when the pedestrian appeared, was the smallest (i.e., 12 meters). In that case, the shuttle needed less than 5 meters (16 ft) to fully stop. It is worth noting that the original distances tested in rainy conditions were intentionally set to be longer than in the dry condition, as an additional measure of safety. To summarize, the shuttle stop test demonstrates that the shuttle was able to successfully detect obstacles/pedestrian suddenly appearing in its path and to react in a safe manner by bringing the shuttle to a full stop, even when the distance between Olli and the sudden obstacle was quite short.

3.3.5 Test 6 and 7: Stationary/Moving Pedestrian Identification Test

These tests were conducted to observe the behavior of the shuttle when stationary or moving pedestrians interfered with its path or had the potential to do so. In that test, Olli was driven along the University at Buffalo's service road across from the Center For Tomorrow, and pedestrians were asked to perform certain actions near Olli. Specifically, pedestrians were asked to do the following: (1) stand stationary on the curb in Olli's vicinity, (2) parallel walk along the curb parallel to Olli, (3) walk toward the curb, and cross the street as the shuttle approached. For these testing scenarios, Olli's behavior was observed and recorded. The testing setup is shown in Figure 17. Below we discuss the results of the test for the three cases of (1) stationary pedestrians, (2) parallel moving pedestrians, and (3) crossing pedestrians.

Figure 17. Pedestrian Identification Test Setup



3.3.5.1 Stationary Pedestrians Test

In this test, the pedestrian was just standing (i.e., stationary and not moving) near the end of the curb as the shuttle approached. The results are summarized in Table 10 below for the different distances the pedestrians stood from the curb. As can be seen from the table, it is evident that, as long as the pedestrian next to the shuttle remained stationary, Olli continued its journey without interruption. This result was encouraging since it showed that the shuttle would only stop or slow down when it correctly detected a potentially hazardous situation.

Table 10. Shuttle’s Reaction to Stationary Pedestrians

Pedestrian’s Distance to the Curb	Shuttle Decelerated?	Shuttle stopped?	Shuttle adjusted path?
0 meters (on the curb)	No	No	No
0.5 meter (1.6 ft)	No	No	No
1 meter (3.3 ft)	No	No	No
1.5 meters (4.9 ft)	No	No	No

3.3.5.2 Parallel Moving Pedestrians Test

In this test, pedestrians moved along the curb, parallel to the path of Olli. As the shuttle approached, the shuttle’s behavior was observed and recorded. Figure 18 shows the pedestrian’s movement routes and the results are shown in Table 11. In this case too, it was observed that the pedestrians’ movements did not have an impact on the shuttle’s driving, as long as they stayed off the road. The shuttle detected the pedestrians in every case, as well as their moving speed, but did not calculate their moving trajectory, which means that the shuttle did not consider them as conflicting obstacles. This once again confirms that the shuttle is not oversensitive to pedestrians; nevertheless, some adjustments for improved safety, may be warranted.

Figure 18. Parallel-Moving Pedestrians Test Setup

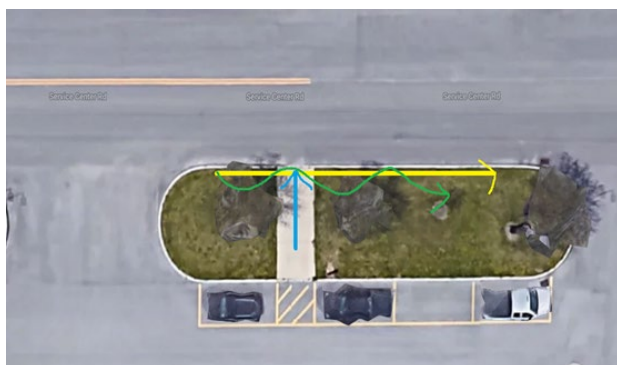


Table 11. Results of Parallel-Moving Pedestrians Test

Pedestrian's Action	Shuttle Decelerated?	Shuttle Stopped?	Shuttle Adjusted Path?
Walking along the curb (yellow)	No	No	No
Walking towards the curb (Blue)	No	No	No
Walking S-shape on the curb (Green)	No	No	No

3.3.5.3 Crossing Pedestrians Test

In this test, pedestrians crossed the street using the walking route showing in Figure 18, as the shuttle approached. Tests were repeated with pedestrians starting the crossing from both sides of the road. The results are shown in Table 12. As can be seen, the shuttle was able to detect all the pedestrians crossing, calculate their moving trajectory, and stop—leaving sufficient distance between the shuttle and pedestrians.

Table 12. Crossing Pedestrian Test Results

Direction	Shuttle Stopped?	Speed before Decelerating	Distance to Pedestrians after Stopped	Time Taken to Fully Stop
Right	Yes	5.04 m/s (11.3 mph)	8.6 meters (28 ft)	3.3 second
Left	Yes	5.1 m/s (11.4 mph)	7.5 meters (25 ft)	3.4 second

In Summary, the stationary and moving pedestrian identification tests demonstrate that Olli is not oversensitive and does not overreact to the presence of pedestrians on the sidewalk, as long as they are stationary or moving parallel to its path (and hence there is no conflict). Moreover, the tests show that the shuttle appears to be capable of detecting any potential hazardous situation, arising from a conflict between Olli and the pedestrian, and of taking safe actions in case the pedestrians end up interfering with its path.

3.3.6 Test 8 and 9: Vehicle Following/Leading Test

These tests were designed to investigate the behavior of the shuttle when following or leading a human driven vehicle. The testing location was on the service road, across from the CFT building, and the shuttle's driving speed was approximately equal to 14 mph. The human-driven vehicle was

controlled by one of the project’s research team members, who drove the vehicle at different speeds relative to the speed of Olli. Specifically, the human-driven vehicle drove at speeds lower than, equal to, and greater than Olli’s speeds for each of the cases when following the human-driven vehicle and when it was leading or in front of the human-driven vehicle. The behavior of the shuttle was recorded for the different cases, as shown in Table 13.

Table 13. Vehicle Following and Leading Test Performance

Shuttle’s Position	Human-Driven Vehicle Speed	Shuttle’s Speed
Following	< 14 mph	Decrease
Following	= 14 mph	Constant
Following	>14 mph	Constant
Leading	< 14 mph	Constant
Leading	= 14 mph	Constant
Leading	>14 mph	Constant/Decrease

As can be seen, the behavior of Olli appears to follow normal human driver behavior when it is following a human-driven vehicle. For instance, when the shuttle was following a human-driven vehicle, Olli maintained its desirable speed of 14 mph when the lead, human-driven vehicle drove no slower than 14 mph. Additionally, when the human driven vehicle decelerated, the shuttle decelerated as well to keep a safe distance with the vehicle in front.

On the other hand, when Olli was the lead vehicle, the shuttle maintained its desirable speed of 14 mph when the human-driven vehicle’s speed was no greater than shuttle’s speed. However, when the human driven vehicle accelerated and was getting close to the shuttle, Olli, in a counter-intuitive way, actually decreased its speed. This was of course not safe and could cause potential accidents. It is worth noting that the research team communicated the behavior to Local Motors and Robotic Research, Inc., and, after some discussions and communications with the manufacturer, the problem seemed to have been fixed. Overall, the vehicle’s tests in following and leading thus show that the shuttle was able to follow the front vehicle at its desirable speed or at the speed of the front vehicle. It also maintained desirable speeds when vehicles were following the shuttle.

3.3.7 Test 10: Passing Vehicle Test

Since the shuttle is designed as a low-speed shuttle, other vehicles needing to pass will be common. The passing test was proposed to test the shuttle's performance in such scenario. The test was conducted on the service road, where a vehicle driven by a research team member accelerated and passed the shuttle as the shuttle drove autonomously. The shuttle's behavior was observed and recorded for each test run.

The test result showed that the shuttle remained traveling at its design speed for most of the test cases, as the human-driven vehicle passed. The only exception was when the human-driven vehicle merged back in the original lane too early, leaving a space headway of less than approximately 12 meters (39 ft) between it and Olli at the moment the passing vehicle merged back onto Olli's lane. In that case, the shuttle would apply a sudden brake, to maintain the safe distance, and would then resume traveling at the desirable or design speed.

3.3.8 Test 11: Object Detection Test

This test was designed to evaluate the shuttle's ability to detect obstacles surrounding the vehicle. The factors evaluated were the detection range and detection accuracy while the vehicle was in stationary mode. Such an evaluation is thus geared at evaluating the combined performance of the sensors onboard Olli (e.g., Radar and Lidar) and the performance of the perception and recognition algorithm utilized by the shuttle. In this test, the shuttle was parked in the Center for Tomorrow (CFT) lot, with a sufficient amount of parking spots around Olli occupied by other parked vehicles. The object detection test was divided into two parts: the front detection test and side detection test. Because the research team does not have direct access to the detection and recognition algorithm and its direct output (because of Robotics Research's proprietary concerns), the research team had to depend upon the shuttle's onboard monitor, which shows the objects detected by Olli. The detection performance was thus assessed by comparing the output from the onboard monitor to what was happening in reality.

The detection range was tested at first. The onboard monitor showed that when stationary, the shuttle recognized objects that were about 30 meters (98 ft) away when the object was located in front of Olli, and objects that were 20 meters (66 ft) away, located to the side of the vehicle. It is worth noting that these distances were determined based on what the onboard monitor was showing, and that this may not necessarily be the actual sensor detection range.

3.3.8.1 Front Detection Test

The shuttle was parked at a distance of around 20 meters (66 ft) from the front vehicles. All the vehicles in front (five in total) were perfectly recognized by the shuttle. One of the research team member then walked toward the parked vehicles, and the research team observed and recorded the shuttle's onboard monitor to determine whether the shuttle detected the moving person. Figure 19 shows the shuttle's onboard monitor during the test. As can be seen from Figure 19a, as the pedestrian was walking toward the vehicle, the shuttle successfully detected the pedestrian, and also calculated the pedestrian's speed. The shuttle was able to detect all obstacles located in front of it on both dry and rainy days.

However, as the walking person got closer to the parked vehicle (Figure 19b), the shuttle began to see both the pedestrian and the vehicle, as one object (this happened when the person was at a distance of less than 1 meter [3.3 ft] from the vehicle). When this occurred, the shuttle did not calculate the speed of the pedestrian, since it assumed that the pedestrian was stationary along with the parked vehicle. It only began to calculate the moving speed once again, as the person started to move away from the vehicle.

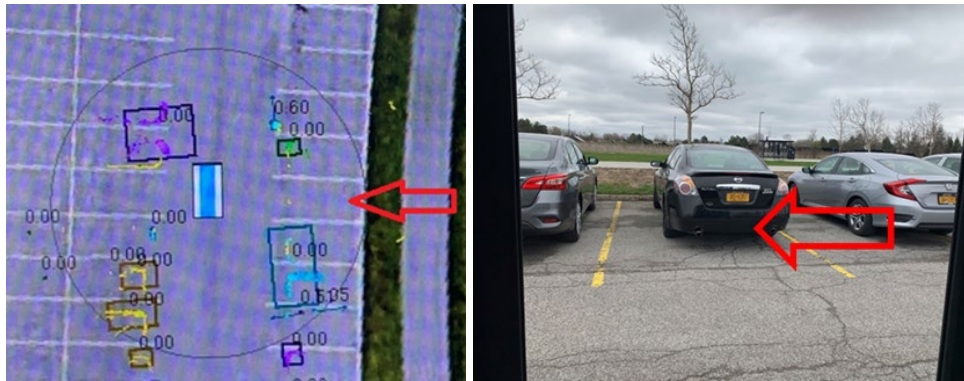
Figure 19. Olli's Onboard Monitor during Front Detection Test



3.3.8.2 The Side Detection Test

The purpose of this test was to assess the ability of the shuttle to detect obstacles located along the side of the vehicle, and to ascertain whether Olli has any blind spots that should be addressed. The testing location was in the same parking lot as the previous test, but a slightly different location was chosen, where there were vehicles parked on both sides of the shuttle. Figure 20a shows the screen capture of the shuttle's onboard monitor during the test, whereas Figure 20b shows the actual situation in reality, where all four parking spots to the right side of Olli were occupied with parked vehicles.

Figure 20. Olli's Onboard Monitor during Front Detection Test



As evident in Figure 20a, it appears that the shuttle failed to detect the vehicle parked in the spot right across from the midpoint of the vehicle (i.e., the black Nissan shown on Figure 20b). For that spot, as the red arrow of Figure 20a shows, the shuttle appears to assume the parking space was unoccupied, which seems to suggest that the shuttle did have a blind spot at its midpoint, where the passenger doors were located. Moreover, it was observed that when a person was standing next to the shuttle's door as it began to drive autonomously, the shuttle started to move first for approximately 1 meter (3.3 ft), and then braked. This seems to indicate that the shuttle initially did not detect the presence of the person, but when the shuttle moved a meter, the person moved out of the shuttle's blind spot and only then did the shuttle detect the person and braked. Another observation worth noting in this context is Olli's response in cases when a person comes out from behind a parked vehicle and moves along the shuttle's side while the shuttle drives normally. In those cases, the team did not observe any emergency braking; instead, Olli would only start to brake after approximately two seconds, which again confirmed the existence of a blind spot at the shuttle's doors.

The main findings of the object detection test can therefore be summarized in the followings. First, the shuttle when parked was able to detect all objects located to the front of the vehicle, with a range equal to at least 20 meters (66 ft). Secondly, Olli appears not capable of distinguishing between a pedestrian and a parked vehicle when the distance between the pedestrian and the parked vehicle was less than 1 meter. Thirdly, Olli seems to have a detection blind spot located on the side of the shuttle at the midpoint, where the passenger doors are located.

3.3.9 Test 12: Static Vehicle Obstruction Test

This test was designed to test the behavior of the shuttle when meeting a static vehicle obstruction. The setup for that test is shown in Figure 21. As can be seen, the test involved three vehicles. The forward vehicle is stopped (representing, for example, a disabled vehicle). The vehicle behind the disabled vehicle is a human-driven vehicle driven by a member of the research team. That vehicle, when it encounters the stopped vehicle, moves into the opposite lane to pass the stopped vehicle. Olli is following the human-driven vehicle. The current test is designed to observe and evaluate the behavior of Olli following the human-driven vehicle, which gets into the opposite lane to pass the disabled vehicle.

The results indicate that Olli was able to detect the stationary vehicle on the route after the leading vehicle had changed lanes, and managed to bring itself to a stop to avoid collision. Olli's stop was reasonably smooth. Table 6 shows the initial speed of Olli, the time it took Olli to come to a full stop, measured from the moment it detected the disabled vehicle after the leading vehicle had changed lanes, and the buffer distance between Olli and the stopped vehicle when Olli had stopped. The results are shown in Table 14.

Figure 21. Static Vehicle Obstruction Test Setup

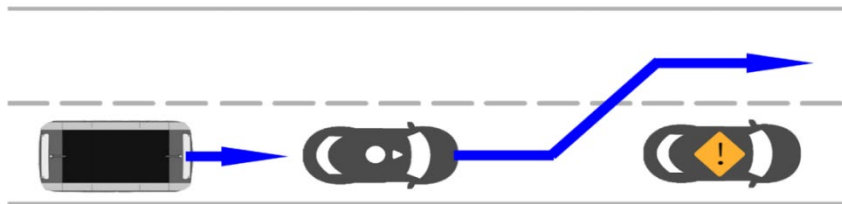


Table 14. Static Vehicle Obstruction Test Results

Test Number	Speed before Decelerating	Distance to the Static Vehicle	Time Taken to Stop
1	5.00 m/s (11.2 mph)	9.5 m (31 ft)	4.7 second
2	4.96 m/s (11.1 mph)	12 m (39 ft)	5 second

As can be seen from Table 14, the results indicate that the shuttle was able to detect the stationary vehicle on the route, after the leading vehicle had changed lanes. The shuttle also managed to bring itself to a stop to avoid collision, and that the shuttle's stop was reasonably smooth. It is worth noting that the time taken to stop was measured from the moment the shuttle detected the stationary vehicle after the leading vehicle had changed lanes, until the shuttle was brought to a full stop.

3.3.10 Additional Physical Testing of Olli in Inclement Weather

Additional physical testing of Olli on UB's CAV Proving Grounds was conducted during the fall of 2019 to ascertain the shuttle's driving behavior in inclement weather (more specifically after a snowstorm). This testing revealed a number of issues. The major challenge encountered was the result of Olli's inability to distinguish between the piles of snow on both sides of UB's CAV Proving Grounds road, and between a real hazard or obstacle that it needed to avoid. Because of this, Olli stopped frequently on its route, and in some cases, manual intervention was needed to override the stop and allow Olli to continue its trip.

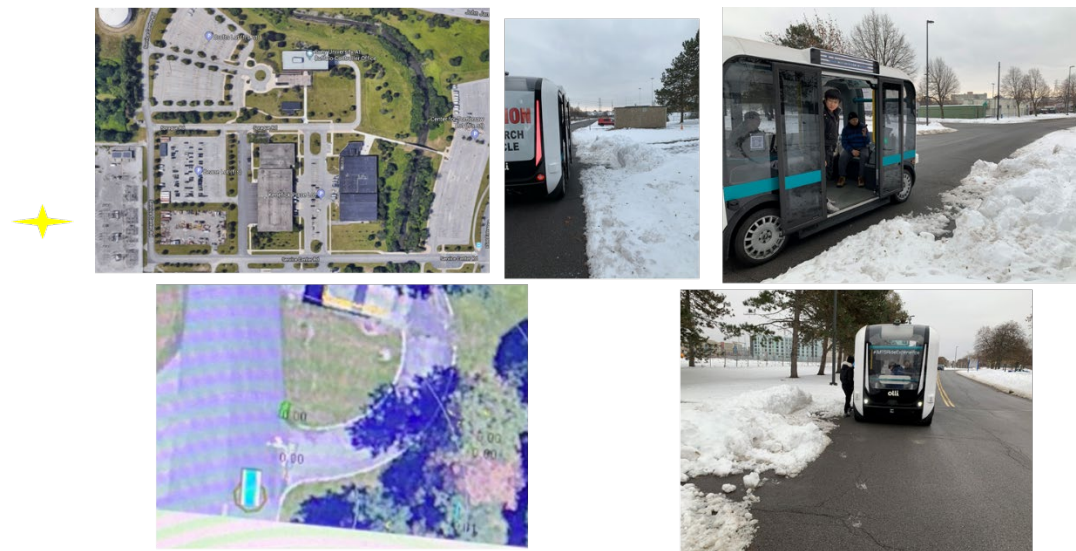
Figure 22 documents the presence and the heights of the snowbanks present on both sides of the Proving Grounds road during Olli's physical testing on November 14, 2019. The Figure shows that the height of the snowbank on the curb varied from about 24 cm to 35 cm. As a result, Olli, when going from the Center for Tomorrow (CFT) Lot to Crofts Hall Lot, it stopped on average more than 10 times, which has the potential to result in rear-end collisions since drivers of human-driven cars following Olli would not expect Olli to stop for no apparent reason. Along the return direction, Olli on average stopped only about three stops. The difference between the number of Olli's stops in the two directions may be explained by the fact that Olli tends to drive closer to the curb in the first direction (i.e., from CFT lot to Crofts Hall), which means that, in this instance, Olli assumed there was a hazard or obstacle more often than there was an one and stop more than it needed.

Figure 22. The Presence and Heights of Snowbanks on the Sides of the Service Road



In one case, because of the snowbanks, Olli came to a full stop and was unable to resume its journey until Olli stewards manually intervened and overrode the shuttle’s system. Figure 23 shows the location of the stop (marked by the yellow asterisk), and the snowbanks present at that location at the time of the test.

Figure 23. Olli’s Permanent Stop as a Result of the Presence of Snowbanks



3.3.11 Olli Power Test

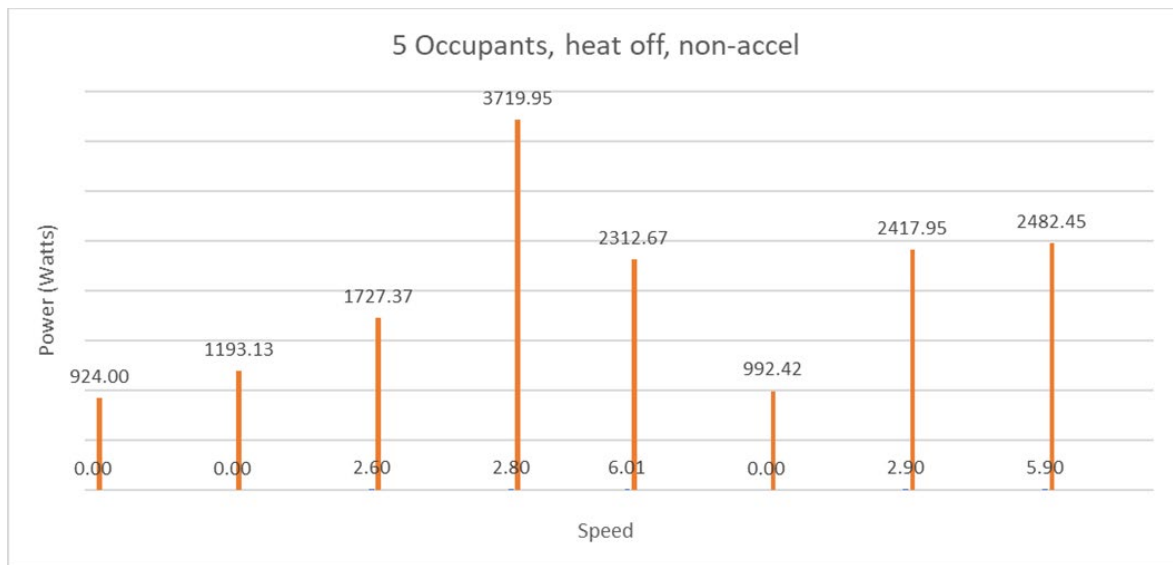
In addition to the safety testing, a power test was also performed on Olli during the month of November 2019. Conditions on that day were as follows: 33-degree Fahrenheit, clear roads, and snow on roadside. As mentioned, Olli performed in an abnormally unstable manner due to the presence of the snowbanks the on roadside, which resulted in frequent stops during route operation. The test measured the speed, voltage (v), current (A), and power (watts). The state of the vehicle was also recorded (see Table 15 for an example). The number of occupants during the test was five passengers.

Table 15. Data Recorded During Olli Power Test

Olli Power Test						
	State	Speed (m/s)	Voltage (v)	Current (A)	Power (Watt)	Batt %
Time	11:46	0.00	385.00	2.40	924.00	
Operation	STOPPED					
Location	CFT LOT					
Occupants	5					
Heat	OFF					
Time	11:46	0.00	384.88	3.10	1193.13	
Operation	STOPPED					
Location	CTF LOT					
Occupants	5					
Heat	ON					

Figure 24 depicts the power consumed during the instances when Olli was not accelerating (i.e., either stopped or driving at a steady speed) with the heat off and five occupants on board. As can be seen, the power consumed during these instances ranged between 924 watts (when Olli was stopped) to 3720 watts (when driving at speed of 2.8 m/s).

Figure 24. Power Consumption—Olli Not Accelerating, Heat Off, and with Five Occupants



3.4 Summary of the Findings from Olli's Safety Testing

This section summarizes and highlights the key findings for the safety test, revealing the capability of the shuttle, its safety, and reliability:

- Olli was able to complete left- and right- turning maneuvers safely and no manual intervention was needed.
- While making a turn, the shuttle was able to accurately, and in a timely fashion, detect any conflicting vehicle or obstruction ahead on its route and to stop by itself.
- The duration in which Olli can complete a turn is a function of the presence or absence of conflicting traffic or any perceived conflict.
- Olli was able to cross a four-way intersection normally without conflicts. In addition, the shuttle would not pass the intersection if there were vehicles present at conflicting directional stop signs, even if those vehicles never moved.
- Olli did not seem to be applying the common traffic rule at four-way stops, which states that the vehicle that arrives first gets to go through the intersection first. Rather, Olli prioritizes safety and would only move when it perceived no other conflicting vehicles at the intersection.
- Olli appears to successfully detect obstacles/pedestrian suddenly appearing in its path and to react in a safe manner by bringing the shuttle to a full stop, even when there was a short distance between Olli and the suddenly introduced obstacle.
- Olli is not oversensitive, and does not overreact, to the presence of pedestrians on the sidewalk, as long as they are stationary or moving parallel to its path (and hence there is no conflict).
- Olli was able to detect any potentially hazardous situation arising from a conflict between Olli and a pedestrian and managed to take safe actions in case the pedestrians ended up interfering with its path.

- Olli was able to follow a front vehicle driving ahead while maintaining its desirable speed. The shuttle also maintained the desirable speed when it preceded other vehicles.
- During the cases, when another vehicle overtook (i.e., passed) Olli, the shuttle generally maintained travel at its design speed. The only exception was when the human-driven vehicle merged back in the original lane too early, leaving a space headway of less than approximately 12 meters (39 ft) between it and Olli. In that case, the shuttle would apply a sudden brake to maintain the safe distance and would then resume traveling at its desirable or design speed.
- The shuttle when parked was able to detect all objects located to the front of the vehicle with a range equal to at least 20 meters (66 ft).
- Olli appears unable to distinguish between a pedestrian and a parked vehicle when the distance between the pedestrian and the parked vehicle is less than 1 meter.
- Olli seems to have a detection blind spot located on the side of the shuttle at the midpoint, where the passenger doors are located.
- Olli managed to detect a stationary vehicle located in front of a human-driven vehicle (i.e., Olli is the third vehicle in line in such a setup), after the human-driven vehicle had changed lanes. The shuttle also managed to bring itself to a stop, in a reasonably smooth manner, to avoid collision.
- The current version of perception and recognition algorithm used for Olli appears to be unable to distinguish between piles of snow located at the sides of the road and a real hazard or obstacle that it needs to avoid. Because of this, Olli stopped frequently when snow was piled to the side of the road.

4 Public Acceptance of Olli and AVs

Despite the numerous likely benefits of vehicle automation previously discussed, the barriers of public acceptance and policy continue to prevent widespread adoption of AVs and other technologies. Many drivers and decision-makers remain wary of full-vehicle autonomy. One of the first widely publicized accidents involving an AV occurred in July of 2015, when a human-driven vehicle struck Google's Waymo, becoming the first injury-causing accident involving an AV. Although the accident was caused by a human driver rear-ending the Google car, some headlines portrayed this as an example of the danger of AVs (Avelar, 2015). Since then, several more collisions involving both partial AVs and fully or highly AVs have occurred, each bringing to the surface questions concerning the safety, reliability, and regulation of AVs.

Despite an accident rate that pales in comparison to human-driven vehicles, the publicity surrounding these collisions shows that the public continues to be wary of vehicle autonomy. While some can overcome this distrust in the technology, there are other secondary issues to using or owning a self-driving vehicle. Many of these concerns surround the issues of liability and cost. The questions of who is responsible, legally, and financially, for an incident involving one or more AVs are still largely unanswered (Albright et al., 2015). Additionally, most drivers who are open to the idea of AVs were unwilling to pay more for the technology (Cole, 2014).

The goal of the research on public reception was thus to determine the factors which contribute to public acceptance of AV technologies in an effort to address the issues. To do so, individuals who rode Olli during the numerous demonstrations performed during the course of this project were surveyed. The survey included a set of questions designed to solicit the views and opinions of Olli's riders regarding AV's safety, reliability, and adoption. Participants in the survey were asked to answer those questions twice, before and after the riding Olli. This was done to gauge the impact and change in opinions after interacting with a fully automated vehicle.

In addition to analyzing the results from the surveys completed by Olli's riders, the research team leveraged two other AV-related surveys which were recently conducted in the Buffalo-Niagara region over the last few years. The first survey was a web survey, open to the travelling public of the Western New York Region. This survey included the collection of demographic information as well as opinions

on fully- and semi-AVs. The second survey was performed for a group who participated in an all-day forum, organized by the Greater Buffalo Niagara Regional Transportation Council (GBNRTC) to learn more about autonomous mobility. They were questioned before and after the workshop to determine how their engagement with the forum affected their opinions.

4.1 Research Tasks in Assessing Public Acceptance of AV

Therefore, to meet the objective of this part of the study, the three surveys (i.e., the Olli surveys, the 2016 web survey, and the AV forum surveys) were analyzed individually and in conjunction with one another to meet the following identified tasks:

- Based on the 2016 web survey, identify what demographic and behavior-related factors affect AV technology acceptance.
- Based on the Olli Ridership Survey, identify how interacting with a live demonstration vehicle affects opinion of and comfort level with AVs.
- Based on the 2019 AV forum results, identify how participation in a workshop such as this impacts familiarity and acceptance of AVs and AV-related topics.
- Identify related questions in the web and AV forum surveys and compare the results to analyze how opinions have changed over time.
- Identify related questions in the Olli Ridership and AV forum surveys and compare the results to determine the relative effectiveness of a workshop and a live demonstration.

The discussion regarding the surveys will be organized as follows. First, background information about the Olli demonstrations performed in this project as well as the AV forum organized by GBNRTC will be provided. Subsequently, the methodology section will explain how the survey results were analyzed and interpreted. Next, the results section will present the outcomes of these analyses. Finally, the concluding section will summarize the results and the recommendations stemming from them.

4.2 Olli's Demonstrations

The research team conducted several demonstrations to various groups and solicited feedback and opinions regarding AVs as discussed later in this section. A partial listing of those demonstrations performed is provided:

- The first official demonstration of Olli took place on August 9, 2018 as part of the fourth Annual Symposium on Transportation Informatics held at UB and the official kick-off of Olli's testing, as previously discussed in section 2.1.5.
- The research team demonstrated Olli to attendees of the 2018 Annual Meeting of the Niagara International Transportation Technology Coalition (NITTEC), which was hosted by NITTEC in the fall of 2018 at UB's Center for Tomorrow.

- The research team demonstrated Olli, as well as the University's Lincoln MKz automated driving platform to the National Science Foundation Director, Dr. France Cordova, on April 3, 2019.
- The team demonstrated Olli and the Lincoln MKz to New York State (NYS) Senator Tim Kennedy and his staff on April 19, 2019. During that visit, the research team discussed with Senator Kennedy our desire to allow for expanded testing of Olli on the North Campus, to provide useful data which can guide rulemaking and regulation of Connected and Automated Vehicle (CAV) testing in New York State. Following the visit, Senator Kennedy introduced a bill to NYS Senate asking New York State Department of Transportation (NYSDOT) to undertake a traffic study to identify and designate roads on the North Campus that can be designated as private roads for the purposes of CAV testing, and hence, may be exempt from the regulations imposed on public roads. A similar bill has also recently been introduced to NYS Assembly by Assemblywoman Karen McMahon. This will be further discussed later in the report.
- The team also demonstrated Olli, and UB's Lincoln MKz, to the former Assistant Director of NSF Computer and Information Science and Engineering (CISE) program, Dr. Jim Kurose, and to the State University of New York (SUNY) Vice Chancellor, Dr. Grace Wang, during their visit to UB on June 4, 2019.
- The research team demonstrated Olli, and UB's Lincoln Mkz, to an eight-member delegation from the Rochester-Genesee Regional Transit Authority on July 11, 2019 and discussed with them our project and the lessons we are learning from the testing and the demonstrations.
- We demonstrated Olli to high school students attending UB's National Summer Transportation Institute (NSTI) on August 6, 2019.
- We held our Fifth Annual Symposium on Transportation Informatics at UB on August 8, 2019. The Symposium featured a strong and diverse group of speakers and participants.¹
- The team worked with the Greater Buffalo Niagara Transportation Council to support their efforts in holding the AV forum that sought to seek public opinion on the use of AV in Western New York. Olli was demonstrated at that event as well.
- The research team also demonstrated Olli to a NYS Bar Association Committee studying some of the legal implications of CAV to support the work of that committee on August 20, 2019.
- The team demonstrated Olli at UB's Sustainable Living Fair on September 23, 2019. Olli attracted a lot of attention from both UB's students, staff, and faculty, who were quite interested in the implications of Olli's technology on sustainability, especially given that Olli is electric and 3-D printed.

¹ Details about the Symposium can be found at the 5th Annual Symposium on Transportation Informatics, <http://www.buffalo.edu/transinfo/news-and-events/events/annual-symposium/2019.html>

- The team demonstrated Olli at the Greater Buffalo Niagara Regional Transportation Council (GBNRTC) workshop titled Smart Mobility in Buffalo Niagara: Working Regionally to Integrate Technology into our Transportation System. The workshop was held on October 1, 2019 at the Center for Tomorrow on UB’s North campus. Attending the workshop were representatives from local governments, transportation providers, businesses, industry, and community-based organizations.

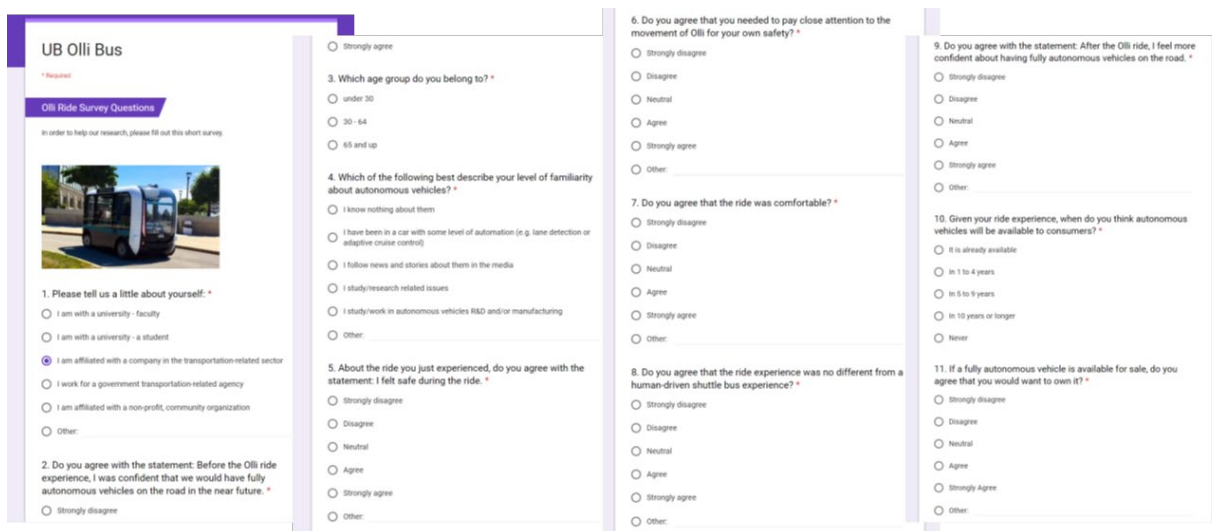
4.3 Olli’s Riders Survey

As previously mentioned, this project designed a simple survey to be administered to riders who rode Olli to gauge their perception of the shuttle’s safety, comfort, and whether the drive felt different from a human-driver vehicle. The survey also tries to gauge the level of confidence of participants in anticipating the near deployment of AVs. The survey can be checked by clicking on the QR Code shown in Figure 25. The different sections of the survey are shown in Figure 26.

Figure 25. QR Code for Taking Olli’s Ride Survey



Figure 26. Various Screens of Olli’s Ride Survey



4.4 NITTEC Web Survey, 2016

This survey included questions about demographic information, driving habits, and opinions regarding AV-related issues (safety, cost, liability, etc.). The target population of the survey was the general public of the Buffalo metro area. This group was selected to minimize bias toward any one age, income, or lifestyle group. In addition, Buffalo was used as the target location due to the University at Buffalo’s strong community connections which were expected to lead to an enthusiastic response to the survey.

The survey was distributed through collaboration with NITTEC, which serves as the region’s traffic management center and disseminates real-time travel information to the drivers. The Driving Technology Survey was linked on NITTEC’s public facing website, which is the primary way members of the public obtain travel information and is visited thousands of times per day. The survey was also shared via the coalition’s social media pages.

Over the six-week duration of the survey (April 13 to May 23, 2016) 233 individual responses were received. Responders ranged in age from 20 years old to older than 60 with an average age of approximately 45. The gender breakdown was 84.5% male, 15.5% female.

4.5 GBNRTC AV Forum, 2019

The Greater Buffalo Niagara Regional Transportation Council (GBNRTC) and its member agencies hosted a community forum about driverless vehicles on Saturday, August 3, 2019 at the University of Buffalo's Hayes Hall. This was part of a series of forums around the world organized by Arizona State University's Consortium for Science, Policy & Outcomes (CSPO) and the Paris-based Missions Publiques to bring public perspectives into ongoing discussions around automated vehicle (AV) development and regulation (Consortium for Science, Policy & Outcomes at ASU, 2019). The daylong forum brought together 97 members of the general public. These individuals were nonexperts with varying levels of familiarity with automated technologies. The input from the forum will be shared with local, national, and international transportation planners to help inform future policies and projects.

GBNRTC is Erie and Niagara County's Metropolitan Planning Organization (MPO), which is a cooperative association of area governments and agencies working together to make decisions on the future of transportation in Buffalo Niagara. GBNRTC's Moving Forward 2050 long-range transportation plan aims to advance AVs in the Buffalo Niagara region in ways that benefit our residents in terms of mobility and safety, and to attract visitors and new investment (GBNRTC and UB Regional Institute, 2018).

Arizona State University's CSPO is part of the Expert Citizen Assessment of Science & Technology network of organizations focused on using deliberative decision-making to support more informed, inclusive, and desirable policy outcomes. In the past this network has done projects with many different partners including the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the Department of Energy. This current project, Our Driverless Futures, is part of an international project coordinated by the French organization Missions Publiques. The project aims to learn about citizens' hopes, dreams, and fears regarding automated mobility. In total, forums were held in 18 cities across nine different countries in North America, Europe, and Asia.

The forum consisted of six sessions, each addressing various topics about automated mobility. Forum participants, totaling of 13 groups, were seated at tables with approximately seven to eight others and a trained facilitator. Short videos produced by Mission Publique introduced concepts before each session. During the session participants completed individual and group worksheets, which were anonymized with

a unique ID number. Trained data entry volunteers simultaneously entered data from these worksheets to show some results to participants at end of the day. To encourage a broad range of attendees, the global AV forum organizers provided \$100 stipends to participants. During the lunch break participants had the opportunity to view the team’s self-driving shuttle, Olli.

While the survey collected a wide variety of data, our focus in this research project is only on the impact a session such as this can have on acceptance and perception of AVs. Specific focus was placed on the forum’s ability to influence participants knowledge and opinions on driverless mobility and related topics. Additionally, while demographic data was collected from the participants, it was anonymized and delinked from the responses to the other survey questions. This meant the analysis conducted with the 2016 survey could not be duplicated.

4.6 Surveys Analysis Methodology

4.6.1 Before and After Comparison for Olli and AV Forum Surveys

The Olli ridership survey and the AV forum presented the opportunity to gauge how the experiences of riding Olli (in case of the Olli surveys) or having attended the forum (in case of the AV forum surveys) may have changed the participants’ thoughts on AVs. To determine if the difference before and after each was statistically significant, a t-test was used for those who rode the Olli, as the sample size was less than 30, and a Z-test was used for the AV forum participants, which included a sample size of greater than 30. The methodology for each is presented in equation 1 and 2 (Roess et al., 2014).

Equation 1

$$t = \frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2} \cdot \frac{1}{\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}}}$$

Equation 2

$$z_d = \frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{\frac{s_1^2}{N_1} + \frac{s_2^2}{N_2}}}$$

t = the t distribution equivalent to the difference between data sets

z_d = the standard normal distribution equivalent to the difference between data sets

\bar{x}_1 and \bar{x}_2 represent the means of the two data sets

s_1 and s_2 represent the standard deviations of the two data sets

N_1 and N_2 or n_1 and n_2 represent the sizes of the two data sets

The t distribution or standard normal distribution are used to determine the probability that a value greater than t, or less than z_d occurs. If this probability is determined to be less than 5% or greater than 95%, respectively, then the difference between the two data sets is statistically significant.

4.6.2 Binary Choice Analysis for 2016 Web Survey

The responses to questions in the survey conducted in 2016 can generally be grouped into binary outcomes (e.g., agree or disagree, would own an AV or would not). While ordered choice models could also be used to model these variables, the smaller sample sizes of the studies do not generally lend themselves to accurate results in this case (Ben-Akiva and Lerman, 1985).

In binary logit models, the probability of one alternative outcome (i) is given as the probability that the difference between the two alternative systematic utility functions (V) is greater than or equal to the difference in the utility errors (ϵ), where the difference in errors is assumed to follow a normal distribution.

Equation 3
$$P_n(i) = \Pr (\epsilon_{jn} - \epsilon_{in} \leq V_{in} - V_{jn})$$

The systematic utility is composed of independent variables (x) and coefficients (β).

Equation 4
$$V_{in} = \beta'_1 x_1 + \beta'_2 x_2 \dots$$

The creation of successful discrete choice models is an iterative process with the objective of including the most significant variables that improve the predictive capabilities of the model. A variable's significance is determined by its p-value, which ranges from 0 to 1, with values closer to 0 being more significant. In the creation of these models, variables were included with p-values less than 0.1, but some exceptions were made for variables which greatly improved the model. A model's predictive ability is measured by its McFadden Pseudo R^2 value, ranging from 0 to 1, where higher values indicate better models. Well-fitting binary choice models generally have R^2 values between 0.1 and 0.3. However, even a model that does not meet this criterion can still provide insights as to which independent variables have significant relationships with the dependent variable (Ben-Akiva and Lerman, 1985).

For this analysis, the following variables shown in Table 16 were extracted from the survey results.

Table 16. Web Survey Modelling Variables

Variable	Definition	Mean	Std. Dev.
ACC	1 if involved in no accidents within the last year, 0 otherwise.	0.893	0.310
AGE	1 if older than 50, 0 otherwise.	0.356	0.480
AGE2	1 if older than 40, 0 otherwise.	0.635	0.482
BOTH	1 if respondent preferred both audio and visual warnings, 0 otherwise.	0.781	0.414
COMM	1 if daily commute is greater than 30 minutes, 0 otherwise.	0.185	0.389
COMM2	1 if daily commute is greater than 15 minutes, 0 otherwise.	0.562	0.497
EDU	1 if respondent had a Bachelor's degree or higher, 0 otherwise.	0.588	0.493
ENJOY	1 if respondent stated they enjoy driving, 0 otherwise.	0.785	0.411
FULL	1 if respondent has a full-time job, 0 otherwise.	0.888	0.316
INC	1 if income is more than \$100,000 per year, 0 otherwise.	0.326	0.470
INC2	1 if income is more than \$150,000 per year, 0 otherwise.	0.060	0.238
LONG	1 if respondent makes long trips at least a few times per month, 0 otherwise.	0.532	0.500
LONG2	1 if respondent makes long trips at least once a month, 0 otherwise.	0.275	0.447
MALE	1 if male, 0 otherwise.	0.846	0.362
MARR	1 if married, 0 otherwise.	0.657	0.476
UND	1 if respondent understood the benefits of AVs, 0 otherwise.	0.502	0.501
URBAN	1 if respondent lives in an urban area, 0 otherwise.	0.103	0.305
VIOL	1 if respondent ticketed for a violation within the last year, 0 otherwise.	0.030	0.171

4.6.3 Ordered Choice Analysis for AV Survey

While the response variables in the AV forum survey could be converted into binary variables, they were, in fact, ordered in nature (e.g., ranging from Strongly Disagree to Strongly Agree). Given this, such responses can also be modeled using ordered logistic models. These are a specific form of multinomial choice model in which the choices have an ordinal nature. The choice is made not by maximizing utility across all alternatives, but rather when the first local optimum is reached. The probability of an individual choosing an alternative (i) is equal to the probability that the utility of proceeding to the next alternative (U_{in}^C) is less than the utility of stopping at the current alternative (U_{in}^S).

Equation 5
$$P_n(i) = \Pr (U_{1n}^C \geq U_{1n}^S \cap U_{2n}^C \geq U_{2n}^S \cap \dots \cap U_{i-1,n}^C \geq U_{i-1,n}^S \cap U_{in}^S \geq U_{in}^C)$$

As with the binary choice models, the p values and R squared values are used to create ordered choice models (Ben-Akiva and Lerman, 1985). For this analysis, the following variables shown in Table 17 were extracted from the survey results.

Table 17. AV Forum Survey Modelling Variables

Variable	Statement	Mean	Std. Dev.
RES	It's clear to me how the forum results will be used.	0.276	0.450
TRB	I had trouble understanding or following the discussion today.	0.552	0.500
PROD	The event used my time productively.	0.402	0.493
PRES	I felt pressure to agree with something that I wasn't sure about.	0.345	0.184
BACK	The background information and videos about driverless mobility were unbiased.	0.333	0.474
INFL	I'm expecting that the results will influence the thinking and actions of expert decision-makers.	0.414	0.495
MOD	The facilitator(s) effectively moderated discussions.	0.609	0.491
COMP	Nothing during the forum compromised the validity of the discussions and my group's final plan (e.g., no biasing of 3rd parties, discussions were inclusive and fair).	0.540	0.501
UND	I understood the information in the background material.	0.460	0.211
FUT	It's beneficial to continue discussions such as the Our Driverless Futures forum in the future.	0.690	0.465
TASK	The assigned tasks were clear to me.	0.402	0.493
SAT	I am fully satisfied with the Our Driverless Futures Forum.	0.460	0.501
OPP	All participants had the same opportunities to voice their opinion.	0.644	0.482
CONT	I was able to contribute my ideas and views during general discussions.	0.724	0.450
LOG	Logistical arrangements for the event (travel, accommodation, meals, etc.) were appropriate.	0.529	0.502
SHOW	Forum results should be shown to expert decision-makers.	0.621	0.488

4.7 Results

4.7.1 Task 1—NITTEC Web Survey Analysis, 2016

4.7.1.1 Survey Summary

Responses to survey questions in the 2016 NITTEC web survey regarding AV use were found to be consistent with results found in a significant portion of previous studies. For example, in the NITTEC's survey, a minority of those surveyed (specifically 39%) said they would ride in an AV, with even fewer saying they would prefer to own an AV to a standard vehicle (specifically 26%), even if cost were not a factor. Concerns with AV safety and liability were also evident, with most drivers stating a need to be able to take control of an AV at any time (85% of those surveyed), as well as be free of any legal or monetary consequences in the event of a collision (81%). In addition, only half of the respondents indicated an understanding of the benefits of AVs. The percentage of those surveyed who either agreed or strongly agreed with each statement regarding AVs is provided in Table 18.

Table 18. 2016 NITTEC Web Survey Results

Statement	Percent Agreeing
I would ride in a self-driving vehicle.	39%
If cost were not a factor I would consider owning a self-driving vehicle.	42%
If cost were not a factor, I would prefer a self-driving vehicle to a standard vehicle.	26%
For me to consider riding in a self-driving vehicle, I would need to be able to take control of the vehicle at any time.	85%
For me to consider riding in a self-driving vehicle, I would need to be free of all liability in the event of an accident.	81%
For me to consider riding in a self-driving vehicle, I would need to be compensated for all damages in the event of an accident.	73%
I understand the potential safety and operational benefits offered by self-driving vehicles.	50%

4.7.1.2 Binary Choice Results

For each of the six statement responses modeled in the NITTEC’s Web Survey, participants were asked to choose how much they agreed with each statement from the options: strongly disagree, disagree, neutral, agree, and strongly agree. To identify the factors influencing the responses to these statements, binary variables were created, and binary choice models were developed, as was previously mentioned in section 4.6.2. Specifically, the following four binary variables (1) RIDE (for the response to whether the respondent would ride in an AV), (2) NCOSTOWN (for the response to the question of owning an AV if cost were not a factor), (3) NCOSTPRF (for the response to the question of preferring an AV over a traditional vehicle if cost were not a factor), and (4) CONTROL (for requiring the ability to manually control the AV at any time) were created by setting responses of agree and strongly agree to 1 and all others to 0. For the variables LIAB (capturing the response to requiring freedom from any liability in case of an accident), and COMP (for the response of requiring to be compensated for any damage) the responses were set as strongly agree only and 0 for all others, due to how respondents chose either of the disagreeing options. Table 19 shows the resulting models for RIDE, NCOSTOWN, NCOSTPRF, CONTROL, LIAB, and COMP, including the Restricted Log Likelihood (RLL) McFadden Pseudo R² (MPR2), and the coefficient and p-value for each independent variable (shown in parenthesis). Below the team summarize some of the important insights gained from the models developed (for the definition of the variable, please refer back to Table 16).

Table 19. AV Use and Cost Binary Choice Models

I would ride in a self-driving vehicle. (RIDE)						
RLL	MPR ²	MALE	UND	ENJOY	COMM	
-154.95	0.2903	-1.1619 (0.0014)	2.7476 (0.0000)	-1.5991 (0.0000)	0.8323 (0.0495)	
If cost were not a factor, I would consider owning a self-driving vehicle.”(NCOSTOWN)						
RLL	MPR ²	MALE	UND	ENJOY		
-158.86	0.2196	-0.5893 (0.0650)	2.2679 (0.0000)	-1.3372 (0.0001)		
If cost were not a factor, I would prefer a self-driving vehicle to a standard vehicle. (NCOSTPRF)						
RLL	MPR ²	UND	ENJOY	INC	VIOL	MARR
-133.96	0.3355	3.1562 (0.0000)	-2.5531 (0.0000)	-1.0452 (0.0178)	1.4349 (0.0028)	0.6496 (0.1113)
For me to consider riding in a self-driving vehicle, I would need to be able to take control of the vehicle at any time. (CONTROL)						
RLL	MPR ²	ENJOY	LONG	AGE		
-100.29	0.1203	1.6360 (0.0000)	0.7747 (0.0209)	0.7340 (0.0831)		
For me to consider riding in a self-driving vehicle, I would need to be free of all liability in the event of an accident. (LIAB)						
RLL	MPR ²	ENJOY	INC	VIOL		
-149.58	0.0404	0.8686 (0.0000)	-0.6415 (0.0227)	-1.4800 (0.0851)		
For me to consider riding in a self-driving vehicle, I would need to be compensated for all damages in the event of an accident. (COMP)						
RLL	MPR ²	INCOME	MARR	AGE3	VIOL	COMM2
-149.73	0.0714	-0.8644 (0.0050)	0.5958 (0.0382)	0.5510 (0.0345)	-1.9951 (0.0739)	-0.5137 (0.0319)

As can be seen from Table 19, the resulting models showed that male participants were less likely to ride in or own an AV, those with higher incomes were less likely to prefer an AV regardless of cost, and those who enjoyed driving were less likely to agree with all three (i.e., riding in an AV, consider owning AV, and preferring an AV). Conversely, those with longer commutes were more likely to ride in an AV, those who were married or had recently been ticketed for a driving violation were more likely to prefer AVs, and those who understood the benefits of AVs were more likely to agree with all three. These relationships make sense, and all models have sufficient McFadden Pseudo R² values.

With respect to needing to control the vehicle, to be free from liability, and to be compensated for all damage in an accident, those with higher incomes or who had recently been ticketed for a driving violation were less likely to be concerned with legal or monetary liability, while those with longer commutes were less likely to be concerned with monetary compensation. In contrast, older individuals and those who made long trips more frequently were more likely to want to be able to take control of the AV, older or married individuals were more likely to be concerned with monetary compensation. Those who enjoyed driving were found to be more likely to want to take control and concerned with the liability issues of AVs. These relationships are once again logical in terms of the signs of the coefficients. While only the R^2 value for CONTROL is sufficient for a well-fitting model, the relationships found in the other models still provide valuable information.

4.7.2 Task 2—Olli Ridership Survey Analysis

4.7.2.1 Survey Summary

Following their experience with the Olli shuttle, participants were asked a series of questions. The results to the questions relevant to the ride itself are provided in Figure 27, Figure 28, Figure 29, and Figure 30. The responses showed that while most riders felt the experience was different from riding in a human-driven shuttle (72%), a majority still felt that the ride was comfortable (76%). Additionally, while most participants felt that the experience was safe (88%), over a quarter of the riders stated that they needed to pay attention to their surroundings (e.g., hanging onto handholds, bracing for stops, etc.) to feel safe (28%).

Figure 27. Responses to: I felt safe during the ride

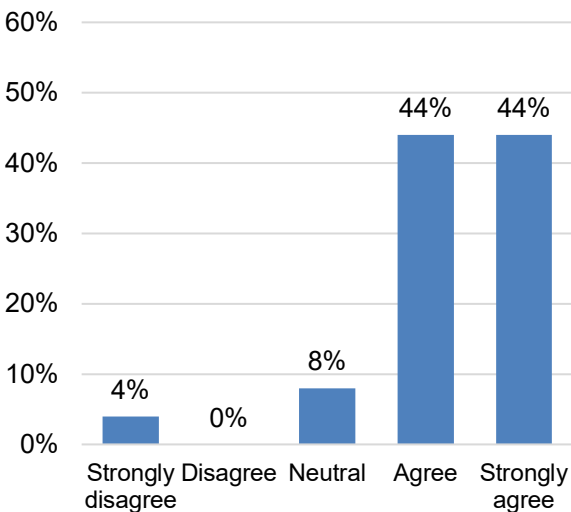


Figure 28. Responses to: I needed to pay close attention to the movement of Olli for my own safety

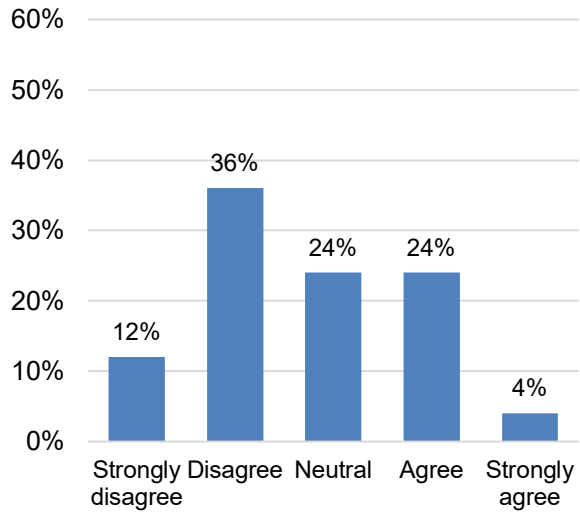


Figure 29. Responses to: The ride was comfortable

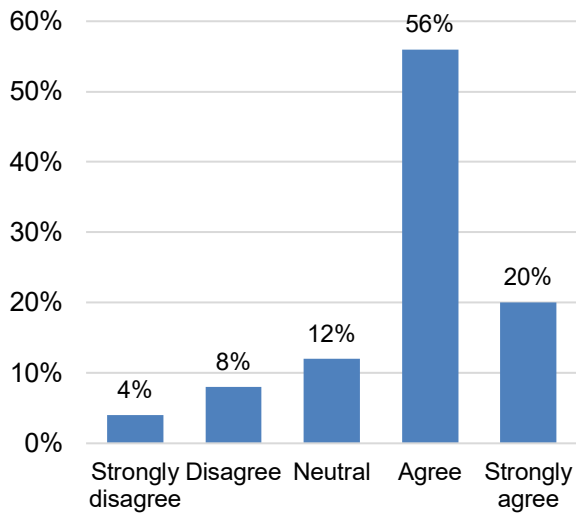
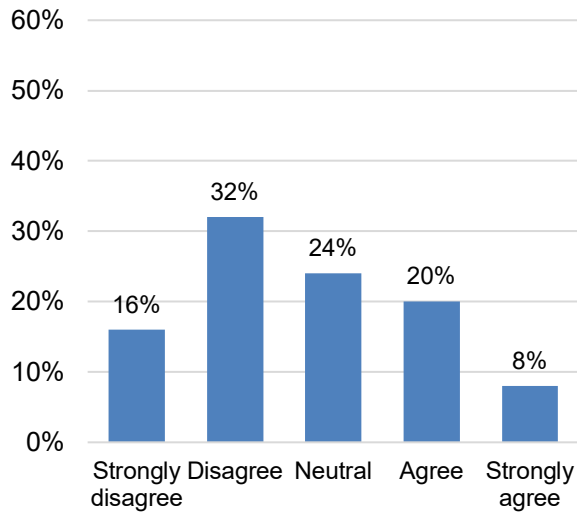


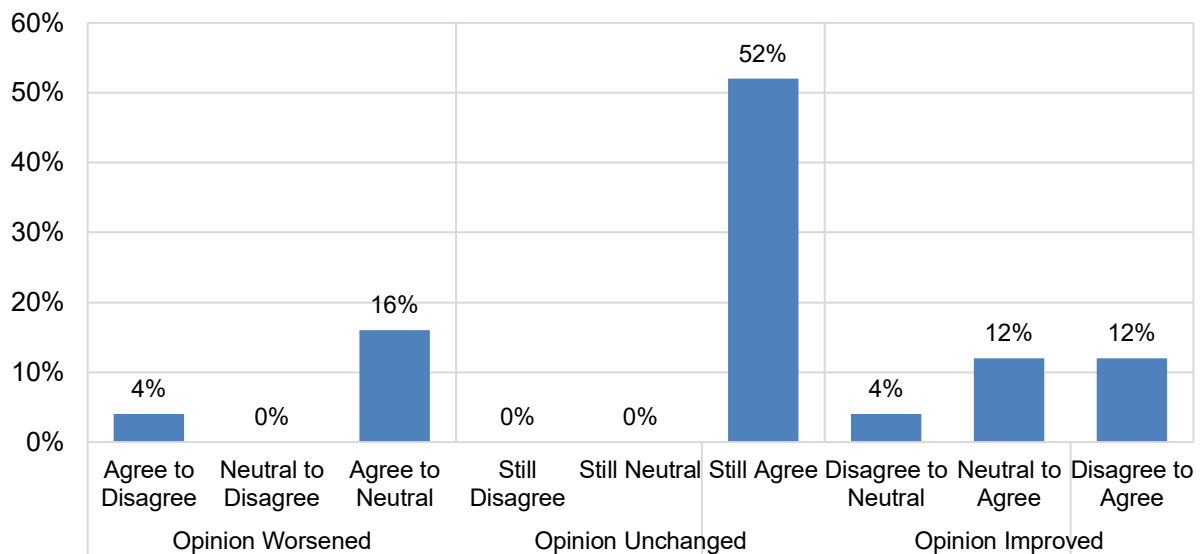
Figure 30. Responses to: The ride was no different than a human-driven shuttle bus



4.7.2.2 Before and After Comparison

Riders were asked about their confidence in the future of AVs before and after riding in the Olli shuttle. Figure 31 shows how opinions changed after the experience. As can be seen, a majority (52% of participants in the survey) still agreed to the promise of AV future. In addition, the percentage of those whose opinion moved in a positive direction or whose confidence in AV future improved after the ride (28%) was more than the percentage of opinions moving in a negative direction (20%).

Figure 31. Shifts in Response to: I am confident that we will have fully automated vehicles on the road in the near future



After performing the t-test, a t-value of 2.48 was found, with a degree of freedom of 24. This indicates that it can be said with approximately 98% certainty that the difference between the responses before and after is statistically significant. Furthermore, when a correlation analysis was performed on the responses, it was found that confidence in the future of AVs was positively correlated with feeling comfortable and safe during the Olli ride, with correlation coefficients of 0.56 and 0.60, respectively.

4.7.3 Task 3—2019 AV Forum Analysis

4.7.3.1 Forum Summary

Some questions answered by the AV forum participants were asked twice: first before the presented information and again after the conclusion of the forum. Table 20 shows the statements with which participants were asked to state the degree they agreed or disagreed as well as the number who chose each response option before and after the forum. Additionally, participants were also asked to what level they agreed with a series of questions about the effectiveness of the forum itself in influencing knowledge and opinions of driverless mobility and related issues. The percentage of responders who agreed with each statement is presented in Table 21.

Table 20. AV Forum Responses to Driverless Mobility Topics

Question		Strongly Disagree	Disagree Somewhat	Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
I am familiar with the topic of Driverless Mobility.	Before	6	3	8	15	23	21	11
	After	0	0	2	3	11	30	41
In comparison with other technological issues, Driverless Mobility is not the most important to me.	Before	7	11	13	32	18	4	2
	After	9	12	5	26	14	13	8
I know the issues, arguments and perspectives related to Driverless Mobility adoption.	Before	8	10	15	17	24	12	1
	After	0	0	3	4	25	30	25
I have sufficient information to make solid judgments about Driverless Mobility.	Before	15	6	16	24	14	9	3
	After	0	4	3	10	24	23	23
I feel like I know what should be done about transportation issues in my region.	Before	7	4	11	24	18	9	14
	After	2	3	4	13	22	15	28
I think that driverless vehicles will replace human-driven vehicles in the future.	Before	1	8	4	20	18	13	23
	After	3	6	5	17	15	19	22
I believe that most car crashes are caused by human error.	Before	0	2	0	7	18	26	34
	After	1	0	2	8	10	28	38
I believe that human-driven vehicles are currently safer than driverless vehicles.	Before	6	4	11	37	7	12	10
	After	3	6	5	30	14	15	14
I would ride in a driverless vehicle.	Before	2	1	10	21	20	13	20
	After	6	3	5	20	17	14	22
I don't trust driverless vehicles.	Before	10	10	17	23	16	5	6
	After	15	13	16	23	9	5	6
Automation of tasks currently performed by humans is a concern for me.	Before	9	6	7	24	15	16	10
	After	9	9	6	14	17	20	12
As a driver, I would feel safe sharing the road with a driverless vehicle.	Before	3	4	14	30	14	12	10
	After	7	3	10	21	22	16	8
As a pedestrian or cyclist, I would feel safe sharing the road with a driverless vehicle.	Before	9	8	19	29	12	5	5
	After	14	7	11	23	16	10	6
I believe driverless vehicles should be restricted to their own lanes.	Before	6	3	7	30	16	8	17
	After	9	8	7	25	10	13	15
I believe a human attendant should be present in all types (freight, buses, taxis, etc.) of driverless vehicles.	Before	3	8	4	28	17	9	18
	After	7	5	3	10	20	14	28
Driverless vehicles will cause more problems than they will solve.	Before	10	11	12	41	8	1	4
	After	10	18	18	26	6	5	4
I would be okay with driverless vehicles collecting my location information so remote operators could manage the system.	Before	6	5	17	27	16	10	6
	After	14	7	12	23	10	10	11
Driverless vehicle safety should be regulated.	Before	0	1	1	8	8	11	58
	After	0	0	0	2	5	9	71
I believe that driverless vehicles would reduce traffic congestion.	Before	9	2	4	33	12	9	18
	After	8	3	6	18	14	16	22
As a driver, I would feel safe sharing the road with a driverless freight vehicle (18-wheeler).	Before	10	10	18	28	12	3	6
	After	16	12	8	18	15	9	9
Driverless vehicles won't reduce traffic-related deaths and injuries.	Before	17	13	11	37	5	1	3
	After	12	25	12	24	9	2	3
Driverless vehicle test areas should be clearly marked with signs that make people aware of the activity.	Before	1	3	5	11	13	14	40
	After	1	2	2	10	9	16	47

Table 21. AV Forum Effectiveness Results

Question: Participation in the forum...	Percent Agreeing
...significantly increased my knowledge about driverless mobility.	86.2%
...significantly influenced my opinion about driverless mobility.	64.4%
...significantly influenced my knowledge of transportation issues.	67.8
...significantly influenced my opinion about transportation issues.	63.2%
...increased my understanding of different perspectives than my own on driverless mobility.	92.0%
...motivated me to follow the development of driverless mobility	79.3%
...motivated me to search for more information on driverless mobility	72.4%
...significantly influenced my knowledge of information collected to operate driverless systems.	79.3%
...significantly influenced my opinion about information collected to operate driverless systems	69.0%
...made me feel that my voice is relevant for driverless mobility experts and policy makers	74.7%

4.7.3.2 Ordered Choice Analysis of AV Forum Results

After examining the forum results, an ordered choice analysis was carried out to determine what factors (of those listed in Table 17 affected participants' responses to the questions concerning survey effectiveness shown in Table 21Table 21. The dependent factors were originally collected as ordered responses (from strongly disagree to strongly agree) but have been converted to binary variables (1 if somewhat agree, agree, or strongly agree, 0 otherwise) to create better fitting models. Table 22 shows the resulting models for the ten survey effectiveness questions, including the McFadden Pseudo R^2 (MPR^2), the coefficient and the p-value for each independent variable (the top and bottom values in the table, respectively).

Table 22. AV Forum Modelling Results

Participation in the forum significantly increased my knowledge about driverless mobility.								
MPR²	Const.	RES	TRB	PROD	PRES			
0.0775	2.1768 (0.0000)	0.7123 (0.0165)	-0.7848 (0.0027)	0.4933 (0.0597)	-1.0279 (0.1104)			
Participation in the forum significantly influenced my opinion about driverless mobility.								
MPR²	Const.	RES	TRB	BACK	INFL			
0.0587	2.4276 (0.0000)	0.5949 (0.0460)	-0.7777 (0.0053)	0.4711 (0.1254)	0.5402 (0.0378)			
Participation in the forum significantly influenced my knowledge of transportation issues.								
MPR²	Const.	RES	MOD	TRB	BACK	COMP	UND	FUT
0.1519	2.3259 (0.0000)	0.8245 (0.0054)	0.6995 (0.0093)	-1.6159 (0.0000)	0.6691 (0.0351)	0.8823 (0.0031)	1.0536 (0.0831)	-0.5544 (0.0630)
Participation in the forum significantly influenced my opinion about transportation issues.								
MPR²	Const.	RES	TRB	BACK	COMP	INFL		
0.1247	1.9302 (0.0000)	0.5551 (0.0600)	-1.4685 (0.0000)	0.6576 (0.0374)	0.6796 (0.0070)	0.5451 (0.0400)		
Participation in the forum increased my understanding of different perspectives than my own opinion on driverless mobility.								
MPR²	Const.	TRB	COMP	PRES	FUT			
0.1366	2.1244 (0.0000)	-0.4402 (0.0921)	0.9426 (0.0014)	-1.6035 (0.0100)	0.6976 (0.0206)			
Participation in the forum motivated me to follow the development of driverless mobility.								
MPR²	Const.	TASK	TRB	SAT				
0.0786	1.6051 (0.0000)	0.8968 (0.0068)	-0.7926 (0.0080)	0.6613 (0.0249)				
Participation in the forum motivated me to search for more information on driverless mobility.								
MPR²	Const.	TASK	OPP	CONT	TRB	INFL	PRES	
0.1956	2.0977 (0.0000)	2.0615 (0.0000)	-1.0630 (0.0108)	1.0542 (0.0181)	-1.2714 (0.0001)	0.5903 (0.0293)	-1.1699 (0.0805)	
Participation in the forum significantly influenced my knowledge about information collected to operate driverless mobility systems.								
MPR²	Const.	RES	TRB	BACK	COMP	INFL		
0.1441	1.5089 (0.0000)	0.5955 (0.0487)	-1.1847 (0.0001)	0.6342 (0.0462)	0.8194 (0.0015)	0.6046 (0.0245)		
Participation in the forum significantly influenced my opinion about information collected to operate driverless mobility systems.								
MPR²	Const.	RES	TRB	BACK	LOG	SAT	COMP	
0.1108	1.6398 (0.0000)	0.6530 (0.0302)	-0.7092 (0.0161)	0.5634 (0.0867)	-0.6543 (0.0386)	1.0169 (0.0014)	0.5763 (0.0321)	
Participation in the forum made me feel that my voice is relevant for driverless mobility experts and policy makers.								
MPR²	Const.	TRB	BACK	PROD	LOG	COMP	SHOW	INFL
0.2368	2.2650 (0.0000)	-0.6736 (0.0226)	0.9603 (0.0052)	0.8775 (0.0128)	-0.7924 (0.0228)	1.1253 (0.0008)	-0.5747 (0.1038)	1.5920 (0.0000)

Across the models developed, some relationships between the independent variables and measures of forum effectiveness were clear. First, every model included participants' ability to understand the discussion as a significant variable (the variable TRB); those who stated they had trouble understanding this were less likely to agree with any of the statements (with the coefficient of the variable TRB displaying a negative sign in all models as can be seen from Table 22). In particular, participants who stated they had trouble following the discussion were 50% less likely to state that the forum increased their knowledge about driverless mobility, 51% less likely to state that it influenced their opinion about transportation issues, and 55% less likely to state that it motivated them to search for more information on driverless mobility.

Another significant variable in several of the models, especially those concerned with the forum's ability to impact participants' knowledge and opinions on AVs, was the clarity with which they understood how the results would be used. Those who stated they agreed with the statement were 45% more likely to state the forum increased their knowledge of driverless mobility and between 18–21% more likely to say it influenced both their knowledge and opinion of transportation issues and data collection. Feeling that the background information provided was unbiased was also influential on forum effectiveness. Those who felt the information was true were between 14–23% more likely to state the forum increased their knowledge of transportation issues and data collection, influenced their opinion on driverless mobility, transportation issues and data collection, and felt their voice was relevant to experts and policy makers.

Participants who stated they expected forum results to influence decision makers were more likely to say that participation influence their opinion about driverless mobility and transportation issues by 17% and 19%, respectively. They were also 26% more likely to search for more information on driverless mobility, 20% more likely to state participation increased their knowledge of data collection, and 33% more likely to feel their opinion was heard.

Clarity of the tasks at hand was influential in motivating participants to continue expanding their knowledge after the study. Those who felt the assign tasks were clear were 38% more likely to follow the development of driverless mobility and 90% more likely to search for additional information on their own. Finally, feeling that discussions which occurred in the forum were not compromised by outside factors (e.g., 3rd party bias, exclusiveness, or unfairness within the group) impacted participants' responses to several of the forum effectiveness questions. Those who felt the discussion was uncompromised were 21% more likely to state that the forum improved their

knowledge of transportation issues and 28% more likely to say the same about data collection in driverless mobility systems. They were also 23% more likely to state that their opinion on transportation issues—and 19% more likely to state that their opinion of data collection—was affected. Lastly, they were 24% more likely to state they felt their opinion would be heard by decision makers and 55% more likely to say that their understanding on other perspectives related to these topics was improved.

4.7.3.3 Before and After Comparison

For the questions asked before and after the forum presented in Table 20, a before and after analysis was conducted to see if there were statistically significant changes in the responses. Table 23 shows the average change (responses from strongly disagree to strongly agree were assigned the values 1 through 7) and the confidence interval (the likelihood that the difference is statistically significant).

Table 23. AV Forum Before and After Results

Question	Avg. Change	Confidence Interval
I am familiar with the topic of Driverless Mobility	1.45	>99.9%
In comparison with other technological issues, Driverless Mobility is not the most important to me.	0.37	96.4%
I know the issues, arguments and perspectives related to Driverless Mobility adoption.	1.92	>99.9%
I have sufficient information to make solid judgments about Driverless Mobility.	1.84	>99.9%
I feel like I know what should be done about transportation issues in my region.	0.94	>99.9%
I think that driverless vehicles will replace human-driven vehicles in the future.	0.03	58.0%
I believe that most car crashes are caused by human error.	0.05	63.0%
I believe that human-driven vehicles are currently safer than driverless vehicles.	0.41	99.0%
I would ride in a driverless vehicle.	-0.07	66.9%
I don't trust driverless vehicles.	-0.31	93.9%
Automation of tasks currently performed by humans is a concern for me.	0.13	73.8%
As a driver, I would feel safe sharing the road with a driverless vehicle.	0.08	68.5%
As a pedestrian or cyclist, I would feel safe sharing the road with a driverless vehicle.	0.14	75.7%
I believe driverless vehicles should be restricted to their own lanes.	-0.24	91.4%
I believe a human attendant should be present in all types (freight, buses, taxis, etc.) of driverless vehicles.	0.44	99.2%
Driverless vehicles will cause more problems than they will solve.	-0.16	80.7%
I would be okay with driverless vehicles collecting my location information so remote operators could manage the system.	-0.19	80.1%
Driverless vehicle safety should be regulated.	0.37	99.9%
I believe that driverless vehicles would reduce traffic congestion.	0.31	97.4%
As a driver, I would feel safe sharing the road with a driverless freight vehicle (18-wheeler).	0.13	78.8%
Driverless vehicles won't reduce traffic-related deaths and injuries.	-0.03	59.2%
Driverless vehicle test areas should be clearly marked with signs that make people aware of the activity.	0.30	97.5%

If a 95% confidence interval is used, then the changes which occurred before and after the survey primarily dealt with participants' knowledge of driverless mobility and transportation issues. Additionally, more participants felt certain regulations should be in place during AV implementation, such as the presence of a human attendant. While more participants felt AVs would reduce traffic congestion, more also felt they were not yet as safe as human-driven vehicles.

In some cases where no significant change was observed, it was a result of participants' already positive opinions of AVs. For example, the percentage of responders who felt AVs would cause more problems than solve or would fail to reduce traffic related deaths remained relatively low, shifting from 15% to 17% and 10% to 16%, respectively. Most participants also remained confident that most car crashes are a result of human error (shifting from 90% to 87%).

In other areas, the forum failed to affect participants' opinions on related topics with no significant change found in responses to whether AVs could replace human-driven vehicles in the future or whether they would ride in a driverless vehicle. The survey results revealed that just under two-thirds of participants agreed to either question (i.e. whether AVs would replace human-driven vehicles and whether the participants would ride in an AV), and that was the case both before and after the forum.

4.7.4 Task 4—Web Survey versus AV Forum Comparison

4.7.4.1 Difference Comparison

This task compared the responses to similar questions from the 2016 Web Survey and AV Forum. The 2016 survey responses only included five values (strongly agree, agree, neutral, disagree, and strongly disagree), whereas the forum responses had seven values (strongly agree, agree, somewhat agree, neutral, somewhat disagree, disagree, strongly disagree) and were grouped into five categories, with strongly agree and agree, and strongly disagree and disagree combined. The different population sizes prevent the use of a t or z test; thus, the conclusions drawn from the comparison are purely qualitative. Table 24 shows the average values for these questions and Figure 32 and Figure 33 show the distributions of the responses.

Table 24. Web Survey versus AV Forum Results

I am familiar with the topic of Driverless Mobility.		
Web Survey	Forum (Before)	Forum (After)
3.38	3.70	4.74
I would ride in a self-driving vehicle.		
Web Survey	Forum (Before)	Forum (After)
3.02	3.80	3.76

Figure 32. Responses to: I am familiar with the topic of driverless mobility

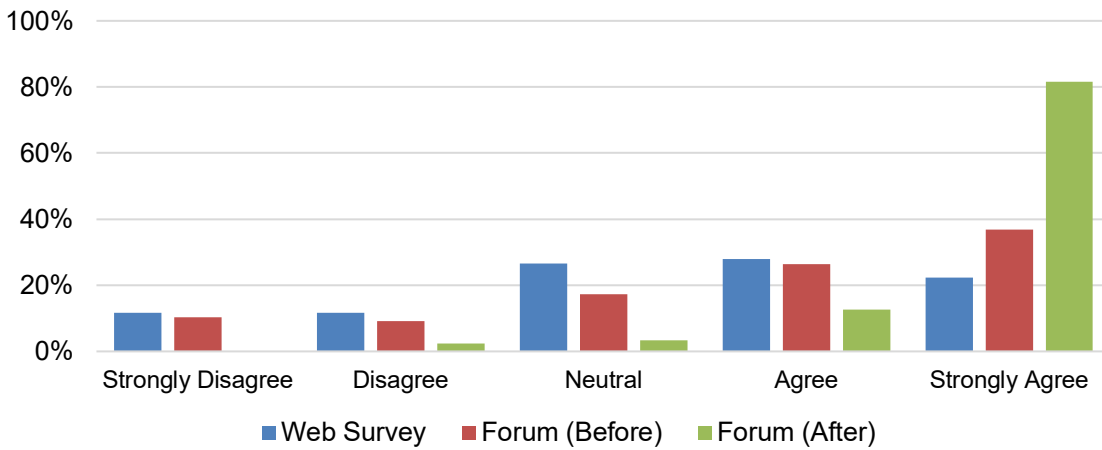
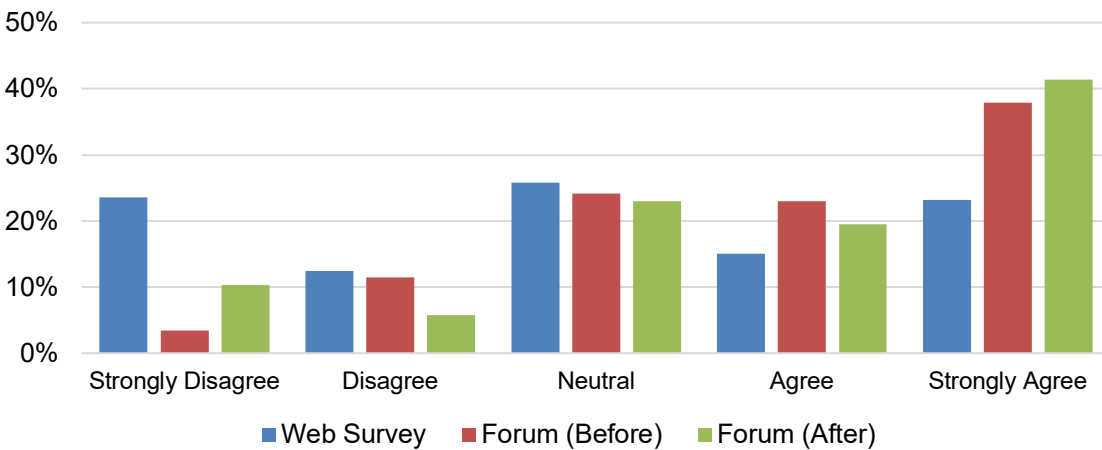


Figure 33. Responses to: I would ride in a self-driving vehicle



In general, it seemed that participants in the 2019 forum were slightly more familiar with driverless mobility and more willing to ride in an AV than those who completed the 2016 survey. This may be a result of changing attitudes of the general public over time or linked to the type of person who is willing to participate in an all-day forum on the topic instead of a brief online survey. Also, while the average response of forum participants who would ride in an AV decreased slightly (from before participating in the forum to after the forum), it still exceeded the average from the 2016 web survey.

4.7.5 Task 5—Olli versus AV Forum Comparison

4.7.5.1 Difference Comparison

This task compared the responses to similar questions from the Olli Ridership Survey and the AV Forum. As with Task 4, the forum responses were grouped into five categories, with strongly agree and agree, and strongly disagree and disagree combined to make comparison possible. Also, as was the case with Task 4, the different population sizes prevent the use of a t or z test; thus, the conclusions drawn from the comparison are purely qualitative. Table 25 shows the average values for these questions and Figures 34, 35, 36, and 37 show the distribution of the responses.

Table 25. Olli Ridership Survey versus AV Forum Results

I think that driverless vehicles will replace human-driven vehicles in the future. (Before Olli Ride/AV Forum)		
Olli	Forum	
3.8	3.68	
I am familiar with the topic of Driverless Mobility.		
Olli	Forum (Before)	Forum (After)
2.96	3.88	4.88
I think that driverless vehicles will replace human-driven vehicles in the future. (After Olli Ride/AV Forum)		
Olli	Forum	
4.04	3.92	
I feel that driverless vehicles are generally safe. (After Olli Ride/AV Forum)		
Olli	Forum	
4.24	3.32	

Figure 34. Responses to: I think that driverless vehicles will replace human-driven vehicles in the future

Before Olli Ride/AV Forum

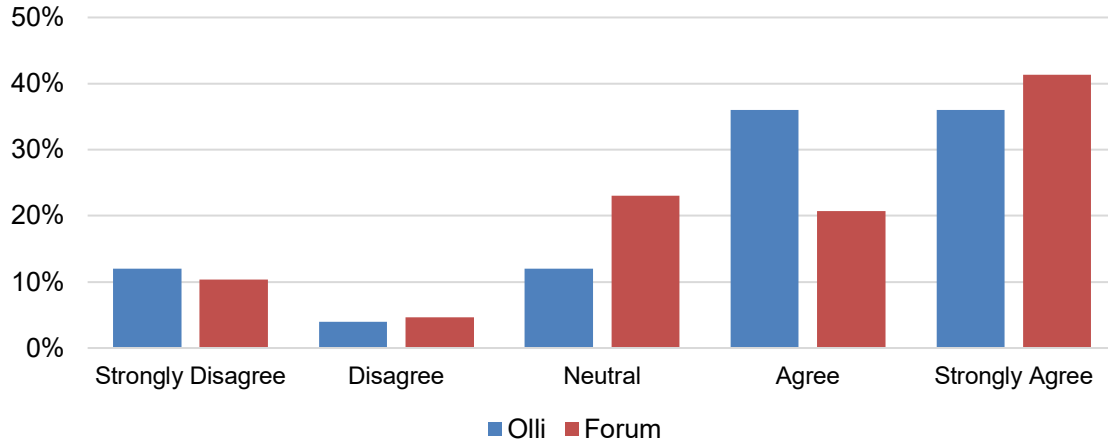


Figure 35. Responses to: I am familiar with the topic of Driverless Mobility

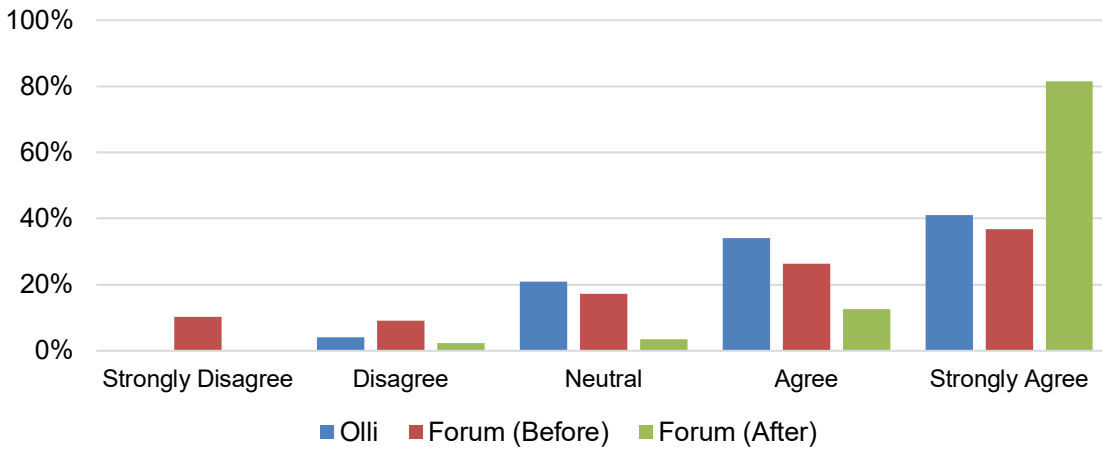


Figure 36. Responses to I think that driverless vehicles will replace human-driven vehicles in the future

After Olli Ride/AV Forum

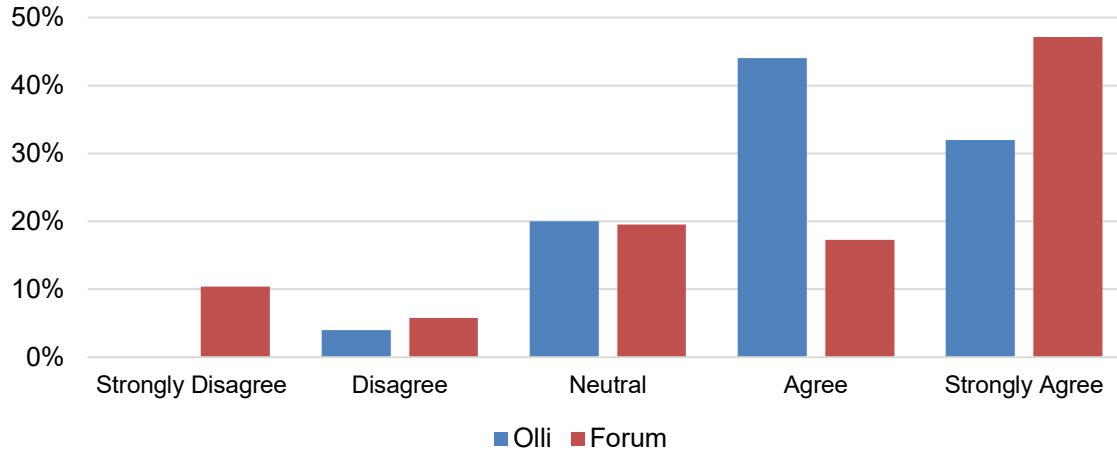
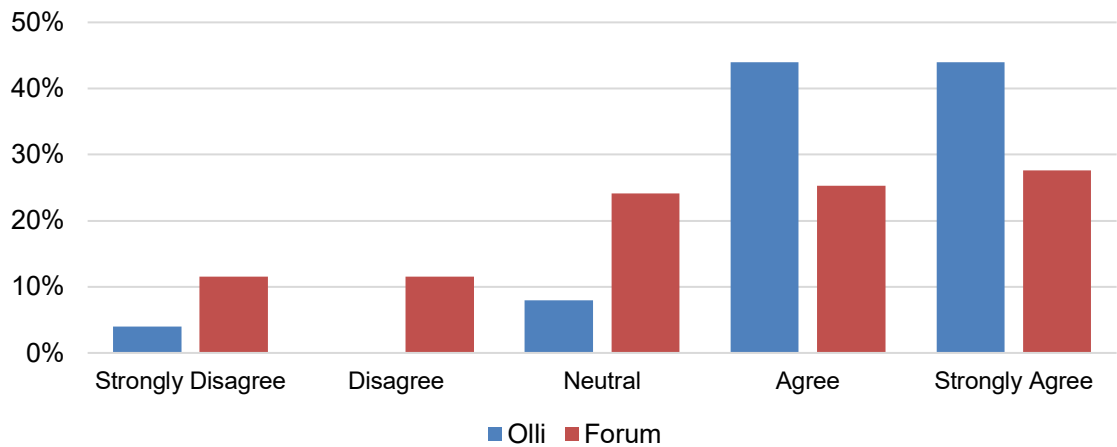


Figure 37. Responses to: I feel that driverless vehicles are generally safe

After Olli Ride/AV Forum



While the significance of the difference between Olli riders and survey participants on the outlook of the future of AVs was unclear, some other responses stood out. The average response from riders indicated they felt AVs were safer than their forum counterparts, even though they were much less familiar with driverless mobility. This may point to the fact that their ride experience was positive and helped either maintain or improve their positive attitude toward the safety of AVs.

4.8 Conclusions and Recommendations

The primary objective of this part of the study was to determine the factors that contribute to public acceptance of AV technologies in an effort to address them. To accomplish this, riders of Olli were surveyed, and their responses, along with responses to two other surveys conducted in the region, were analyzed in the following five tasks:

- Based on the 2016 Web Survey, identify what demographic and behavior-related factors affect AV technology acceptance.
- Based on the Olli Ridership Survey, identify how interacting with a live demonstration vehicle affects one's opinion of and comfort level with AVs.
- Based on the 2019 AV Forum results, identify how participation in a workshop such as this impacts one's familiarity and acceptance of AVs and AV-related topics.
- Identify related questions in the 2016 Web and the 2019 AV Forum surveys and compare the results to analyze how opinions have changed over time.
- Identify related questions in the Olli Ridership and AV Forum surveys and compare the results to determine the relative effectiveness of a workshop and a live demonstration.

Below, we summarize the main conclusions drawn from outcomes of the aforementioned five tasks. Based on these conclusions, we also provide some recommendations on the importance of public engagement in the introduction to AVs.

4.8.1 Addressing Public Concerns Regarding AVs from 2016 Survey (Task 1)

- The majority of those surveyed are uncomfortable with AVs, with only 39% stating they would ride in one and 26% saying they would prefer them to a standard vehicle.
- A significant majority of those surveyed cited issues with control and liability, with many stating they would need to be able to take over control of the vehicle (85%), or be free of any legal (81%) or monetary (73%) consequences of an accident in an AV.
- Those who stated they understood the benefits of AVs were more likely to say they would ride in, own, and prefer an AV, while those who stated they enjoyed driving were less likely to agree with all three statements. Responders who enjoyed driving were also more likely to say they needed the ability to take control of an AV and be concerned with legal and monetary liability.
- In general, those who were recently ticketed for driving violations were more accepting of AVs and less concerned about control and liability issues.
- Those with longer commutes were more open to AV usage and unlikely to be concerned with liability, but also showed a need for optional manual control.
- Older users, as well as those with higher incomes, tended to be averse to AV usage and ownership; older individuals were also more likely to be concerned with control and liability, while those with higher incomes were less likely to have these associated concerns.
- Race, education, and type of employment were not found to have a significant impact on how individuals responded to any of these statements.

4.8.2 Olli Ridership Before and After (Task 2)

- Following the interactive experience with the autonomous shuttle, participants were found to be more likely to agree with the statement: I am confident that we will have fully automated vehicles on the road in the near future.
- The responses most highly correlated with this increase in confidence were those who felt comfortable and safe during the ride.

4.8.3 Impact of the AV Forum (Task 3)

4.8.3.1 Forum Results

In relation to the ability of the forum to influence participants' knowledge and opinions on the topics discussed, responses showed that a majority felt the event was effective in all regards. A particularly strong majority felt that their participation:

- Increased their understanding of different perspectives than their own opinion on driverless mobility (92%).
- Significantly increased their knowledge about driverless mobility (86%).
- Significantly influenced their knowledge about information collected to operate driverless mobility systems (79%).
- Motivated them to follow the development of driverless mobility (79%).

4.8.3.2 Ordered Choice Analysis

The outcomes of the ordered choice models revealed several relationships between how the participants rated forum effectiveness and various other factors. Key findings included the following:

- Overall, it proved important to not only ensure participants understood the information and tasks, but also develop an understanding of how the results will be used; participants who agreed that these were true were more likely to state their knowledge and opinions of driverless mobility and related topics were improved by the event.
- Ensuring that participants felt the information was unbiased, discussion was uncompromised, and findings would influence decision-makers were also vital. Those who felt this was the case not only felt that their knowledge and opinions were impacted but were also more likely to state they understood other perspectives on the topics discussed and would follow these topics on their own.

4.8.3.3 Before and After Comparison

Following participation in the event:

- Participants felt more familiar with driverless mobility and were more concerned with driverless mobility, relative to other technological issues.
- Participants understood issues, arguments, and perspectives related to driverless mobility.
- Participants have sufficient information to make judgments about driverless mobility and feel they know what should be done about transportation issues in their region.
- No significant change was observed in participants' confidence that AVs will replace human-driven vehicles in the future or willingness to ride in a driverless vehicle.

4.8.4 Comparison of Forum Participants to 2016 Survey and Olli Riders (Tasks 4 and 5)

- On average, forum participants were more familiar with driverless mobility and more willing to ride in an AV than those who completed the 2016 survey.
- The average response from riders indicated they felt AVs were safer than their forum counterparts even though they were much less familiar with driverless mobility.

4.8.5 Overall Recommendations

- Providing the public with a clear understanding of AVs in terms of safety and operations is key to gaining their trust in the technology.
- A forum such as the one described here is an effective tool in improving public knowledge of AVs.
- Future forums should ensure that the information provided is not only clear, but also fair and unbiased to better meet the event's goals; ensuring that discussions are uncompromised and that participants feel their input is valued are also important.
- While useful in improving public understanding, the forum by itself was not effective in convincing participants that AVs are a safe alternative to a human-driven vehicle; to achieve this, interaction with a functioning AV such as the Olli is significantly more effective.

5 AV and Public Policy Research

This section documents one of the three key objectives of the current project: the research of public policy changes needed to allow AVs to be driven on public roads in New York State. Today, in the U.S., there are approximately 1,400 AVs that are or have been tested on public roads out of the over 263 million total vehicles registered in the U.S. The sustainable deployment of AVs on public roads is limited by the requirement for AVs to adhere to Federal Motor Vehicle Safety Standards (FMVSS) that were promulgated in 1966 long before AVs were contemplated. Despite State-level legislative action since 2011 to enable the testing of AVs on public roads, the supremacy of FMVSS remains. The Buffalo Principles outline four critical tenets to support continued advancement of AVs in NYS and across the U.S. at the State and local level until effective action is taken at the federal level. To address the fundamental difference of AVs, policy makers need to develop a new legal and regulatory regime based on system-controlled vehicles to replace the incompatible FMVSS, universally constructed for human operation and human control of vehicles.

5.1 Introduction

5.1.1 Initial AV Deployments and Legislation

Industry observers mark the first Defense Advanced Research Projects Agency (DARPA) Grand Challenge held on March 13, 2004 as the beginning of a new epoch in AV Technology research and development for civilian applications. The DARPA Grand Challenge was a first-of-its-kind race to foster the development of “self-driving ground vehicles.” That day, 15 automated vehicles competed in the Grand Challenge, but none completed the 142-mile course. The second DARPA Grand Challenge held on October 8, 2005 consisted of 195 teams. This time, five automated vehicles completed the 132-mile course, and the Stanford University team finished first to claim the \$2 million prize. In 2007, DARPA held the Urban Challenge, its third competition, in which the Carnegie Mellon University team placed first out of six finishers based on the successful completion of assigned tasks within the allotted the six hours while following California driving rules.

Many individuals involved in these DARPA competitions went on to lead the numerous university, industry, and government efforts currently underway across the AV technology ecosystem to develop and advance the technology necessary to enable AVs and realize the many potential benefits. The most prominent of these, first incubated within Google (which in a corporate reorganization Alphabet in 2015) became the start-up known as Waymo. When the project first launched in Google in 2009, it was led by

Sebastian Thrun, the former director of the Stanford Artificial Intelligence Laboratory and a member of the Stanford team that won the 2005 DARPA Grand Challenge. With substantial commercial gains at stake, numerous high-profile start-up companies, and eventually several corporate initiatives within established automotive manufacturers, joined Waymo in the race to develop and commercialize AV technology. Dozens of further efforts emerged in universities and research institutions across the country, each seeking to make distinct technical contributions to the advancement of science and industry.

This burst of activity and accompanying media interest suggested the United States was poised to usher in an age when AV would soon share public roads with regular vehicles. This caused lawmakers at the federal and State level to begin to contemplate how to authorize and regulate this new technology to support safe deployment on the public roadways. In 2011, hoping to reap benefits from being the first to host Google's testing of their new project, the state of Nevada enacted AB 511 to authorize AV testing. Nevada was the first state to take legislative action but hardly the last. Soon thereafter, 28 other states enacted AV technology-related legislation in the similar hope of spurring technology, industry, and jobs. Eager to spur innovation, enhance national competitiveness, and realize the potential benefits of AV technology, the Federal Government introduced guidance and other initiatives to support the industry.

As previously mentioned in this report, AV technology has the potential to solve intractable mobility issues, from unsnarling suburban traffic congestion and mobility-on-demand for the aged and sick, to accident-free highways, and even a solution to climate change due to reduced fossil fuel usage (Picolli et al., 2018). In a future where AV are ubiquitous and fully integrated with regular traffic, some researchers have written about the implications of reduced car ownership (Standage, 2018) or the impact on real estate (CBRE Research, 2018), while others consider what to do with newly freed-up parking space (Nourinejad et al., 2018).

However, despite the perceived benefits, and despite the degree of investment, research, and legislative activity around the development of AV technology, few AV deployments have occurred in the 16 years since the first DARPA Challenge. In fact, of the roughly 263 million cars on the road in the U.S. today, only approximately 1,400 are AV. An AV without a human operator present at all times and without human controls are unable to be registered and thus illegal to drive on public roads, resulting in technological advances that have been modest at best, and their availability to the general public remains distant.

Only rigorous, scientific methods will achieve the technological breakthroughs that are required to bring AV technology and their corresponding benefits to fruition. Specifically, advances occur when solutions are rigorously tested through a combination of computer modeling and simulation (M&S), closed-track testing in a controlled environment, open-road testing through real-world deployments and thorough data analysis. This approach has proven effective in identifying attributes that define the Operational Design Domain (ODD), advancing event detection and response (OEDR) capabilities, and assessing failure modes and failure mitigation strategies. However, while private-industry efforts involving computer modeling and simulation and closed-track testing are plentiful and well-documented, the paucity of testing of AV technology via deployments on public roads indicates a key bottleneck impeding technological progress. Without more testing on public roads, the technology will not advance to the level of capabilities required for the safe deployment of AV on a more widespread and fully commercialized basis.

This is the context in which the current project was undertaken. The project sought to investigate the nature of AV technology through hands-on execution coupled with rigorous observation and data collection in order to produce findings that advance the state of the industry by producing repeatable and scalable methods to overcoming technical and other barriers. This section of the report presents the findings from for Task 3 of the project pertaining to AV public policy research. It is organized into seven sub-sections that each discuss a critical facet of public policy and lessons which emanate from, or were applicable to, deploying the Olli Bus on public roads.

Current federal regulations inadvertently pose insurmountable challenges to AV technology deployments on public roads. Our own experience overcoming the challenges of deploying the Olli Bus on public roadways in New York State corroborates this fact. Hence, this section of the report focuses on the regulatory barriers that impede the testing and real-world AV technology deployments necessary to achieve technological progress, not the technology itself. Through our introduction of the Buffalo Principles in this report, we define a tangible path toward enabling the sustainable, real-world AV-technology deployments, which are the key to achieving such breakthroughs.

5.1.2 New York State AV Legislation Activities Prior to Current Project

Approximately seven months before the official start of the project, on April 9, 2017, Chapter 55 of the laws of 2017, which included Sections 1 to 3 of Part FF, enacted the New York State Demonstration and Testing of AV Technology legislation. The legislation defined that "AV technology" will mean the hardware and software that are collectively capable of performing part or all dynamic driving

tasks on a sustained basis, and that "Dynamic Driving Task" will mean all of the real-time operational and tactical functions required to operate a vehicle in on-road traffic, excluding the strategic functions such as trip scheduling and selection of destinations and waypoints. This marked the first time in the history of New York State in which AVs are mentioned in law. Since its initial adoption, the New York State Demonstration and Testing of AV Technology legislation has been slightly amended in Part H of Chapter 58 of the laws of 2018 and Part M of Chapter 58 of the laws of 2019 and is currently set to expire on April 1, 2021.

Prior to the initial adoption of this legislation, our public policy research team (consisting of Joah Sapphire of UB GDG IoT, John Wolff of GDG IoT and Steve Madra of GDG IoT) helped to inform the Office of the New York State Governor, members of the New York State Legislature and senior staff of the Governor, the State Legislature and several State agencies, including NYSDOT on AV technology by organizing and hosting two real-world demonstrations of an AV built by Southwest Research Institute (SwRI) as part of their Mobile Autonomous Robotics Technology Initiative (MARTI). The first demonstration was held on June 9, 2016 in the parking lot of the Gideon Putnam Hotel as part of the Intelligent Transportation Society of New York's Annual Meeting in Saratoga Springs, NY. The second was held on June 24, 2016 in the parking lot of Davis Hall on UB North Campus. Both demonstrations were funded by NYSDOT and University Transportation Research Center (UTRC) Region 2. MARTI consists of a set of state-of-the-art perception and autonomy algorithms, which were designed to be independent of specific platform/vehicle, actuator, computing platform, and sensor selection.

These demonstrations provided our team with first-hand knowledge and insight into the initial responses and reactions of several elected officials and senior staffers to viewing and experiencing AV technology. Overall, our observation was that the reaction was positive and that there was general agreement that safe testing and deployment of AV technology would be beneficial to the New York State. The demonstrations in Saratoga Springs and Buffalo served to garner the support necessary for the legislation passage of the New York State Demonstration and Testing of AV Technology. No other official demonstrations of AV technology funded by NYSDOT and UTRC Region 2 were organized or held for State elected officials and senior staffers prior to the April 9, 2017 enactment of that legislation. The lessons learned from the demonstrations in Saratoga Springs and Buffalo also helped to inform the writing of this report.

5.1.3 State AV Legislation

According to the National Conference of State Legislatures (NCSL), the New York State, with its New York State Demonstration and Testing of AV Technology legislation, has joined 28 other states² in enacting AV testing legislation (National Conference of State Legislatures, 2020). In a following section of this report, we review and summarize previously enacted AV legislation from twenty states and executive orders from ten Governors that we believe best inform the project.

As we noted previously, the first state to enact AV related legislation was Nevada. In 2011, the state of Nevada enacted AB 511 which “authorizes operation of AVs and a driver’s license endorsement for operators of AVs.” The legislation defines an “AV” and “directs state Department of Motor Vehicles (DMV) to adopt rules for license endorsement and for operation, including insurance, safety standards and testing” (National Conference of State Legislatures, 2020). As a result, a Toyota Prius retrofitted by Google with AV capabilities was licensed by the Nevada DMV in May of 2012 and tested on public roadways in Nevada later that year. This signified the first licensing of an AV in the U.S. and ushered in the era of testing of AVs on public roadways.

5.1.4 United States Department of Transportation AV Guidance

On June 11, 2019, at the Uber Elevate Summit in Washington, D.C., U.S. Department of Transportation (U.S. DOT) Secretary Elaine Chao offered that currently more than “1,400 self-driving cars, trucks, and other vehicles are in testing by more than 80 companies” across the U.S. There is no official count of all the individual AVs that have been tested on public roadways in the U.S. since Google conducted its first test in May 2012 (Etherington, 2019). In addition, there is no public information available that summarizes all the current AV tests that are being conducted nationwide in terms of individual vehicles or vehicle miles traveled (VMT). Nonetheless, Secretary Chao’s count of 1,400 AVs tested equates to only 0.0005 percent of the 263,610,219 total registered vehicles on the roadways in the U.S. (Office of Highway Policy Information, 2017). In seven years since the first test of an AV in the state of Nevada, the small quantity of AVs tested on public roadways today represents an extremely low-penetration rate and a substantial lack of progress in advancing the adoption of AVs.

² The states of Alabama, Arkansas, California, Colorado, Connecticut, Florida, Georgia, Hawaii, Illinois, Indiana, Kentucky, Louisiana, Maine, Michigan, Mississippi, Nebraska, Nevada, North Carolina, North Dakota, Oregon, Pennsylvania, South Carolina, Tennessee, Texas, Utah, Virginia, Vermont, Washington and Wisconsin.

To date, the U.S. Congress has not passed any legislation that defines AVs or authorizes AV testing. At the federal level, starting in September 2016, the U.S. DOT has published non-binding voluntary guidance on AV technology. The first guidance document was entitled: Federal Automated Vehicles Policy: Accelerating the Next Revolution in Roadway Safety. In September 2017, U.S. DOT released Automated Driving Systems 2.0, A Vision for Safety, followed by Automated Vehicles 3.0, Preparing for the Future of Transportation in October 2018. Most recently, in January 2020, U.S. DOT published Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0. In a coming section of this report, we provide a summary of U.S. DOT AV guidance published from 2016 to 2020 and highlight sections most relevant to the project.

Due to the fact that U.S. DOT has only offered voluntary guidance on AV technology at the federal level, the 29 states that have enacted state-level AV legislation since 2011 must all adhere to the laws, rules, and regulations promulgated by Congress and implemented by federal agencies per the Supremacy Clause of the U.S. Constitution. Article VI, Clause 2 of the U.S. Constitution establishes that the U.S. Constitution, and federal laws made pursuant to it, constitute the "supreme Law of the Land" and thus take priority over any conflicting state laws. Of particular note is that in the AV legislation enacted by the states, any executive order signed by a governor, or any other binding rule or regulation promulgated at the state level related to AV testing on public roads, all explicitly or implicitly require that in order for an AV to be registered by the state to be tested on public roads, it must adhere to all applicable Federal Motor Vehicle Safety Standards (FMVSS).

The New York State Demonstration and Testing of AV Technology legislation in part FF of charter 55 of the laws of 2017, Section 1. a. states:

Such demonstrations and tests shall take place in a manner and form prescribed by the commissioner of motor vehicles including, but not limited to a requirement that a natural person holding a valid license for the operation of the motor vehicle's class be present within such vehicle for the duration of the time it is operated on public highways; a requirement that the motor vehicle utilized in such demonstrations and tests complies with all applicable Federal Motor Vehicle Safety Standards and New York State motor vehicle inspection standards; and a requirement that the motor vehicle utilized in such demonstrations and tests has in place, at a minimum, financial security in the amount of five million dollars.

Therefore, New York State law explicitly articulates “that the motor vehicle utilized in such demonstrations and tests complies with all applicable Federal Motor Vehicle Safety Standards” in conformance with the Supremacy Clause.

5.1.5 Federal Motor Vehicle Safety Standards

The Federal Motor Vehicle Safety Standards (FMVSS) are U.S. Federal regulations which specify design, construction, performance, and durability requirements for motor vehicles and regulated automobile safety-related components, systems, and design features. The FMVSS for motor vehicles and motor vehicle equipment are codified in the United States Code of Federal Regulations (CFR) Title 49–Transportation and were originally established under Section 103 of the National Traffic and Motor Vehicle Safety Act of 1966 enacted on September 9, 1966. This act also established the National Highway Traffic Safety Administration (NHTSA) to develop and enforce FMVSS on an ongoing basis. NHTSA has a legislative mandate over FMVSS and regulations to which manufacturers of motor vehicles and items of motor vehicle equipment must conform and certify compliance. Since the adoption of the National Traffic and Motor Vehicle Safety Act, the innovation of safety and imposition of safety regulations for motor vehicles in the U.S. accelerated.

Over the past 50 years, throughout the entire adoption and implementation of FMVSS, there has been the principle that safety regulations for motor vehicles were formulated for human operators and human controls. In fact, “driver” is defined as the occupant of a motor vehicle seated immediately behind the steering control system per 49 CFR § 571.3 of Federal Motor Vehicle Safety Standards Subpart A. General Section. Section 571.3. Even recent technologically driven features, such as adaptive cruise control, lane-keeping, lane departure warning systems, and other similar features are characterized as driver assistance technologies and emanate from a human-at-the-wheel or human-controlled vehicle paradigm.

Overall, Title 49, Part 571 defines Federal Motor Vehicle Safety Standards and Subpart A of Title 49, Part 571 provides general Federal Motor Vehicle Safety Standards. Subpart B of Title 49, Part 571 details specific sections of Federal Motor Vehicle Safety Standards (§571.101 - §571.500). We reviewed Subpart A and Subpart B and highlight that there is no mention of a motor vehicle or motor vehicle equipment that was not designed for a human driver. In section 3 of this report, we provide a policy review of FMVSS and a detailed analysis of seven specific safety standards to detail the fundamental incompatibility of the current U.S. legal and regulatory regime for motor vehicles and AV technology. Due to the primacy of federal law, the AV legislation enacted at the State-level must all adhere to FMVSS.

Based on this point, the supremacy of FMVSS presents the dominant roadblock preventing the Olli Bus, or any other AV, from deployment on public roadways. Because the Olli Bus is designed without human controls for a human operated vehicle, it is precluded from securing approval from any DMV for testing on public roads in New York State, any of the other 28 states that have passed AV legislation, as well as any other state in the U.S. because it does not comply with FMVSS. As a temporary measure, the Olli Bus that was used for this project, was fitted with a joystick and emergency brake to allow a human safety operator to manually take control of steering and braking from the Automated Driving System (ADS)whenever needed during testing of the vehicle. However, the joystick does not meet FMVSS. U.S. DOT acknowledged this fact in Preparing for the Future of Transportation Automated Vehicles 3.0, published in October of 2018, when it noted that “there may be no steering wheel, accelerator pedal, brakes, mirrors, or information displays for human use. For such Automated Driving System (ADS)-equipped vehicles, NHTSA’s current safety standards constitute an unintended regulatory barrier to innovation.”

5.1.6 FMVSS Exemptions

We also conducted comprehensive public policy research to identify other paths that the Olli Bus might seek to pursue to gain approval for testing on public roadways without requiring action by Congress or NHTSA to modify or amend FMVSS to properly accommodate AV technology. We found that, because current rules and regulations may sometimes be incomplete, NHTSA authorizes the Secretary of Transportation to exempt a motor vehicle from a FMVSS or bumper standard on a temporary basis under specific circumstances and on terms the secretary deems appropriate. This authority is set forth at 49 U.S.C. 30113. The secretary has delegated the authority for granting such exemptions to NHTSA (NHTSA, 2018a). Hence, NHTSA has the authority to grant exemptions from FMVSS that provide sufficient flexibility to accommodate a wide array of automated operations, particularly for manufacturers seeking to engage in research, testing, and demonstration projects. We explore the exemption authority available to NHTSA in section 4 of this report.

In addition, we examined the potential for Olli Bus to be granted an exemption for the purposes of the project by reviewing three cases where companies manufacturing motor vehicles utilizing AV technology were granted exemptions by NHTSA. NHTSA guidance specifies certain conditions for manufacturer exemptions, including substantial financial hardship, development or field evaluation of a new motor vehicle safety feature, development or field evaluation of a low-emission vehicle, or an overall safety level of the exempted vehicle that is at least equal to the overall safety level of nonexempt vehicles.

Exemptions from FMVSS for vehicle design, construction, and performance have been relatively obscure. Companies requesting exemptions have done so to test a new technology that does not fit into existing rules. Since 1994, according to a RAND Corporation study, there have been only eight requests on the basis of developing or evaluating new safety features. Generally, NHTSA denied exemptions because the petition failed to show that the new safety feature provided a safety level equal to that of the FMVSS, that the exemption would facilitate testing, or both.

The three cases we studied clearly demonstrate that any understanding or evaluation of AV technology can only be addressed by NHTSA during the exemption process because, by definition, AV technology is noncompliant with FMVSS and therefore cannot be tested on public roadways. Further, if AV technology could be tested on public roadways, there exist no performance measurement standards to objectively determine if such technology achieves or exceeds current safety standards. In the first case we researched, we found the Mcity exemption to be informative for the project but it only applied to a closed campus setting. In the second case, the EasyMile exemption was relevant to the project, but it required a human attendant at all times. Finally, in the third case, the Nuro exemption provided an interesting data point for but ultimately does not apply since it involved transporting cargo whereas the Olli Bus is designed to carry human passengers. In addition to these challenges with exemptions (this will be discussed in more detail later in the report), it is important to further note that all exemptions granted are temporary and thus do not provide a permanent solution. We find that without permanent action by Congress or NHTSA, FMVSS remains a substantial obstacle to the advancement of AV technology and to the sustainable deployment of the Olli Bus on public roadways.

In this report, we document the policy implications of the FMVSS and the exemption process to dispel the notion that New York State is behind other states in AV technology research and development and economic development opportunities due to the substance of its AV technology legislation. It is a common misperception that the limited number of AV deployments in NYS relative to other states is due to a deficiency in the State's AV technology legislation (i.e., that the legislation has somehow failed to promote or address impediments to AV deployments). Instead, we found that the lack of deployments in New York State have been due to other issues affecting the choice of where manufacturers have undertaken AV technology deployments and that policy at the federal level, not the State level, continues to impose a greater impact.

Since 2017, when the New York State Demonstration and Testing of AV Technology legislation was first adopted, there have only been two approved tests in the State of AV technology. The first test was in June 2017 when an Audi AI drove about 170 miles in the Albany area during a seven-hour period, according to a report compiled by the New York DMV. Audi indicated no safety issues and reported the technology performed as expected. A second test was completed in September of 2017, when Cadillac launched a hands-free drive from its global headquarters in New York City into New Jersey, with an ultimate destination of California. Nine vehicles were part of the test, which covered the FDR Parkway and George Washington Bridge, and the company reported "no safety issues relating to the system," according to the New York DMV (see DMV of the State of New York Annual AV Report in the appendices to this report).

Compared to the State of California, which according to its DMV, as of May 6, 2020, has 66 AV testing permit holders that are conducting thousands of miles of test per year with hundreds of vehicles, New York State's Automotive Vehicle testing lags far behind. However, since California and New York State are both subject to the FMVSS, we have found no public policy difference between California and New York State in terms of potential impact on the level of AV testing due to the substance of each state's AV legislation. We posit that all companies that are testing AV technology without a NHTSA exemption are utilizing motor vehicles retrofitted with AV technology. Hence, the motor vehicles tested meet FMVSS. This, combined with the fact that these companies are also testing their AV technology with a human safety driver present, renders the location of the test an irrelevant distinction. Thus, the number of tests in New York State versus California, or any other state in the nation, is immaterial to the advancement of AV technology. Further, there exists no metric to evaluate to what extent the hundreds of tests in California might be advancing AV technology any more effectively than the two tests in New York State. Until Congress or NHTSA act to define how to evaluate the safety of AV technology and reform or revise FMVSS, the incremental competitive advantage for companies that are testing AV technology in one state or another is nonexistent.

This point is supported by the fact that no company testing AV technology without a NHTSA exemption has generated any revenue using their technology in a real-world setting other than where a human safety operator has been in the vehicle at all times. We note that Waymo, which offers Waymo One, a service in the Phoenix, Arizona area that allows customers to hail rides in its vehicles equipped with Automated Driving Systems, is generating revenue from this service. However, the service still only occurs with a

trained human safety operator behind the wheel, and the operation of the service involves motor vehicles that comply with FMVSS which are then retrofitted with AV technology. This fails to provide NHTSA, regulators, or public policy decision makers with any new information necessary to support the deployment of the Olli Bus on public roadways.

5.1.7 Buffalo Principles

Recognizing these facts, through our research for the project, we have identified a new set of four principles, that we have defined as the Buffalo Principles (later in the report, we define each of the four Buffalo Principles and provide analysis of their potential value). We argue that the proper application of the Buffalo Principles will more quickly enable policymakers to gain the in-depth understanding of AV Technology necessary for them to take the legal and regulatory action required for the sustainable testing and deployment of AVs. More importantly, the Buffalo Principles offer a pathway to deployment for AVs without requiring a NHTSA exemption. In this way, the Buffalo Principles support the continued advancement of this new technology until the necessary legal and regulatory changes are enacted at the federal level. Our experience indicates that the Buffalo Principles are a unique multidisciplinary public policy approach that serve as a creative strategy to overcome the current roadblock posed by 50 years of motor vehicle rules and regulations designed for human-controlled vehicles to unlock the transformational potential of AVs.

The Buffalo Principles are comprised of four tenets. The first is testing on private roads. The value of this principle is evident by the impact of the two real-world demonstrations of an AV built by Southwest Research Institute (SwRI), held on June 9, 2016 in Saratoga Springs, NY and on June 24, 2016 in Buffalo, NY on public policy makers in New York State to later enacted on April 9, 2017 the New York State Demonstration and Testing of AV Technology legislation. These two demonstrations could not have occurred unless they were conducted in parking lots at both locations since parking lots are deemed private property and exempt from federal, State, and local law.

The second tenet of the Buffalo Principles is testing using slow speeds. As detailed later in this section of the report, the vast majority of FMVSS exemptions for AV testing granted by NHTSA are for the testing of slow speed vehicles. NHTSA has granted these exemptions because their analyses found that AVs at slow speeds are as safe as traditional vehicles, and that the operation of AVs at slow speeds are safer than current safety standards. The third tenet of the Buffalo Principles is to record data and the fourth is the use of integrated simulation. More details about the extensive detail of the value of recording data and integrated simulation for the sustainable real-world deployment of the Olli Bus and AVs will be

presented in an upcoming section of this report, which will highlight the U.S. DOT AV guidance from 2016 to 2020 that has emphasized the importance of recording and sharing data, as well as the use of integrated simulation. We find that the concurrent execution of all four tenets of the Buffalo Principles offered the greatest opportunity to expedite the ability for the Olli Bus to conduct further real-world testing per the objectives of the project.

5.1.8 Suggested Language for New York State

We will also include suggested language for draft permanent legislation for NYS to allow for testing and deployment of AVs beyond the April 1, 2018, as required by the contract of this project. In the preparation of this suggested language, we applied the Buffalo Principles strategy detailed and found that the clarity and features of the Buffalo Principles supported the basis for achieving rapid and unprecedented legislative action.

The research team submitted a memo and draft legislation to Senator Kennedy on May 9, 2019 as a tangible next step to advance the project. On May 16, 2019, Senator Kennedy introduced our Suggested Language for NYS as S. 6052 in the New York State Senate. Later, on July 8, 2019, Assemblywoman Karen McMahan, introduced A. 8460 in the New York State Assembly, with identical provisions to S. 6052. This marked the first time in the history of the New York State legislature that a bill regarding AV technology was introduced concurrently in the New York State Senate and Assembly. We offer this as practical evidence of the value and impact of the Buffalo Principles.

The bill introduced by State Senator Kennedy and Assemblywoman McMahan codifies the New York State Legislature's recognition that AV technology possesses the capability of increasing safety but is unproven and requires greater testing, and that the University at Buffalo has the legal authority to test AV technology on certain roads that have been determined to be private and therefore not under the jurisdiction of the New York State Department of Motor Vehicles (NYS DMV) for AV technology testing approval. In addition to testing on these private roads, University at Buffalo may also test AV technology in its parking lots, which are defined separately in the law, and which are also outside of NYS DMV's jurisdiction. Thus, the legislation seeks to increase the routes available on the University at Buffalo North Campus for AV technology testing and requires the NYSDOT to identify roads that could be deemed private without impacting existing traffic conditions in and around the University at Buffalo North Campus. This would directly increase the testing geography of the Olli Bus in accordance with Task 3 of the project.

5.1.9 System-Controlled Vehicles

At the conclusion of this section, we summarize our lessons learned from the project and include additional observations and findings that we believe will support further improvements. Our findings in that regard are based in part, on our discussions with participants in the DARPA Grand Challenge. Key among these additional observations is the introduction of the concept of a system-controlled vehicle (SCV). The difference between a human-controlled vehicle, which has been standard up to this point, and a system-controlled vehicle, such as the Olli Bus, is that the system-controlled vehicle utilizes AV Technology by employing an Automated Driving System to operate the vehicle and does not rely on any human control. Therefore, as a fully automated system, the Olli Bus is designed to be operated without a person in-control of Dynamic Driving Tasks. Hence, it does not include the equipment to facilitate manual control such as a driver's seat, steering wheel, accelerator pedal, brakes, or mirrors which are all required by the FMVSS and standard for all motor vehicles operating on public roadways.

We conclude that federal action is required to remove regulatory barriers to the wider deployment of AVs on public roads. This is a critical step required to support the advancement of AV technology. Due to the fundamental distinctions between system-controlled vehicles and human-controlled vehicles, any changes to existing FMVSS to support AV Technology, under the current paradigm of the assumption of a human operator and human controls of a vehicle, will be inadequate. The federal government, either through new Congressional legislation or through U.S. DOT's existing regulatory authority, should develop new legal and regulatory regime around SCVs that establish performance-based requirements based on desired levels of operational efficacy and safety to truly unleash the potential of this transformative technology.

5.2 State AV Legislation

Motivated to be the first state to host Google testing of their new project, the State of Nevada on June 17, 2011 enacted AB 511 which authorizes operation of AVs, specifies a driver's license endorsement for operators of AVs, defines "AV" and directs the state Department of Motor Vehicles (DMV) to adopt rules for license endorsement and for operation, including insurance, safety standards, and testing. As a result, a Toyota Prius retrofitted by Google, was licensed by the Nevada DMV in May 2012 and tested on Nevada public roadways. This signified the first licensing of AV technology in the U.S. and commenced the era of testing on public roadways.

Since Nevada enacted its law authorizing operation of AVs, 28 other states³ have enacted legislation related to AV technology. In addition, Governors in Arizona, Delaware, Hawaii, Idaho, Illinois, Maine, Massachusetts, Minnesota, Ohio, Washington and Wisconsin have issued executive orders related to AV technology (NCSL, 2020). Below we present a summary of the rules and regulations for AV technology in 30 states (review of legislation from 20 states and summary of executive orders in 10 other states) which we found to be most relevant to informing this project.

5.2.1 Alabama

The state passed Alabama SJR-81 on April 27, 2016. This legislation establishing a Joint Legislative Committee to Study Self-Driving Vehicles. With Alabama S-125, Act No. 2018-286, enacted on March 22, 2018, Alabama also has enacted legislation allowing for truck platooning where trucks may follow each other at electronically coordinated speed that might otherwise have received a citation for following too closely.

5.2.2 Arizona

Arizona relies on Executive Order 10 established by Governor Doug Ducey on March 1, 2018, that allows fully AVs on the roadway for testing. The order specifies the usage of the Society of Automotive Engineers' (SAE) definition of autonomous as one recognized in law. The order supersedes and amplifies a prior order that allowed testing on university campuses to now giving authority for testing of up to level five vehicles on Arizona's roadways so long as they abide by all Arizona statutes. Further, it gives authority to the Arizona Department of Transportation to implement further rules as necessary (Gov. Doug Ducey, 2018).

5.2.3 Arkansas

With regards to AV technology, Arkansas focuses on truck platooning. Arkansas Act No. 797, enacted on April 1, 2017, which amends Arkansas Code to allow trucks to follow each other in a platoon with the use of technology.

³ Alabama, Arkansas, California, Colorado, Connecticut, Florida, Georgia, Illinois, Indiana, Kentucky, Louisiana, Maine, Michigan, Mississippi, Nebraska, New York, North Carolina, North Dakota, Oregon, Pennsylvania, South Carolina, Tennessee, Texas, Utah, Virginia, Vermont, Washington and Wisconsin and Washington D.C.

5.2.4 California

Overall, the authority over the implementation of AVs has been given to the California DMV. The most significant related legislation includes the following:

- CA S 145, Enacted on October 12, 2017 as Chapter 725 of the laws of 2017, deals with Vehicle Testing and Operation on Public Roads. It repeals the requirement that the CA DMV notify the legislature of a vehicle seeking approval to operate as an AV without the presence of a driver on public roads.
- CA A 669, Enacted on October 4, 2017, as Chapter 472 of the laws of 2017, deals with Vehicle Testing and allows the DOT to conduct “platooning” testing. The testing of technologies that enable drivers to safely operate vehicles with less than 100 feet between each vehicle or combination of vehicles. The driver of the motor vehicle must hold a valid driver’s license of the appropriate class for the participating vehicle.
- CA A 1444, Enacted on October 12, 2017, Chapter 719 of the laws of 2017, authorizes the Livermore Amador Valley Transit Authority to conduct a demonstration project of an AV. Said vehicle would not have a driver seat, no steering wheel, brake pedal or an accelerator.
- The bulk of California’s rules on AVs comes from its DMV regulations. Notable regulations are summarized as follows below:
 - Notable within their regulations is that it allows for a fully AV to be tested so long as a “remote” driver, a human in the loop, is ready to take control. The driver need not be physically present within the vehicle.
 - The DMV regulations also impose insurance requirements of \$5 million.
 - Further, they advise under what conditions would self-insurance be allowed.
 - The vehicle must be further registered with the DMV with its make, model, license plate number and vehicle identification number.
 - Prior to roadway testing being allowed, the DMV requires a permit be issued. Said permit will only be issued if it can be shown that the AV has undergone some prior type of simulated driving that replicates the driving conditions it is likely to face. For each Operational Design Domain, the manufacturer must state that the vehicle is safe, based on simulations, for that design domain.
 - The DMV regulations specifically prevent the charging of fees for rides in the AVs.
 - Motorcycles, trucks, and any vehicle over 10,000 lbs is barred from being tested on the roadway.
 - The AV test driver is either in immediate physical control of the vehicle or is actively monitoring the vehicle’s operations and capable of taking over immediate physical control.
 - The AV test driver is an employee or designee of the manufacturer and is aware of the limitations of the vehicle.
 - The test driver will obey all the rules of the road and Vehicle and Traffic Laws and will only break said rules if it is for the safety of the occupants or other drivers/pedestrians.
 - The test driver must meet some minimum qualifications.
 - The manufacturer of the AV must provide a test driver training program so that the driver is familiar with the vehicle and can operate it where necessary.

- Where there is no driver and the vehicle shall be operated or monitored remotely, California states the following: There is a communication link between the vehicle and the remote operator to provide information on the vehicle's location and status and allow two-way communication between the remote operator and any passengers if the vehicle experiences any failures that would endanger the safety of the vehicle's passengers or other road users, or otherwise prevent the vehicle from functioning as intended, while operating without a driver. The certification shall include: (A) That the manufacturer will continuously monitor the status of the vehicle and the two-way communication link while the autonomous test vehicle is being operated without a driver (B) A description of how the manufacturer will monitor the communication link; and (C) An explanation of how all of the vehicles tested by the manufacturer will be monitored.
- Further, the manufacturer certifies that the AVs are capable of operating without the presence of a driver inside the vehicle and that the autonomous technology meets the description of a level 4 or level 5 automated driving system.
- The manufacturer informs the department of the intended operational design domains of the AV. The manufacturer provides a copy of a law enforcement interaction plan, which includes information that the manufacturer will make available to the law enforcement agencies and other first responders in the vicinity of the operational design domains of the AVs that will instruct those agencies on how to interact with the vehicle in emergency and traffic enforcement situations.
- The manufacturer shall maintain a training program for its remote operators and certify that each remote operator has completed training sufficient to enable him or her to safely execute the duties of a remote operator and possesses the proper class of license for the type of test vehicle being operated. The manufacturer shall provide the department of motor vehicles with a course outline and description of the remote operator training program and the date that each remote operator completed the program.
- The manufacturer is to prepare an annual report whenever there is a disengagement of the autonomous mode of the vehicle whether it be by the safety driver or the remote operator. Disengagement means a deactivation of the autonomous mode when a failure of the autonomous technology is detected or when the safe operation of the vehicle requires that the AV test driver disengage the autonomous mode and take immediate manual control of the vehicle, or in the case of driverless vehicles, when the safety of the vehicle, the occupants of the vehicle, or the public requires that the autonomous technology be deactivated. Within the report the manufacturer must list the conditions upon which disengagement occurred.
- Finally, Section 228.24 of the DMV Regulations relates to Information Privacy and states that all information not necessary for the safe operation of the vehicle shall be anonymized or written disclosure to the driver of an AV, and for vehicles that do not require a driver, the passengers of the vehicle, that describes the personal information collected by the autonomous technology that is not necessary for the safe operation of the vehicle and how it will be used.

5.2.5 Colorado

With Colorado Act No. 277, enacted on June 1, 2017, Colorado passed legislation that recognizes the SAE International Standard J3016 as the definition for AVs. It further recognizes that vehicles with SAE levels 0-3 are recognized as legal under Colorado law. With respect to SAE levels, 4-5, Colorado recognizes that the ability of these vehicles to cross multiple jurisdictions presents a statewide concern. Further, it allows level 4 or 5 vehicles to conduct dynamic driving tasks, as defined in the statute, on Colorado roadways as long as the vehicle complies with state and federal laws. It notes that liability for accidents that occur will be determined in accordance with state, federal or common law. It requires vehicle manufacturers to make a report to the State Department of Transportation about the use of level 4 or 5 vehicles.

5.2.6 Connecticut

In Connecticut, Public Act No. 17-69, enacted on June 27, 2017, establishes a task force to study fully AVs which will include: an evaluation of the standards established by the NHTSA regarding state responsibilities for regulating fully AVs, an evaluation of laws, legislation and regulations proposed or enacted by other states, and provide for recommendations on how the state should regulate.

5.2.7 Delaware

In Delaware, on September 5, 2017, Governor John Carney signed Executive Order 14 entitled “Establishment of the Advisory Council on Connected and AVs” creating an advisory council tasked with developing recommendations for tools and strategies to prepare Delaware for Connected and AVs (Gov. John Carney, 2017).

5.2.8 Florida

In Florida, the state passed legislation, as early as 2012, declaring the legislative intent to encourage the safe development, testing and operation of motor vehicles with AV technology on public roads of the state. Additional legislation in 2016 eliminated requirements to testing of AVs including, but not limited to the presence of a driver in the vehicle. Finally, House Bill 311 on AVs, which passed the House and Senate and was signed into law by the Governor on June 13, 2019 to become Chapter No. 2019-101, exempts AVs and operators from certain prohibitions, provides that human operator is not required to

operate fully AV, authorizes fully AV to operate regardless of presence of human operator, provides that Automated Driving System is deemed the operator of an AV operating with the system engaged, authorizes Florida Turnpike Enterprise to enter into agreements to fund and operate facilities, provides requirements for insurance and operation of on-demand AV networks, revises registration requirements for AVs and provides for uniformity of laws governing AVs.

5.2.9 Georgia

On May 8 and May 9, 2017 Georgia respectively enacted two laws, Georgia Act No. 214 and Georgia Act No. 267, as controlling legislation on AVs. These amend the definition of motor vehicles to include Automated Driving Systems and Dynamic Driving Tasks. The legislation further provides that a fully AV is one that is capable of conducting Dynamic Driving Tasks without the assistance of a human driver and does not request the assistance of a human driver in a limited or unlimited operational domain. They exempt a driver's license for an occupant of a fully AV. They provide authority for the use of AVs so long as they are compliant with state and federal laws and can reach a minimal risk condition if the Autonomous System is unusable. Lastly, the legislation allows for the platooning of vehicles through the use of technology and vehicles are not subject to rules about vehicles not following too closely.

5.2.10 Hawaii

In Hawaii, Governor David Ige signed an Executive Order 17 on November 22, 2017, which creates a contact for AVs in the governor's office and which requires certain government agencies to work with the AV industry to allow for the testing of self-driving vehicles in the state (Gov. David Ige, 2017).

5.2.11 Idaho

In Idaho, Governor C.L. Otter signed Executive Order 1 on January 2, 2018 to create an Autonomous and Connected Vehicle Testing and Deployment Committee to support the testing and deployment of Autonomous and Connected Vehicles. The committee will study which relevant agencies are needed to support the testing of said vehicles and determine how best to administer the testing in relation to vehicle owner liabilities and responsibilities (Gov. C.L. Otter, 2018).

5.2.12 Illinois

Illinois enacted Act No. 352 on August 25, 2017 which amends the Vehicle Code, provides that a unit of local government, including a home rule unit, may not enact an ordinance prohibiting the use of AVs on its roadways. It limits the concurrent exercise of home rule powers and defines AV.

5.2.13 Indiana

With Indiana Act No. 185, enacted on March 21, 2018, Indiana allows for vehicle platooning.

5.2.14 Kentucky

Kentucky enacted Kentucky Act No. 33 on March 29, 2018, which allows for commercial vehicle platooning. It sets forth requirements for commercial motor vehicles to operate as a platoon, defines the term platoon as a group of commercial vehicles traveling in a unified manner at electronically coordinated speeds at following distances that are closer than would ordinarily be allowed, defines a prearranged ride with a transportation network.

5.2.15 Maine

In Maine, Governor Paul LePage signed Executive Order 1 on January 17, 2018 creating the Maine Highly AVs Advisory Committee to assess, develop and implement recommendations on pilot projects to advance AV technology. Prior to operating an AV in a pilot project, the interested parties must contact the committee for a permit prior to operation of any pilot vehicles on public roadways (Gov. Paul LePage, 2018).

5.2.16 Massachusetts

Under Executive Order 572 To Promote the Testing and Deployment of Highly Automated Driving Technologies signed on October 20, 2016, Governor Charlie Baker created a working group on AVs to work with experts in vehicle safety and automation. It is also to work with members of the Legislative branch and support agreements that AV manufacturers enter into with the state DOT, municipalities and state agencies (Gov. Charlie Baker, 2016).

5.2.17 Minnesota

In Minnesota, Governor Mark Dayton issued an Executive Order 18-04 on March 5, 2018, establishing a Governor's Advisory Council on Connected and Automated Vehicles to study, assess and prepare for the adoption of automated and connected vehicles. The council is to include one member from each party from each legislative house (Gov. Mark Dayton, 2018).

5.2.18 Nebraska

Nebraska has passed legislation allowing AVs on their roadways. Legislative Bill 989 was signed into law by its Governor on April 23, 2018. Nebraska does not discuss the different levels of autonomy with their statute. Rather, the statute provides a blanket authorization for AVs to operate within the state. It requires AV's to remain on the scene after they have had an accident or collision. It specifically allows for there to be no human occupant in the vehicle and allows AV's to be used as for hire vehicles.

5.2.19 Nevada

The State of Nevada, on June 17, 2011, first enacted AB 511 which authorizes operation of AVs, specifies a driver's license endorsement for operators of AVs, defines "AV" and directs the state Department of Motor Vehicles (DMV) to adopt rules for license endorsement and for operation, including insurance, safety standards and testing. Later, Nevada passed AB 69 and was signed into law on June 20, 2017. The legislation allows for testing and operations of fully AVs; simplifies and clarifies the legal authority for entities testing or operating AVs in Nevada; authorizes commercial use of fully AVs; authorizes testing and operations of driver-assistive platooning technologies. The state DMV issues regulations related to AVs and requires a permit be issued to the AV prior to driving on the roadway. It should be noted that Nevada provides a set of red license plates that indicate the vehicle is autonomous. Prior to the bill's enactment, Nevada's driverless car laws focus primarily on the consumer side of the equation and have a more limited definition of who or, in the case of artificial intelligence, what should count as a driver or vehicle operator.

5.2.20 North Carolina

On July 21, 2017, North Carolina enacted Act No. 166-2017. This legislation creates an AV committee within the State Department of Transportation to review AV issues. Further, they provide a list of definitions for AVs, Dynamic Driving Task, minimal risk condition and Operational Design Domain. Additionally, it provides that an AV must come to a complete stop after an accident and waives the requirement that an occupant of an AV have a driver's license. It also prohibits children under 12 from being occupants in the vehicle.

5.2.21 North Dakota

North Dakota enacted North Dakota Act No. 388 on April 12, 2017, a simple law that commissions a study of AVs to be conducted with the AV industry. Said study will look at the insurance, registration with other regulatory and operational concerns.

5.2.22 Ohio

Governor John Kasich signed Executive Order 2018-01K on January 18, 2018. The order created the DriveOhio initiative which, among other things, creates a smart mobility platform, bringing together “those who are responsible for building infrastructure in Ohio with those who are developing the advanced mobility technologies needed to allow our transportation system to reach its full potential by reducing serious and fatal crashes and improving traffic flow (Gov. John Kasich, 2018).

5.2.23 South Carolina

South Carolina enacted Act No. 66, signed in 2017 and reauthorized in 2018, formerly known as SC H 3289, states that vehicles are to maintain a reasonable following distance. It makes a distinction for vehicles that are operating in tandem with AV technology by stating they are not subject to the rules on following distance.

5.2.24 Tennessee

In Tennessee, Senate Bill 151 was enacted into law as Act No: 474 on June 6, 2017. The legislation follows the template of many of the states by defining Autonomous Driving Systems, their use (defined as Dynamic Driving Tasks) and the requirement that the ADS can achieve a minimal risk condition if there is any critical failure of the ADS systems. It further delineates a \$5 million insurance requirement and specifies that, in the event of an accident, nothing within the law would affect liability under product liability or common law. The law is to be read as product liability, and common law would control in the event of an accident.

5.2.25 Texas

Texas enacted Texas Act No. 973 on June 15, 2017, to create AV legislation that defines Dynamic Driving conditions and minimal risk conditions. It further advises that the owner of a vehicle is responsible for the operation of an engaged AV. It goes further in allowing vehicles that are without a human driver to be operated within the state. The statute requires insurance coverage that is consistent with Texas law for motor vehicles within the state and does not impose an additional insurance requirement. Much like the other states in our review, the statute makes clear that no other locality may pass an ordinance that would abrogate or limit the reach of the statute.

5.2.26 Utah

Utah passed HB 373 on March 27, 2015, which authorizes the study of connected vehicles and further exempts them from statutory regulation on following too closely to the vehicle ahead of it where the vehicles are electronically connected. SB 56, which passed on March 19, 2018, further amplifies the statute by making reference to a connected platooning system being exempt from the traffic code.

5.2.27 Vermont

In Vermont, VT H 494, enacted as Act No. 38 on May 17, 2017, calls for a meeting of public and private stakeholders to convene and discuss all issues related to AVs including but, not limited to, licensing of AV's, use within the state, laws related to, enforcement or non- enforcement of certain traffic codes, emergency response and infrastructure needs as well as social, economic, and environmental consequences of a roll out of AV's.

5.2.28 Washington

In Washington, Governor Jay Inslee signed Executive Order 2 on June 7, 2017 to both address AV testing and to establish an AV working group. The order requires state agencies to “support the safe testing and operation of AVs on Washington’s public roads (Gov. Jay Inslee, 2017)”. It establishes an interagency workgroup and the order spells out requirements for vehicles operating with or without a human driver.

5.2.29 Wisconsin

In Wisconsin, Governor Scott Walker signed Executive Order 245 on May 18, 2017 which created a committee on autonomous and connected vehicles. The committee was tasked with advising the governor “on how best to advance the testing and operation of autonomous and connected vehicles in the state of Wisconsin.” The state DOT was to deliver a report to the Governor on the committee’s findings by June 30, 2018 (Gov. Scott Walker, 2017).

5.2.30 New York State

In New York State, Sections 1 to 3 of Part FF of Chapter 55 of the laws of 2017 delivered to the Governor on April 9, 2017 enacted the New York State Demonstration and Testing of AV Technology legislation, subsequent amendments in Part H of Chapter 58 of the laws of 2018 delivered to the Governor on April 2, 2018 and amendments in Part M of Chapter 58 of the law of 2019 enacted on April 12, 2019 (see full text in the Appendices).

The legislation does the following:

- Notwithstanding New York State Vehicle and Traffic Law Section 1226 Control of Steering Mechanism (i.e., the requirement for driver to have their hands on the steering wheel).
- Enables commissioner of DMV to approve demonstrations and test.
- Identifies potential impacts on safety, traffic control, traffic enforcement, emergency services, and such other areas.
- Take place under the direct supervision of the New York State police.
- In a form prescribed by the superintendent of the New York State police.
- Requires law enforcement interaction plan.
- Requires natural person holding a valid driver's license present in the vehicle.
- Requires that vehicle complies with all applicable federal motor vehicle safety standards.
- Requires that vehicle complies with all New York State motor vehicle inspection standards.
- Requires that vehicle includes financial security in the amount of 5 million dollars.
- Must abide by New York State Vehicle and Traffic Law Article 22 accidents and accident reports.
- Must abide by New York State Vehicle and Traffic Law Title VII—rules of the road.
- Defines that "AV Technology" shall mean the hardware and software that are collectively capable of performing part or all dynamic driving task on a sustained basis.
- Defines that "Dynamic Driving Task" shall mean all real-time operational and tactical functions required to operate a vehicle in on-road traffic, excluding the strategic functions such as trip scheduling and selection of destinations and waypoints.
- Requires the commissioner of DMV in consultation with Superintendent of the New York State Police to provide reports on June first of each year that law is in effect.
- Expires on April 1, 2021.

It should be noted that New York State Vehicle and Traffic Law Section 1226 Control of Steering Mechanism states, "No person shall operate a motor vehicle without having at least one hand or, in the case of a physically handicapped person, at least one prosthetic device or aid on the steering mechanism at all times when the motor vehicle is in motion." The legislation, notwithstanding this section, thus begins to address the outdated nature of New York State Vehicle and Traffic law which had been crafted with an assumption that a human would be in control of a vehicle at all times.

In addition, the legislation details that New York State Vehicle and Traffic Law Article 22 Accidents, and Accident Reports must continue to be abided by. Here is summary of descriptions for those sections of law:

- Section Description
 - 600 Leaving scene of an incident without reporting.
 - 600 1a Left scene accident with property damage.
 - 600 2a Left scene accident with physical injury.
 - 600 2a Left scene accident with serious physical injury/death.
 - 601 Leaving scene of injury to certain animals without reporting.
 - 601 Left scene accident with injury to dog/horse/cattle.
 - 602 Arrest for violations of sections six hundred and six hundred one.
 - 603 Accidents; police authorities and coroners to report.
 - 603-a Accidents; police authorities to investigate.
 - 603-b Accidents; police to indicate serious physical injury and death on simplified traffic information or summons and compliant.
 - 604 Reports; contents; preparation; distribution; filing.
 - 605 Report required upon accident.
 - 605 (a) Fail to report accident with death, physical injury or property damage in excess of \$1000.
 - 606 Processing of required reports.

These provisions of law require a human operator to fulfill these requirements. Also, the legislation details that New York State Vehicle and Traffic Law Title VII—Rules of The Road must continue to be abided. These sections of law are summarized below.

- Article Section Description
 - 23 1100-1105 Obedience to and Effect of Traffic Laws
 - 24 1110-1117 Traffic Signs, Signals and Markings
 - 25 1120-1131 Driving on Right Side of Roadway, Overtaking and Passing, Etc.
 - 26 1140-1146a Right of Way
 - 27 1150-1157 Pedestrians` Rights and Duties
 - 28 1160-1166 Turning and Starting and Signals on Stopping and Turning
 - 29 1170-1176 Special Stops Required
 - 30 1180-1182b Speed Restrictions
 - 31 1192-1199 Reckless Driving and Driving While in an Intoxicated Condition
 - 32 1200-1204 Stopping, Standing, And Parking
 - 33 1210-1229c Miscellaneous Rules
 - 34 1230-1241 Operation of Bicycles and Play Devices
 - 34-A 1250-1253 Operation of Motorcycles
 - 34-B 1260-1265 Riding Horses
 - 34-C 1270-1277 Operation of Electric Personal Assistive Mobility Devices

Again, these provisions of law require a human operator to fulfill these requirements.

During the first year of the legislation (from April 1, 2017 to April 1, 2018) there were only two approved tests in New York State. The first test was in June 2017 when an Audi AI drove about 170 miles in the Albany area during a seven-hour period, according to a report compiled by the state Department of Motor Vehicles. The company indicated no safety issues and reported the technology performed as expected. A second test was completed in September of 2017, when Cadillac launched a hands-free drive from its global headquarters in New York City into New Jersey, with an ultimate destination of California. Nine vehicles were part of the test, which covered the FDR Parkway and George Washington Bridge. The company conducting the pilot reported "no safety issues relating to the system," according to the State DMV report. Since September of 2017, there have been no additional approved tests on public roadways in New York State.

5.3 U.S. DOT AV Guidance

5.3.1 AV 1.0 Federal Automated Vehicles Policy: Accelerating the Next Revolution in Roadway Safety

Since the initial DARPA challenge 2004, along with Nevada passing first-in-the nation AV technology legislation in 2011, the proliferation of industry-borne efforts to develop commercial applications for AV technology quickly captured the attention of policymakers at the highest levels. By September of 2016, U.S. DOT released Federal Automated Vehicles Policy: Accelerating the Next Revolution in Roadway Safety (NHTSA, 2016a), or AV 1.0. Published in reaction to the plethora of advancements made in the AV technology space, AV 1.0 was U.S. DOT's effort to provide initial guidance by emphasizing safety as the key objective for ongoing AV technology research and development. Despite its focus on safety in testing and development, several accidents with vehicles outfitted with AV technology have, unfortunately, occurred in the time since the document was published, including three widely publicized fatalities (these were, the March 18, 2018 pedestrian fatality in Tempe, AZ, the driver fatality involving the Tesla Model X on auto-pilot in Mountainview, California on March 23, 2018, and the driver fatality with the Tesla Model 3 on auto-pilot in Delray Beach, Florida on March 1, 2019). These fatalities have had a dramatic effect on policymaker thinking about how to legislate and regulate AV technology.

AV 1.0 was comprised of four key sections, as follows:

1. Vehicle Performance Guidance for Automated Vehicles
2. Model State Policy
3. NHTSA's Current Regulatory Tools
4. New Tools and Authorities

The Vehicle Performance Guidance for Automated Vehicles (or “Guidance”) section outlined what U.S. DOT determined at the time to be “best practices for the safe pre-deployment design, development and testing of Highly Automated Vehicles (HAVs) prior to commercial sale or operation on public roads.” This section was intended to guide the safe testing and deployment of HAVs. It set U.S. DOT’s expectation of industry by providing reasonable practices and procedures that manufacturers, suppliers, and other entities should follow in the immediate short term to test and deploy HAVs.

AV 1.0 also stated that “the data generated from these activities should be shared in a way that allows government, industry, and the public to increase their learning and understanding as technology evolves but protects legitimate privacy and competitive interests.” Despite the inherent recognition of the importance of data as a critical strategy to accelerate the collective advancement of AV technology, where sufficiently large quantities of useful data are made widely available via mutual sharing, little AV technology data has been shared to date. Private initiatives to develop AV technology have, until recently, kept their data secret and not shared it as U.S. DOT had requested. This is a feature of private-market development where profit is the underlying motive. Currently, since the majority of AV technology is backed by private capital in the form of venture, private equity or corporate investment in research and development, AV technology data is considered to be critical to competitive advantage and to generate risk-adjusted returns. Hence, the data is treated as highly proprietary. In the view of most private investors, sharing proprietary data not only undermines their ability to attain first-mover market benefits, but it also erodes those benefit while supporting competitors.

However, were industry to instead approach data through co-opetition, a portmanteau of cooperation and competition and which refers to when competitors cooperate to solve a shared problem, the generation and availability of critical data would fulfill the market condition necessary to accelerate technological advancements. Overall, U.S. DOT has not yet found an appropriate way to influence the private market to participate in data sharing of AV technology research and development. In contrast, as an indication of its research value, this project intentionally captured and made available the data generated from the Olli Bus to help inform both the technology and also the development of sensible rules and regulations to support the safe and sustainable deployment of AV technology in the U.S.

To promote safety, AV 1.0 stated that that “manufacturers and other entities voluntarily provide reports regarding how the Guidance has been followed” to NHTSA. Entities would submit a Safety Assessment to NHTSA for each HAV system, outlining how they are meeting this guidance at the time they intend their product to be ready for use (testing or deployment) on public roads. AV 1.0 described this reporting process as may voluntary, at least initially, pending future rulemaking.

This safety assessment process would “assist NHTSA, and the public, in evaluating how safety is being addressed by manufacturers and other entities developing and testing HAV systems.” Even though no standards of safety or performance had been quantified to denote whether or not any deployment would maintain safety to any degree, the safety assessment required entities to comment on the following areas:

- Data recording and sharing
- Privacy
- System safety
- Vehicle cybersecurity
- Human machine interface
- Crashworthiness
- Consumer education and training
- Registration and certification
- Post-crash behavior
- Federal, state, and local laws
- Ethical considerations
- Operational design domain
- Object and event detection and response
- Fall back (minimal risk condition)
- Validation methods

According to the NHTSA website, only the following 20 entities thus far have provided Voluntary Safety Self-Assessment: Apple, Aurora, AutoX, BMW, Ford, GM, Ike Local Motors, Mercedes-Benz/Bosch L4-L5, Mercedes Benz L3, Navya, Nuro, Nvidia, Robomart, Starsky Robotics, Toyota, TuSimple, Uber, Waymo, and Zoox (NHTSA, 2020a).

AV 1.0 also outlined a Model State Policy to “ensure the establishment of a consistent national framework rather than a patchwork of incompatible laws,” and to ensure that States retained their “traditional responsibilities for vehicle licensing and registration, traffic laws and enforcement, and motor vehicle insurance and liability regimes.” Since 2014, U.S. DOT had collaborated with the

American Association of Motor Vehicle Administrators (AAMVA) to explore HAV issues and policies. The collaboration formed the basis for the Model State Policy framework presented in AV 1.0 and identified where issues fit into the existing federal-state structure.

As previously detailed in section 5.2, from 2011 to the present, 29 states have enacted various forms of legislation related to AV technology. Certainly, as our analysis indicates, the majority of the states have not followed the Model State Policy framework that was envisioned by U.S. DOT. However, as we discuss in a subsequent section below, the need for Model State Policy framework is in fact unnecessary due to the Supremacy Clause in the U.S. Constitution. Per Article VI, Clause 2 of the U.S. Constitution, which establishes that the U.S. Constitution, and federal laws made pursuant to it, constitute the "supreme Law of the Land," and thus take priority over any conflicting state laws. Therefore, it is more critical for Congress and U.S. DOT to take action to amend or revise FMVSS to properly address the needs of AV technology. Since FMVSS automatically apply nationally to all states, it would serve to more quickly harmonize the regulatory environment for AV technology compared with the Model State Policy framework approach. Vehicle licensing and registration, traffic laws and enforcement, and motor vehicle insurance and liability regimes were created for human controlled vehicles. They are incompatible with AV technology as we explore in greater detail in Section 5.8.

In setting forth the Model State Policy as part of AV 1.0, U.S. DOT recognized the need to minimize complications for vehicles equipped with AV Technology in crossing state lines where different states might promulgate conflicting laws pertaining to AV technology. The complications arising from inconsistent rules, U.S. DOT hypothesized, would have also represented a significant barrier to original equipment manufacturers (OEMs) developing AV technology for deployment nationwide. As it turns out, since 2016, the greatest barrier to OEMs has been perfecting AV technology, not in addressing differences in State laws. In the section on New Tools and Authorities, AV 1.0 stated that "NHTSA's existing regulatory tools will help to expedite the safe introduction and regulation of new HAVs." However, AV 1.0 recognized that "because today's governing statutes and regulations were developed when HAVs were only a remote notion, those tools may not be sufficient to ensure that HAVs are introduced safely, and to realize the full safety promise of new technologies."

AV 1.0 embraced the SAE approach of defining AV technology in terms of increasing levels of automation assisting a human driver. However, AV 1.0 drew a further distinction between levels 0–2 and 3–5 based on whether an automated system was primarily responsible for monitoring the driving environment. AV 1.0 defined an automated vehicle system as “a combination of hardware and software (both remote and on-board) that performs a driving function, with or without a human actively monitoring the driving environment.” AV 1.0 all but mandated the term Highly Automated Vehicle (HAV) and expected OEMs to classify their systems accordingly. AV 1.0 stated that, “this Policy defines “HAV systems” as automated vehicle systems that are capable of monitoring the driving environment as defined by SAE J3016. HAV systems are SAE Level 3 and higher by definition.”

This point of differentiation became an arbitrary distinction. Although how a vehicle or its operator monitors its driving environment is a critical component affecting safety, it is not the singular factor that does so. Nor does the question of how a vehicle monitors its driving environment intrinsically define safe operations of that vehicle. It is our contention, which we offer later in this report, that the only key and important distinction in vehicle technology is whether or not a human driver is in control of the vehicle, irrespective of how much automated technology is available to assist the driver in any Dynamic Driving Task.

5.3.2 AV 2.0 Automated Driving Systems (ADS): A Vision for Safety 2.0

One year later in 2017, to update its guidance to industry regarding AV Technology, U.S. DOT released, “Automated Driving Systems (ADS): A Vision for Safety 2.0” or AV 2.0 (U.S. DOT, 2017). This publication contained several differences from AV 1.0, including new language to describe AV technology. While abandoning the term HAVs proscribed in AV 1.0, in AV 2.0, U.S. DOT now embraced the term Automated Driving Systems (ADS) to describe vehicles defined at SAE Level 2 through 5. AV 2.0 focused on data sharing in the narrower context of accident data only, perhaps to reflect the market reality of the challenges inherent in competitors sharing vital trade secrets. AV 2.0 presented “Voluntary Guidance for Automated Driving Systems,” which consisted of “12 priority safety design elements for consideration, including vehicle cybersecurity, human machine interface, crashworthiness, consumer education and training, and post-crash ADS behavior.” U.S. DOT believed that these 12 safety elements “represent the consensus across the industry, that are generally considered to be the most salient design aspects to consider and address when developing, testing, and deploying ADSs on public roadways.”

Regarding System Safety, AV 2.0 encouraged entities to “follow a robust design and validation process based on a systems-engineering approach with the goal of designing ADSs free of unreasonable safety risks. The overall process should adopt and follow industry standards, such as the functional safety process standard for road vehicles, and collectively cover the entire operational design domain (i.e., operating parameters and limitations) of the system.” AV 2.0 also encouraged entities to “adopt voluntary guidance, best practices, design principles, and standards developed by established and accredited standards-developing organizations (as applicable) such as the International Standards Organization (ISO) and SAE International, as well as standards and processes available from other industries such as aviation, space, and the military and other applicable standards or internal company processes as they are relevant and applicable.

On the subject of system validation, AV 2.0 encouraged entities “to develop validation methods to appropriately mitigate the safety risks associated with their ADS approach. Tests should demonstrate the behavioral competencies an ADS would be expected to perform during normal operation, the ADS’s performance during crash avoidance situations, and the performance of fallback strategies relevant to the ADS’s ODD. To demonstrate the expected performance of an ADS for deployment on public roads, test approaches may include a combination of simulation, test track, and on-road testing.”

AV 2.0 encouraged entities to “define and document the Operational Design Domain (ODD) for each ADS available on their vehicle(s) as tested or deployed for use on public roadways, as well as document the process and procedure for assessment, testing, and validation of ADS functionality with the prescribed ODD.” AV 2.0 states that the ODD “should describe the specific conditions under which a given ADS or feature is intended to function. The ODD is the definition of where (such as what roadway types and speeds) and when (under what conditions), an ADS is designed to operate,” including the geographic area, the speed range, the weather, time of day or night, and other notable domain constraints.

AV 2.0 explored the complex issue of “understanding the interaction between the vehicle and the driver, commonly referred to as Human Machine Interface (HMI),” and how this “has always played an important role in the automotive design process. New complexity is introduced to this interaction as ADSs take on driving functions, in part because in some cases the vehicle must be capable of accurately conveying information to the human driver regarding intentions and vehicle performance. This is particularly true for ADSs in which human drivers may be requested to perform any part of the driving task. In noting that “the driver always must be receptive to a request by the system to take back driving responsibilities,” AV 2.0 even went so far as to encourage entities “to consider whether it is reasonable

and appropriate to incorporate driver engagement monitoring in cases where drivers could be involved in the driving task so as to assess driver awareness and readiness to perform the full driving task.” The two underlying assumptions implicit in this passage are that a human driver is present and that a human driver has the ability to take control of the vehicle because the proper equipment is present.

AV 2.0 noted that entities should have a “documented process for assessment, testing, and validation of their ADS’s Object and Event Detection and Response (OEDR) capabilities,” which refers to the detection of any condition relevant to the immediate driving task and the appropriate driver or system response to it. That is, “when operating within its ODD, an ADS’s OEDR functions are expected to be able to detect and respond to other vehicles (in and out of its travel path), pedestrians, bicyclists, animals, and objects that could affect safe operation of the vehicle.” AV 2.0 further noted that an the OEDR “should also include the ability to address a wide variety of foreseeable encounters, including emergency vehicles, temporary work zones, and other unusual conditions (e.g., police manually directing traffic or other first responders or construction workers controlling traffic) that may impact the safe operation of an ADS.”

In its guidance around Data Recording, AV 2.0 encouraged entities “to establish a documented process for testing, validating, and collecting necessary data related to the occurrence of malfunctions, degradations, or failures in a way that can be used to establish the cause of any crash. Data should be collected for on-road testing and use, and entities are encouraged to adopt voluntary guidance, best practices, design principles, and standards issued by accredited standards developing organizations such as SAE International. Likewise, these organizations are encouraged to be actively engaged in the discussion and regularly update standards as necessary and appropriate.” The adoption of a narrow focus on crash data meant that U.S. DOT guidance stayed clear of the challenges raised by asking industry participants to share broader performance data. However, in doing so, U.S. DOT did not address the underlying issue. It might have instead, for example, developed a framework to facilitate industry-wide data sharing that also addressed how participants could protect proprietary trade secrets.

Also, in this section, U.S. DOT affirmed its nonregulatory approach to promoting its chief goal of safety in the development and testing of AV technology. Unlike in AV 1.0, which called for industry participants to report to NHTSA how planned AV technology deployment would meet safety criteria in 15 areas of vehicle operation, AV 2.0 emphasized that “entities are not required to submit a Voluntary

Safety Self-Assessment, nor is there any mechanism to compel entities to do so.” AV 2.0 further emphasized that, “while these assessments are encouraged prior to testing and deployment, NHTSA does not require that entities provide disclosures nor are they required to delay testing or deployment.” In case any uncertainty on this point remained, AV 2.0 spelled it out. “Assessments are not subject to federal approval.”

In recognition of the fact that states were beginning to draft legislation to deploy emerging AV technology, and to support state-level work, AV 2.0 also contained the section “Technical Assistance to States, Best Practices for Legislatures Regarding Automated Driving Systems (Best Practices).” This section was intended to clarify and delineate federal and state roles in the regulation of AV technology. According to AV 2.0, NHTSA was to be responsible for regulating the safety design and performance aspects of motor vehicles and motor vehicle equipment while states would continue to be responsible for regulating the human driver and vehicle operations.

The section also provided “Best Practices for Legislatures, which incorporates common safety-related components and significant elements regarding ADSs that States should consider incorporating in legislation.” The “Best Practices for State Highway Safety Officials” were meant to serve as a framework for states to develop procedures and conditions for the safe operation of AV technology on public roadways. It included “considerations in such areas as applications and permissions to test, registration and titling, working with public safety officials, and liability and insurance.” This guidance suggested that currently limited options exist for Automated Vehicle manufacturer exemptions. Conversely, this guidance indicates that NHTSA would encourage, as appropriate, safety exemptions for automated vehicle testing because “[t]he Federal Government wants to ensure it does not impede progress with unnecessary or unintended barriers to innovation.”

5.3.3 AV 3.0 Preparing for the Future of Transportation: Automated Vehicles 3.0

In October of 2018, U.S. DOT published Preparing for the Future of Transportation: Automated Vehicles 3.0 (AV 3.0) to “advance its commitment to supporting the safe, reliable, efficient, and cost-effective integration of automation into the broader multimodal surface transportation system (U.S. DOT, 2018).”

AV 3.0 included “six principles that guide U.S. DOT programs and policies on automation and five implementation strategies for how the department translates these principles into action.” These were:

1. prioritizing safety
2. remaining technology neutral
3. recognizing the need to modernize regulations
4. encouraging a consistent regulatory environment across federal and state governments
5. proactively preparing for automation
6. protecting freedom of choice in transportation options

In AV 3.0, all surface transportation operating agencies within U.S. DOT incorporated feedback from manufacturers and technology developers, infrastructure owners and operators, commercial motor carriers, the bus transit industry, and state and local governments to publish a departmental-wide policy statement on automation. AV 3.0 was intended to build upon but not replace voluntary guidance provided in AV 2.0 and it affirmed the approach that encouraged automated driving system developers to make their Voluntary Safety Self-Assessments (VSSA) public to increase transparency and confidence in the technology.

AV 3.0 “considered automation broadly, addressing all levels of automation (SAE automation Levels 1 to 5), and recognizes multimodal interests in the full range of capabilities this technology can offer.” By outlining “how automation will be safely integrated across passenger vehicles, commercial vehicles, on-road transit, and the roadways on which they operate,” AV 3.0 provided new multimodal safety guidance.

AV 3.0 clarified that, “rather than requiring a one-size-fits-all approach, the Federal Transit Administration will provide transit agencies with tailored technical assistance as they develop an appropriate safety management system approach to ensuring safe testing and deployment of automated transit bus systems.” AV 3.0 referenced the Public Transportation Agency Safety Plan (PTASP) rule that “requires transit agencies to incorporate Safety Management System (SMS) policies and procedures as they develop their individual safety plans” related to automated transportation. This PTASP rule required public transportation agencies to “identify safety risks and hazards and to develop plans to mitigate those risks; to develop and implement a process to monitor and measure their safety performance; and to engage in safety promotion through training and communication.”

AV 3.0 also “recognizes that given the rapid increase in automated vehicle testing activities in many locations, there is no need for U.S. DOT to favor particular locations or to pick winners and losers. Therefore, the department no longer recognizes the designations of ten Automated Vehicle Proving Grounds announced on January 19, 2017.”

Some key priorities introduced in AV 1.0 and AV 2.0 were reaffirmed in AV 3.0. This included U.S. DOT’s effort to promote data sharing across the industry to facilitate technological breakthroughs. U.S. DOT published separate Guiding Principles on Data for Automated Vehicle Safety that “defined an approach that seeks to prioritize and enable voluntary data exchanges to address critical issues that could slow the safe integration of ADS technologies.”

As AV 1.0 had addressed issues of compatibility of laws across state lines, AV 3.0 urged “States and localities to work to remove barriers—such as unnecessary and incompatible regulations—to automated vehicle technologies and to support interoperability.” It also provided “considerations and best practices for State and local governments to support the safe and effective testing and operation of automation technologies. Supports the development of voluntary technical standards and approaches as an effective non-regulatory means to advance the integration of automation technologies into the transportation system.”

To “support State and local governments in the design, construction, and maintenance of the Nation’s roads,” AV 3.0 affirmed the Manual on Uniform Traffic Control Devices (MUTCD) as “the national standard for all traffic control devices installed on any street, highway, bikeway, or private road open to public travel. Traffic control devices generally refer to signs, signals, markings, and other devices used to regulate or guide traffic on a street, highway, and other facilities.” Finally, AV 3.0 affirmed U.S. DOT’s policy intent to preserve the ability for transportation safety applications to function in the 5.9 GHz spectrum.

AV 3.0 expressed U.S. DOT’s intention to “collaborate with stakeholders to review the existing Uniform Vehicle Code (UVC). Each State creates its own laws governing traffic codes, and many municipalities enact ordinances as allowed in the State.” But while AV 3.0 gives States flexibility to promulgate their own law to promote AV technology deployments and govern AV technology safety on public roadways, the provision is a wholly futile exercise. State law is not the barrier, and federal law does create an obstacle. Even under the flexibility AV 3.0 granted to states, Olli Bus could not be legally tested on

public roads given its continued noncompliance with FMVSS. The availability of state flexibility is irrelevant given the primacy of federal regulations that AV 3.0 clearly affirms. “Under Federal law, no state or local government may enforce a law on the safety performance of a motor vehicle or motor vehicle equipment that differs in any way from the Federal standard.”

Regarding Voluntary Safety Self-Assessment (VSSA), AV 3.0 reaffirmed “U.S. DOT's reliance on a self-certification approach, rather than type approval, as the way to balance and promote safety and innovation; U.S. DOT will continue to advance this approach with the international community.” In essence, U.S. DOT had asked AV technology practitioners to self-certify their vehicles were safe. Ostensibly, this voluntary approach to safety certification supports industry efforts by providing maximum flexibility and remaining neutral on key issues affecting technology. However, this is problematic because it lacks a rigorous framework to ensure safety on a consistent basis across the industry. This has, in turn, prompted staunch opposition among those who believe that, given the pressure to achieve technological advances, AV technology industry practitioners will make trade-offs about safety at the expense of consumers.

More importantly, AV 3.0 affirmed U.S. DOT's authority, through NHTSA, “to establish motor vehicle safety standards that allow for innovative automated vehicle designs—such as vehicles without steering wheels, pedals, or mirrors—and notes that such an approach may require a more fundamental revamping of the National Highway Traffic Safety Administration's (NHTSA) approach to safety standards for application to automated vehicles (AV3.0, page IX).” AV 3.0 further stated that “NHTSA has broad authority over the safety of ADS-equipped vehicles and other automated vehicle technologies equipped in motor vehicles. NHTSA has authority to establish Federal safety standards for new motor vehicles introduced into interstate commerce in the United States.”

However, federal safety standards aside, AV 3.0 expressed U.S. DOT's understanding that “automation technologies are new and rapidly evolving. The right approach to achieving safety improvements begins with a focus on removing unnecessary barriers and issuing voluntary guidance, rather than regulations that could stifle innovation.” Also, AV 3.0 also sought to address issues previously raised by stakeholders around the assumption that vehicles are operated by human drivers inherent in FMVSS. “Several NHTSA safety standards for motor vehicles assume a human occupant will be able to control the operation of the vehicle, and many standards incorporate performance requirements and test procedures geared toward

ensuring safe operation by a human driver. Some standards focus on the safety of drivers and occupants in particular seating arrangements. Several standards impose specific requirements for the use of steering wheels, brakes, accelerator pedals, and other control features, as well as the visibility for a human driver of instrument displays, vehicle status indicators, mirrors, and other driving information.”

As such, AV 3.0 included certain policy and role clarifications, such as, that “U.S. DOT will interpret and, consistent with all applicable notice and comment requirements, adapt the definitions of “driver” and “operator” to recognize that such terms do not refer exclusively to a human, but may include an automated system.” AV 3.0 continued in this vein in recognizing that “some level 4 and 5 automated vehicles may be designed to be controlled entirely by an ADS, and the interior of the vehicle may be configured without human controls. There may be no steering wheel, accelerator pedal, brakes, mirrors, or information displays for human use. For such ADS-equipped vehicles, NHTSA’s current safety standards constitute an unintended regulatory barrier to innovation.” In stating accordingly that, “NHTSA recognizes that the accelerating pace of technological change, especially in the development of software used in ADS-equipped vehicles, requires a new approach to the formulation of the Federal Motor Vehicle Safety Standards (FMVSS),” AV 3.0 clearly states NHTSA’s acknowledgement of the need to revise FMVSS.

As part of its effort to “modernize or eliminate outdated regulations that unnecessarily impede the development of automated vehicles or that do not address critical safety needs,” AV 3.0 stated that, whenever regulation was necessary, U.S. DOT would “seek rules that are as nonprescriptive and performance-based as possible. As a starting point and going forward, the department will interpret and, consistent with all applicable notice and comment requirements, adapt the definitions of “driver” and “operator” to recognize that such terms do not refer exclusively to a human, but may in fact include an automated system.” Further, according to AV 3.0, “whenever possible, the department will support the development of voluntary, consensus-based technical standards and approaches that are flexible and adaptable over time.”

AV 3.0 also touched upon other aspects affecting the advancement of AV Technology. “Existing standards assume that a vehicle may be driven anywhere, but future standards will need to take into account that the operational design domain (ODD) for a particular ADS within a vehicle is likely to be limited in some ways that may be unique to that system.” AV 3.0 also noted that, standards “could be designed to account for factors such as variations in weather, traffic, and roadway conditions within a given system’s ODD, as well as sudden and unpredictable actions by other road users.”

To facilitate an open, industry-friendly and collaborative process to federal rulemaking around AV technology safety, AV 3.0 noted that “NHTSA will seek comment on existing motor vehicle regulatory barriers and other unnecessary barriers to the introduction and industry self-certification of ADS. NHTSA is developing an Advance Notice of Proposed Rulemaking (ANPRM) to determine methods to maintain existing levels of safety while enabling innovative vehicle designs. The ANPRM also explores removing or modifying requirements that would no longer be appropriate if a human driver is not operating the vehicle. NHTSA previously published a Federal Register notice requesting public comment on January 18, 2018. NHTSA is issuing an ANPRM requesting public comments on designing a national pilot program that will enable it to facilitate, monitor, and learn from the testing and development of emerging advanced driving technologies and to assure the safety of those activities.”

5.3.4 AV 4.0 Automated Vehicles 4.0 Ensuring American Leadership in Automated Vehicle Technologies

The U.S. DOT published Automated Vehicles 4.0 Ensuring American Leadership in Automated Vehicle Technologies or AV 4.0, on December 23, 2019 (U.S. DOT, 2019) with the intent “to facilitate and guide future efforts in a safe and consistent way in order to embolden AV innovators and entrepreneurs and enable the public.” In contrast to previous U.S. DOT guidance that was more narrowly focused on addressing issues impeding or advancing the development of AV technology, AV 4.0 takes a broader view of how U.S. Government efforts around AV technology affect peripheral issues, such as access to mobility among disabled or elderly populations, how it can augment and compliment military applications, or how “developing AV tools and systems that decrease labor requirements for managing animals in ranching operations.” This underscores the potential importance of AV technology in other Operational Design Domains, such as in the agricultural domain, automated tractors and farm equipment where use of automated vehicle and other emerging data sensing, collection and monitoring technologies can be deployed for specific tasks in various industrial sectors.

However, the development of AV technology remains paramount in AV 4.0. The U.S. DOT recognizes that “the landscape for AV innovation is complex and evolving. While significant investments and achievements are being made by industry, academia, and nonprofit organizations, further development of the technology itself is needed.” Accordingly, realizing “the full potential of AVs will require collaboration and information sharing among stakeholders from industry, State,

local, tribal, and territorial governments, academia, not-for-profit organizations, standards development organizations (SDO), and the Federal Government.” To this end, AV 4.0 highlights numerous Federal Government efforts that directly and indirectly contribute to the advancement or support of AV technology.

In affirming the Federal Government’s commitment to “fostering surface transportation innovations to ensure the United States leads the world in automated vehicle (AV) technology development and integration while prioritizing safety, security, and privacy and safeguarding the freedoms enjoyed by Americans,” AV 4.0 expresses that the U.S. Government “recognizes the value of industry leadership in the research, development, and integration of AV innovations. Such innovation requires appropriate oversight by the government to ensure safety, open markets, allocation of scarce public resources, and protection of the public interest.” According to AV 4.0, the role of the Federal Government is to be “proactive about AVs and will provide guidance, best practices, conduct research and pilot programs, and other assistance,” while also preparing for “complementary technologies that enhance the benefits of AVs, such as communications between vehicles and the surrounding environment” and while remaining neutral to any particular approach. AV 4.0 affirms the Federal Government’s desire to address “legitimate public concerns about safety, security, and privacy without hampering innovation” and documents a select sample of federal investments and resources related to AVs in order to support “American leadership in AV and AV-related research and development (R&D) to inform efforts to work together in the AV domain.”

As an update to the principles enumerated in AV 3.0, AV 4.0 enumerates 10 U.S. Government principles to protect users and communities, promote efficient markets, and to facilitate coordinated efforts to ensure a standardized federal approach to American leadership in AVs. It also presents ongoing efforts supporting AV technology growth and leadership, as well as opportunities for collaboration including federal investments in the AV sector and resources for AV sector innovators. It is notable that, within these principles, AV 4.0 articulates that the Federal Government “will focus on opportunities to improve transportation system-level performance, efficiency, and effectiveness while avoiding negative transportation system-level effects from AV technologies” rather than on policies supporting the direct advancement of AV technology. The 10 principles and three core areas of interests are as follows:

- I. Protect users and communities
 - 1. Prioritize safety
 - 2. Emphasize security and cybersecurity
 - 3. Ensure privacy and data security
 - 4. Enhance mobility and accessibility

- II. Promote efficient markets
 - 5. Remain technology neutral
 - 6. Protect American innovation and creativity
 - 7. Modernize regulations

- III. Facilitate coordinated efforts
 - 8. Promote consistent standards and policies
 - 9. Ensure a consistent federal approach
 - 10. Improve transportation system-level effects

In summarizing the potential benefits of AV technology, AV 4.0 illustrates the four main areas that NHTSA has highlighted as sources of potential benefit with regard to AVs: safety, economic and societal benefits, efficiency and convenience, and mobility. These four areas, while not novel, present a concise and useful summary.

AV 4.0 highlights Federal Government efforts in the “development and promotion of physical and cybersecurity standards and best practices across all data mediums and domains of the transportation system to deter, detect, protect, respond, and safely recover from known and evolving risks.” AV 4.0 also notes that the U.S. Government will use a “holistic, risk-based approach to protect the security of data and the public’s privacy as AV technologies are designed and integrated. This will include protecting driver and passenger data as well as the data of passive third-parties—such as pedestrians about whom AVs may collect data—from privacy risks such as unauthorized access, collection, use, or sharing.” Further, AV 4.0 affirms from AV 2.0 that elements involving the sharing of data beyond crash data remain important and are areas for further discussion and research but makes no new pronouncement or commitment to require data sharing. Nevertheless, AV 4.0 is silent and does not offer guidance on the need to provide a mechanism for those developing AV technology to share data that will support technological advances without undermining proprietary trade secrets. We believe this is a missed opportunity to address a critical industry need.

In the principle to Enhance Mobility and Accessibility, AV 4.0 affirms the Federal Government support for “an environment in which AVs operate alongside conventional, manually driven vehicles and other road users” where AV technology enhances consumer access to goods and services while “allowing individuals to live and work in places that fit their families’ needs and expanding access to safe, affordable, accessible, and independent mobility options.” In our interpretation, we find that the federal principle of public roadways implicitly supports the need to expand access to open-road AV testing. AV 4.0 affirms that safety is “a key component for the development of a transportation system that efficiently and effectively incorporates AVs. The U.S. Government prioritizes safety for vehicle operators—including low-speed vehicles, motorcycles, passenger vehicles, medium-duty vehicles, and heavy-duty commercial motor vehicles (CMVs), such as large trucks and buses—and vehicle occupants, pedestrians, bicyclists, and all other road users.” AV 4.0 explicitly endorses the practice of low speeds as a central tenet to safety in the context of AV technology.

We did find some NHTSA efforts to be more promising in their potential to support substantive advances to AV technology. These include efforts to establish alternative metrics and safety assessment models applicable to the performance of ADS and “identify the methods, metrics, and tools to assess how well the ADS perform at a system level to avoid crashes including system performance and behavior relative to the system’s ODD and stated Object and Event Detection and Response (OEDR) capabilities.” Further, research will be conducted to explore the “functional performance and safety benefits of ADS implementations” and to “assess normal driving capabilities of an ADS” and evaluate the Dynamic Driving Tasks previously undertaken by the human driver “as behavioral competencies or maneuvers that can be measured and tested much in the way a human driver is evaluated to ensure driving competency.”

Finally, AV 4.0 expresses the federal commitment to the idea that, “when regulation is needed, the U.S. Government will seek rules, both at home and abroad, that are as performance-based and non-prescriptive as possible.” In spirit, albeit not yet in practice, NHTSA is acknowledging the type of performance-based regulatory regime required to provide the necessary regulatory regime to support AV technology while freeing ADS-based vehicles from the current regulatory regime that is designed for human-controlled vehicles.

AV 4.0 also highlights the abundance of current administration’s initiatives which directly or indirectly support the advancement of AV technology, as follows:

- Advanced Manufacturing
- Artificial Intelligence
- Connected Vehicles and Spectrum
- STEM Education
- STEM Workforce
- Supply Chain Integration
- Quantum Information Science

In addition, AV 4.0 highlights areas where, through the activities of various Departments and Agencies, the Federal Government has “invested in the development of foundational and complementary technologies for AVs to advance novel science and technology and provide support to innovators and entrepreneurs bringing technological advances to market.” These activities include the following:

Government Investments in the Automated Vehicle Sector

- Safety
- Ensuring Mobility for All Americans
- Fundamental Research
- Security and Cybersecurity
- Infrastructure
- Spectrum and Connectivity
- Economics and Workforce Research

U.S. Government Enabling Activities in the Automated Vehicle Sector

- Fostering Collaboration with Government
- Voluntary Consensus Standards and Other Guidance
- Regulatory Authority and Automated Vehicles
- Taxation, Trade, and Intellectual Property
- Environmental Quality
- Competition, Privacy, and Market Transparency

U.S. Government Resources for Automated Vehicle Sector Innovators

- Federal Laboratories Test Beds and Technology Transfer
- Small Business Administration Resources
- United States Patent and Trademark Office’s Inventor and Entrepreneur Resources
- USAspending.gov
- Additional U.S. Government Resources

In our analysis, regardless of how significant, each of these initiatives are peripheral to the advancement of AV technology and their inclusion in AV 4.0 do not provide the rigorous policy analysis necessary to spur action in Congress as requested by numerous AV technology developers and practitioners. Unfortunately, despite publication of this substantive guidance by U.S. DOT since 2016, there remains fundamental lack of action at the federal level as it relates to AV technology to support or advance this new technology.

5.4 Federal Motor Vehicle Safety Standards

5.4.1 Increasing Vehicle Safety Resulted from Greater Vehicle Safety Regulation

The Federal Motor Vehicle Safety Standards are U.S. Federal regulations which specify design, construction, performance, and durability requirements for motor vehicles and regulated automobile safety-related components, systems, and design features. The FMVSS for motor vehicles and motor vehicle equipment are codified in the United States Code of Federal Regulations (CFR) Title 49–Transportation and were originally established under Section 103 of the National Traffic and Motor Vehicle Safety Act of 1966 enacted on September 9, 1966. This act also established the National Highway Traffic Safety Administration to develop and enforces FMVSS on an ongoing basis. NHTSA has a legislative mandate over FMVSS and regulations to which manufacturers of motor vehicles and items of motor vehicle equipment must conform and certify compliance.

The cars we drive today are exceptionally safe, due in large part to the work of NHTSA over the past half century. Compared to the state of car safety when NHSTA was formed, and even in comparison to cars from just a few years ago, the trajectory of motor vehicle safety has been one of continuous improvement. In this narrative, a steady stream of technological advances in driving and safety features, often the result of safety regulations imposed on the automotive industry by the Federal Government, have led to corresponding reductions in accidents and fatalities.

The trend has been sustained despite a steady increase in the population of cars on the road and vehicle miles travelled. For example, total U.S. fatalities from motor vehicles, including non-motorists, decreased from 40,716 in 1994 to 37,133 in 2017 (NHTSA, 2020b). During this same period, VMT increased from 2.358 billion to 3.212 billion, the number of registered vehicles increased from 192,497,000 to 290,387,000, and the quantity of licensed drivers nationwide increased from 175,403,000 to 225,346,000 (NHTSA, 2020b).

The invention of traffic rules and regulation was not a companion to the invention of the automobile. In fact, there exist many examples of regulating roadways and traffic from 19th-century U.S. and British law, and dating back to ancient Rome, such as speed limits, one-way streets, parking laws, designated places for street crossing, roundabouts, pedestrian-only walkways, and requirements for maintaining vehicle control. Nevertheless, the notion of vehicle safety did not exist when horseless carriages first arrived on public roads. The first recorded traffic death in the U.S. was September 14, 1899 when Henry Hale Bliss was purportedly hit by an electric motorized carriage in Manhattan while helping a female companion from a streetcar.

With the advent of automobiles on the road in the first decade of the 20th century, a litany of traffic regulations and safety improvements quickly followed. Among the more notable examples are the use of glass windshields, first included as a standard feature by the Ford Model T in 1908, to the first three-colored traffic light installed in Detroit in 1913, followed soon thereafter by the first stop sign (also in Detroit) in 1914. By 1939, electric turn signals on vehicles had become common although the first seat belts did not appear until 1950. In 1955, Michigan became the first state to require driver education. The landmark book, *Unsafe at Any Speed*, Ralph Nader's seminal work on consumer auto safety, awakened public awareness to what Nader termed the "designed-in dangers of the American automobile," and promoted public demand for vigorous public policy action to improve auto safety.

Since the adoption of the National Traffic and Motor Vehicle Safety Act in 1966, the innovation of safety and imposition of safety regulations for motor vehicles in the U.S. accelerated. For example, in 1974, General Motors produced the first airbags, and in 1979 there was an introduction of official crash-testing regimes among auto manufacturers, which have fueled ongoing safety improvements for motor vehicles over the intervening decades. In 1984, New York became the first State in the nation to require that motor vehicle occupants use seat belts in accordance with the FMVSS 49 CFR § 571.209 - Standard No. 209, which was first safety standard adopted on March 1, 1967, mandating seat belt equipment (while use of seat belts at the State level were optional before legislative action in the State). In 1985, Mercedes became the first to make anti-locking brakes and airbags a standard feature. Since 1966, numerous motor vehicle safety features have been developed, defined, or inspired by FMVSS, resulting in a dramatic decrease in motor vehicle fatalities in the U.S.

Following, this period, a number of advanced safety features were introduced, including electronic stability control, blind spot detection, forward collision warning, lane departure warning. This was soon followed by the introduction of advanced driver assistance features such as rearview video systems, automatic emergency braking, pedestrian automatic emergency braking, rear automatic emergency braking, rear-cross traffic alerts, and lane centering assistance. The most recent phase of safety innovation has included partially automated safety features such as lane keeping assistance, adaptive cruise control, traffic jam assistance and self-parking capabilities.

5.4.2 The Human-at-the-Wheel Paradigm Inherent in FMVSS

The predominant feature throughout this history has been the assumption that the human driver is always in control of the motor vehicle and, therefore, efforts to improve safety have been grounded in this understanding. It has taken over 50 years for NHTSA regulations to reach its current state of maturity and despite rapid advancements in technology these regulations remain firmly formulated for human operators and human controls. In fact, “driver” is still only defined as the occupant of a motor vehicle seated immediately behind the steering control system. Even recent technologically driven features, such as adaptive cruise control, lane-keeping, lane departure warning systems, and other similar features can be characterized as driver assistance technologies and emanate from a human-at-the-wheel paradigm. Overall, as evident by a review of FMVSS, exemptions and recent regulatory action related to AV technology documented in this report, it is clear that NHTSA continues to approach regulatory consideration of emerging technology with human operators in mind, despite the fact that AVs, as software-driven systems, begin with the opposite assumption.

A section-by-section analysis of key FMVSS provisions, using the Olli Bus deployment as a case study, shows that this paradigm remains firmly rooted in how NHTSA approaches vehicle safety, to the detriment of the testing needs of AV technology. The Olli Bus deployment demonstrates how no AV technology deployment could ever meet federal safety standards given that AVs are driven by a computer and the FMVSS regulatory framework is explicitly set up for a human driver at the controls.

Title 49, Part 571 defines Federal Motor Vehicle Safety Standards. Subpart A of Title 49, part 571 provides general Federal Motor Vehicle Safety Standards. Subpart B of Title 49, part 571 details specific sections of Federal Motor Vehicle Safety Standards (§§ 571.101 - 571.500). In our analysis, we observe that both Subpart A and Subpart B never considered motor vehicle and motor vehicle equipment that was not designed for a human driver. The first two sections of Subpart B, § 571.101 and § 571.102, detailed below, illustrate the human-centric nature of these safety standards.

5.4.3 § 571.101 Standard No. 101; Controls and Displays

S1. Scope. This standard specifies performance requirements for location, identification, color, and illumination of motor vehicle controls, telltales, and indicators.

S2. Purpose. The purpose of this standard is to ensure the accessibility, visibility and recognition of motor vehicle controls, telltales, and indicators, and to facilitate the proper selection of controls under daylight and nighttime conditions to reduce the safety hazards caused by the diversion of the driver's attention from the driving task, and by mistakes in selecting controls.

S3. Application. This standard applies to passenger cars, multipurpose passenger vehicles, trucks, and buses.

The above regulatory requirement means that vehicles must ensure that the driver's cockpit controls or indicators with which it is equipped for the location, identification, color, and illumination of that control, telltale, or indicator, are visible to human drivers under both daylight and nighttime driving conditions. In most cases, regulations also require that the positioning of such controls and indicators be upright and sufficiently illuminated to ensure a human driver can easily see or control them. In this case, the rule is explicit around the main point. This rule not only assumes a human driver at the controls of all vehicles, but it was also written specifically for and with human drivers in mind. But this set of rules is absurd in the context of AVs, where an ADS, not a person, controls the Dynamic Driving Tasks. The Olli Bus design does not take into consideration any of the requirements of Standard 101.

Since the Olli Bus was not designed for control by a human driver and assumes no driver is present, it fails to comply with this safety standard in two ways. First, none of the functional controls specified in this provision are present or available in the Olli Bus for human operation. These functions are either superfluous in the context of an AV and are therefore not included as part of the Olli's AV technology or otherwise embedded internally within the Olli's control algorithm. Second, given that there is no cockpit, by definition, no such controls are visible or properly positioned. This provision was clearly promulgated with a human driver in mind and does not contemplate a scenario where the vehicle is controlled by adaptive functions. While the substance of the provision is not applicable to Automated Driving Systems, AVs are still required to comply with this and all other FMVSS provisions. For the Olli Bus, or any vehicle designed with Automated Driving System to control all Dynamic Driving Tasks, compliance is simply not possible.

5.4.4 § 571.102 Standard No. 102: Transmission Shift Position Sequence, Starter Interlock, and Transmission Braking Effect

S1. Purpose and scope. This standard specifies the requirements for the transmission shift position sequence, a starter interlock, and for a braking effect of automatic transmissions, to reduce the likelihood of shifting errors, to prevent starter engagement by the driver when the transmission is in any drive position, and to provide supplemental braking at speeds below 40 kilometers per hour (25 miles per hour).

S2. Application. This standard applies to passenger cars, multipurpose passenger vehicles, trucks, and buses.

The above regulations require that vehicles, in addition to meeting safety standards related to door crush resistance, moving deformable barrier tests, or vehicle-to-pole tests, must also include features that prevent driver error or assist drivers in the operation of the vehicle. One clause requires that, regarding the gear shift of a vehicle, a neutral position shall be located between forward drive and reverse drive positions. Another requires that, if a steering-column-mounted transmission shift lever is used, movement from neutral position to forward drive position shall be clockwise. Others state that, if the transmission shift lever sequence includes a park position, it shall be located at the end, adjacent to the reverse drive position. And yet another clause requires the engine starter to be inoperative when the transmission shift position is in a forward or reverse drive position. These regulations, which micromanage the positioning and function of certain human controls, once again underscore the predominant reality that they were promulgated solely in the context of a human driver behind the wheel. The rule is illogical in the context of AVs.

The Olli Bus transmission was designed for automated operation. It assumes no human driver is present and was not designed for control by a human driver. All powertrain functions are part of the Olli's control algorithm software subsystem that support its Automated Driving System. Although the Olli Bus can change gears, it does not need, and therefore does not include a gear shift mechanism. It would be superfluous and even irrational to include one except for decorative purposes. Because it has no steering column or gear shift, the Olli Bus cannot comply with the requirements regarding a steering-column mounted transmission shift lever or its clockwise movement from a neutral to forward drive position. The Olli Bus cannot ensure that a transmission shift lever sequence include a park position, or that it be located at the end, adjacent to a reverse drive position, when it has

no shift lever. Nor can the Olli Bus ensure that the engine starter be inoperative when the transmission shift position is in a forward or reverse drive position since it is not equipped with transmission that has shift positions. This equipment is only present in the context of a human driver, not an automated system. Clearly, the substance of the regulation has zero application to AV technology, yet AVs are still required to comply with this and all FMVSS provisions in all fifty states and any other jurisdiction under control of the Federal Government. Hence, the Olli Bus again, by definition, fails to comply with this safety standard.

5.4.5 § 571.103 Standard No. 103: Windshield Defrosting and Defogging Systems

S1. Scope. This standard specifies requirements for windshield defrosting and defogging systems.

S2. Application. This standard applies to passenger cars, multipurpose passenger vehicles, trucks, and buses.

This provision requires that passenger car windshields shall include defrosting and defogging systems which operate with a certain degree of efficacy and are tested in accordance with certain requirements. Such provisions are understandably important to vehicles operated by a human driver where effective visibility through the windshield determines a driver's ability to steer a vehicle and navigate traffic. However, for the Olli Bus and other AVs, the windshield has no functional role on how the vehicle steers or navigates its environment. These functions are accomplished through cameras, LIDAR, RADAR and other perception-sensing devices and communications that feed information into the perception algorithm of the ADS. The Olli Bus can certainly include a windshield, perhaps as a cosmetic appeal and for the visual enjoyment of its passengers. Further, it is technically capable of meeting defrosting and defogging safety standards. Regardless, whether or not the Olli Bus complied with these requirements would have absolutely no impact on its safe operation as envisioned by this standard. At risk of being redundant, we find this regulatory provision to be absurd in the context of AVs. Windshield defrosting and defogging safety provisions present further empirical evidence of the overwhelmingly human-centric nature of current FMVSS which leave little room for compromise or accommodation for the needs of vehicles operating with AV technology.

5.4.6 § 571.108 Standard No. 108: Lamps, Reflective Devices, And Associated Equipment

S1 Scope. This standard specifies requirements for original and replacement lamps, reflective devices, and associated equipment.

S2 Purpose. The purpose of this standard is to reduce traffic accidents and deaths and injuries resulting from traffic accidents, by providing adequate illumination of the roadway, and by enhancing the conspicuity of motor vehicles on the public roads so that their presence is perceived, and their signals understood, both in daylight and in darkness or other conditions of reduced visibility.

This required safety standard, as in the case of the previous safety standard, represents a subset of federal safety standards to which the Olli Bus can technically comply, and where doing so is not necessarily onerous. Nevertheless, they further underscore how the human-centric paradigm fails to provide any improvement to the safety or operation of AVs. In this case, this provision requires a degree of illumination by a vehicle to make it more visible to other human drivers or non-motorists nearby. This rule makes sense when nearby vehicles are driven by humans who depend on human sight as the primary means to navigate traffic and who need sufficient lighting and conspicuity of others in the vicinity to aid their visibility. However, for AVs, navigational perception is not solely dependent on environmental lighting or visibility. The Olli has perception-sensing devices, such as RADAR, which do not utilize visible light. Hence, the requirements for sufficient illumination and visibility are misplaced in the context of AV technology.

These provisions exist solely in the service of vehicles operated by humans and further underscore the other side of the coin for how poorly the current regime of federal safety regulations serve the needs of AVs. FMVSS are not only human driver centric, they fail to provide any guidance at all to AVs in their current form. AV technology practitioners, who might otherwise wish to apply a standard of safety regarding the efficacy of how well an AV successfully achieves visibility of its path and physical environment, would be hard-pressed to find guidance within this particular rule.

5.4.7 § 571.111 Standard No. 111: Rear Visibility

S1. Scope. This standard specifies requirements for rear visibility devices and systems.

S2. Purpose. The purpose of this standard is to reduce the number of deaths and injuries that occur when the driver of a motor vehicle does not have a clear and reasonably unobstructed view to the rear.

This provision sets standards for the types of rear-view and exterior-mounted mirrors that a vehicle must provide to aid the visibility of human drivers during a backing event (i.e., driving toward the rear of the vehicle rather than forward). These provisions specify angles for the field of view and degree to which a driver's line-of-sight may or may not be obscured by passengers or cargo sitting behind the driver. One

specific provision even states that, each convex mirror shall have permanently and indelibly marked at the lower edge of the mirror's reflective surface, in letters not less than 4.8 mm nor more than 6.4 mm high the words "Objects in Mirror Are Closer Than They Appear," while the average radius of curvature of each such mirror, as determined by using the procedure in S12., shall be not less than 889 mm and not more than 1,651 mm.

Given the literal specificity of rear visibility standards, the Olli Bus is woefully noncompliant in two ways. First, the Olli Bus lacks a human driver for which these standards are clearly meant to apply. One cannot comply with line-of-sight requirements, for example, if there is no driver to do the seeing. Second, the Olli Bus lacks any convex mirrors, or any effective mirror surfaces, or any environmental fixtures designed to aid human visibility in the operation of the vehicle. While, technically, the Olli Bus could affix the required interior and exterior mirrors to its cabin, such a maneuver would be pointless and noncompliant, given the absence of a human driver to use them. Such requirements themselves only further demonstrate the incongruity of the assumption of a human driver in the context of an AV deployment.

5.4.8 § 571.124 Standard No. 124: Accelerator Control Systems

S1. Scope. This standard establishes requirements for the return of a vehicle's throttle to the idle position when the driver removes the actuating force from the accelerator control, or in the event of a severance or disconnection in the accelerator control system.

S2. Purpose. The purpose of this standard is to reduce deaths and injuries resulting from engine overspeed caused by malfunctions in the accelerator control system.

This FMVSS regulates driver-operated accelerator control systems and pertains to all vehicle components, except the fuel metering device, that regulate engine speed in direct response to movement of the driver-operated control and that return the throttle to the idle position upon release of the actuating force. Under this requirement, throttle means the component of the fuel metering device that connects to the driver-operated accelerator control system and that, by input from the driver-operated accelerator control system, controls the engine speed.

Further, idle position means the position of the throttle at which it first comes in contact with an engine idle speed control appropriate for existing conditions according to the manufacturers' recommendations. These conditions include, but are not limited to, engine speed adjustments for cold engine, air conditioning, and emission control, and the use of throttle setting devices. The requirement states that the throttle shall return to the idle position from any accelerator position or any speed of which the engine is capable whenever any single component of the accelerator control system is disconnected or severed at a single point. The return to idle shall occur within the time limit specified in regulation, measured either from the time of severance or disconnection or from the first removal of the opposing actuating force by the driver.

The set of safety standards pertaining to accelerator control systems clearly assume a human driver, and by definition, exclude systems whose acceleration is not controlled by the actions of a human driver. Thus, the wording of these safety standards automatically renders all AVs, by definition, to be noncompliant by virtue of their lack of a human driver, irrespective of the efficacy of their accelerator control systems. The Olli Bus can never achieve compliance since its throttle does not comprise “a component of the fuel metering device that connects to the driver-operated accelerator control system and that by input from the driver-operated accelerator control system controls the engine speed.” The Olli Bus has an accelerator control system but has no vehicle throttle nor human driver to apply input to it “in direct response to movement of the driver-operated control.” The Olli Bus achieves acceleration through its ADS which controls the electric transmission (the Olli Bus is an all-electric vehicle and uses a quantity of electric power, not fuel, per se).

5.4.9 49 CFR § 571.500 - Standard No. 500: Low Speed Vehicles

S1. Scope. This standard specifies requirements for low-speed vehicles.

S2. Purpose. The purpose of this standard is to ensure that low-speed vehicles operated on the public streets, roads, and highways are equipped with the minimum motor vehicle equipment appropriate for motor vehicle safety.

S3. Applicability. This standard applies to low-speed vehicles.

A low-speed vehicle is a four-wheeled motor vehicle whose top speed is more than 32 km/h (20 mph) and not more than 40 km/h (25 mph). The Olli Bus is a low-speed vehicle.

According to this FMVSS, each low-speed vehicle shall be equipped with the following: (1) headlamps, (2) front and rear turn signal lamps, (3) taillamps, (4) stop lamps, (5) reflex reflector (one red on each side as far to the rear, as practicable, and one red on the rear, an exterior mirror mounted on the driver's side of the vehicle and either an exterior mirror mounted on the passenger's side of the vehicle or an interior mirror), (6) a parking brake, (7) a windshield that conforms to the federal motor vehicle safety standard on glazing materials, (8) a compliant Vehicle Identification Number, and (9) a seat belt assembly installed at each designated seating position. Low-speed vehicles must also comply with the rear visibility requirements, and an alert sound as similarly required for hybrid and electric vehicles.

The above list of required equipment has no inherent relevance to the Olli Bus or impact on its safety and once again pertains to and is for the benefit of human drivers operating vehicles on the road, low-speed or otherwise. Nevertheless, outfitting the Olli Bus with only the required visual effects would be helpful to the human drivers operating other vehicles on the road and who depend on visual cues to aid in navigation. However, the provision also requires that low-speed vehicles have a maximum unloaded vehicle weight of 78 kg (170 lbs). The Olli Bus weighs more than 3,000 pounds. Once again, the Olli Bus is, by its definition, non-compliant with federal safety standards. This regulation was clearly intended for a different type of vehicle and the Olli's engineers would be hard-pressed to achieve such a low weight to match its low speed.

In Safety Standards 101, 102, 103, 108,111, 124 and 500, we summarized where compliance was affected by the question of who controls the vehicle. For many other safety standards, they neither applied to nor affected the Olli Bus, or, in our view, did not impede or pertain specifically to the successful deployment of AVs on public roads. In these cases, such regulatory provisions were generally generic or esoteric and thus warrant no comment. For example, § 571.301 Fuel system integrity did not apply to Olli Bus since it is an all-electric vehicle, and the provision applies equally to all internal combustion engine vehicles, regardless of whether a human or ADS is in control. Also, to avoid redundancy, we did not include an assessment of FMVSS which resulted in similar findings as those already cited above, particularly those pertaining to visibility and functions intended for human drivers.

5.4.10 Current FMVSS Impede Advancement of AV Technology

Our analysis indicates that an AV, such as the Olli Bus, built to be operated by ADS, can never be in compliance with regulations which assume a human driver at the wheel and which are designed to support safety through the regulation of functions and equipment pertaining solely to human drivers. The Olli Bus cannot be legally tested on public roads because it does not meet FMVSS. Even if the

Olli Bus could achieve compliance, current FMVSS contain few provisions that provide meaningful guidance to AV Technology practitioners regarding the safety of AVs, much less that are, as written, even applicable to AVs.

Overall, the advent of AV technology has raised the question of who controls the vehicle and has exposed the underlying assumptions of a human-at-the-wheel inherent in the current regulatory regime. As we have shown, each of the FMVSS provisions cited above not only assumes that a vehicle is operated by a human driver, but that compliance to these provisions itself requires that a vehicle must be operated by a human driver. As a function of how the provisions are written, whether intentional or not, federal safety standards render all AVs that operate via ADS to be noncompliant. At best, some federal safety standards merely require that certain equipment normally used by human drivers be present and positioned in the vehicle in a particular way to optimize human control and visibility. The notion that AV technology practitioners might be required to outfit an AV with superfluous equipment, solely to meet federal safety requirements, even though the inclusion of such equipment has no impact on vehicle operation nor safety, immediately exposes the defects of a regulatory regime founded upon the human-at-the-wheel paradigm.

States have no power to provide regulatory relief from this issue. The 29 states that have enacted AV legislation since 2011 must each still adhere to the laws, rules and regulations promulgated by Congress and implemented by federal agencies per the Supremacy Clause of the U.S. Constitution. The New York State Demonstration and Testing of AV Technology legislation in part FF of chapter 55 of the laws of 2017, Section 1. a. states that “Such demonstrations and tests shall take place in a manner and form prescribed by the commissioner of motor vehicles including, but not limited to a requirement that a natural person holding a valid license for the operation of the motor vehicle's class be present within such vehicle for the duration of the time it is operated on public highways; a requirement that the motor vehicle utilized in such demonstrations and tests complies with all applicable Federal Motor Vehicle Safety Standards and New York state motor vehicle inspection standards; and a requirement that the motor vehicle utilized in such demonstrations and tests has in place, at a minimum, financial security in the amount of five million dollars.” Therefore, New York State’s law explicitly states “that the motor vehicle utilized in such demonstrations and tests complies with all applicable Federal Motor Vehicle Safety Standards” in conformance with the Supremacy Clause.

A new regulatory regime is needed that promotes safety through the regulation of a vehicle's functional performance, in addition to a vehicle's features, but that does not assume a human driver. We contend that such an approach is possible when regulations focus on efficacy and performance rather than human operations. In fact, we find that several FMVSS already follow this approach and thus prove the concept.

To demonstrate this point, we note that several dozen federal safety requirements pertain to the mechanical efficacy of a vehicle part—such as, § 571.106 Brake hoses, § 571.109 New pneumatic and certain specialty tires, § 571.116 Motor vehicle brake fluids, and § 571.117 Retreaded pneumatic tires. We also examined remain dozens of FMVSS that pertain specifically to the efficacy of vehicle systems, such as, § 571.105 Hydraulic and electric brake systems, § 571.113 Hood latch systems, § 571.114 Theft protection and rollaway prevention, and § 571.118 Power-operated window, partition, and roof panel systems, among many others.

We found in our analysis of these and other FMVSS that, unlike the other safety provisions examined in this report, do not inherently require that a driver be at the wheel, even if the assumption of a human driver remains implicit. Since these provisions focus on the mechanical efficacy of a specific tool or system, these provisions promote safety by ensuring functional performance independent of driver activities.

We emphasize this point because these regulations present tangible examples of our recommended approach that NHTSA should take with respect to the regulation of AVs and formulation of appropriate AV technology safety regulations. By removing the assumption that a human is driving the vehicle, and by instead focusing on the efficacy of the particular function, we contend that NHTSA can promulgate a new regime of safety regulations that help guide rather than impede the real-world deployment of AVs.

It is clear that current FMVSS fails to offer regulatory language that accommodates the construct of a vehicle operated by automated software systems as opposed to human actions. The human-at-the-wheel paradigm so pervasive to the current regulatory regime continues to have far-reaching adverse implications for the industry. This defect severely impedes the ability for practitioners to conduct the type of testing on public roads necessary to achieve learnings and technological breakthroughs.

5.5 FMVSS Exemptions

5.5.1 NHTSA Exemptions From FMVSS

The National Traffic and Motor Vehicle Safety Act authorizes the Secretary of Transportation to exempt a motor vehicle from a FMVSS or bumper standard on a temporary basis under specific circumstances and on terms the U.S. DOT Secretary deems appropriate. This authority is set forth at 49 U.S.C. 30113. The secretary has delegated the authority for granting such exemptions to NHTSA (NHTSA, 2018). NHTSA has the authority to grant exemptions from FMVSS that provide sufficient flexibility to accommodate a wide array of automated operations, particularly for manufacturers seeking to engage in research, testing, and demonstration projects.

This offers vehicles using AV Technology the opportunity to apply for a temporary exemption from the requirement to comply with FMVSS through the NHTSA exemption process. NHTSA guidance specifies certain conditions for manufacturer exemptions, including substantial financial hardship, development or field evaluation of a new motor vehicle safety feature, development or field evaluation of a low-emission vehicle, or an overall safety level of the exempted vehicle that is at least equal to the overall safety level of nonexempt vehicles. A general exemption for inconsequential defect or noncompliance is also available.

Exemptions from FMVSS for vehicle design, construction, and performance, have been relatively obscure. Companies requesting exemptions have done so to test a new technology that does not fit into existing rules. For automakers and industry practitioners seeking to deploy AV Technology on public roadways in the U.S., these rules seem to provide a basis for relief from requirements to comply with FMVSS that even the U.S. DOT has recognized pose a barrier to innovation. The availability of this exemption process, however, has not had the desired effect of providing a sustainable basis for ongoing AV technology deployments. A search of the Federal Register of temporary exemptions from Motor Vehicle Safety and Bumper Standards revealed that a total of only 54 notices, rules, or proposed rules have been published by NHTSA over the past ten years. There were 13 in 2011, five in 2012, eight in 2013, four in 2014, five in 2015, two in 2016, two in 2017 and four in 2018, six in 2019 and five in 2020 (up to April 30, 2020). This demonstrates that NHTSA only acts on few exemptions per year.

Of the 54, only three related directed to AV technology. The first and most recent was a Notice of Proposed Rulemaking (NPRM), published on March 30, 2020 as Docket No. NHTSA-2020-0014, entitled Occupant Protection for Automated Driving Systems, which stated that the proposal “is one of a series of regulatory actions that NHTSA is considering to address the near- and long-term challenges of testing and verifying compliance with the federal motor vehicle safety standards (FMVSS) for vehicles equipped with Automated Driving Systems (ADS) that lack the traditional manual controls necessary for human drivers, but that are otherwise traditional vehicles with typical seating configurations.”

The second was the granting of a petition, published on February 11, 2020 as Docket No. NHTSA-2019-0017, entitled “Nuro, Inc.; Grant of Temporary Exemption for a Low-Speed Vehicle with an Automated Driving System.” The published notice granted the petition of Nuro, Inc. (Nuro) for a temporary exemption from three requirements of FMVSS No. 500 under two bases (1) that an exemption would make the development or field evaluation of a low-emission motor vehicle easier and would not unreasonably lower the safety level of that vehicle and (2) that compliance with these requirements would prevent Nuro from selling a motor vehicle with an overall safety level at least equal to the overall safety level of a nonexempt vehicle. The vehicle that Nuro intends to manufacture under this exemption—the R2X—is a highly automated, electric, low-speed vehicle (LSV) that lacks seating positions and manual driving controls and is smaller, lower, and narrower than conventional vehicles. The exemption applies to the requirements that an LSV be equipped with exterior and/or interior mirrors; have a windshield that complies with FMVSS No. 205, Glazing materials; and a backup camera system that meets the requirement in FMVSS No. 111, Rear visibility, limiting the length of time that a rearview image can remain displayed by the system after a vehicle's transmission has been shifted out of reverse gear.

The third was a receipt of petition, published on March 19, 2019 as Docket No. NHTSA-2019-0016, entitled General Motors, LLC-Receipt of Petition for Temporary Exemption From Various Requirements of the Safety Standards for an All-Electric Vehicle With an Automated Driving System. It stated that, in accordance with the procedures in the Temporary Exemption from Motor Vehicle Safety and Bumper Standards, General Motors, LLC, (GM) has applied for a temporary exemption for its driverless Zero-Emission AV (ZEAV), an all-electric vehicle with an Automated Driving System (ADS), from part of each of 16 Federal Motor Vehicle Safety Standards (FMVSS). The ZEAVs would not be equipped with a steering wheel, manually operated gear selection mechanism, or foot pedals for braking and accelerating. If the requested exemption were granted, GM would use the ZEAVs to provide on-demand mobility services in GM-controlled fleets. GM requested the exemption be

granted on either or both of two statutory bases. First, it would facilitate the development or field evaluation of a new motor vehicle safety feature providing a level of safety at least equal to those of FMVSS from which exemption was requested. Second, it would facilitate the development or field evaluation of a low-emission vehicle without unreasonably lowering the safety performance of the vehicle. NHTSA sought comment on the merits of and most appropriate statutory basis for GM's exemption petition and whether the petition satisfied the substantive requirements for an exemption. NHTSA assessed the merits of the petition after receiving and considering the public comments on the notice, the petition, public responses to the questions in the notice, and any additional information that might be forthcoming from GM (NHTSA, 2019a).

The narrow scope of exemptions is further illustrated by NHTSA's own website which details Petitions For Rulemaking Received During This Administration and only lists six examples. This list does include the exemption requests by Nuro and General Motors detailed above (NHTSA, 2020c).

5.5.2 Expedited NHTSA Exemption Process

The exercise of NHTSA's authority to grant a temporary exemption to a vehicle manufacturer is conditioned upon certain findings. NHTSA must comprehensively evaluate the request for the exemption and find that the exemption is consistent with the public interest and with the objectives of the Vehicle Safety Act. In addition, NHTSA must make one of the following findings:

1. Compliance with the standard[s] [from which exemption is sought] would cause substantial economic hardship to a manufacturer that has tried to comply with the standard[s] in good faith.
2. The exemption would make easier the development or field evaluation of a new motor vehicle safety feature providing a safety level at least equal to the safety level of the standard.
3. The exemption would make the development or field evaluation of a low-emission motor vehicle easier and would not unreasonably lower the safety level of that vehicle.
4. Compliance with the standard would prevent the manufacturer from selling a motor vehicle with an overall safety level at least equal to the overall safety level of nonexempt vehicles.

A petitioner must provide the basis of its petition with certain required information explaining why the exemption would be in the public interest and consistent with the objectives of the Safety Act. In addition, the petitioner must submit data and analysis supporting the making of one of the four findings specified above.

If NHTSA determines that a petition is complete, it publishes a notice in the federal register summarizing the petition and inviting public comment on whether it should be granted or denied. However, if NHTSA

finds that a petition does not contain some type of the information required, NHTSA informs the applicant of the areas of insufficiency and that the petition will receive no further consideration until the required information is met. If the petitioner submits sufficient additional information and analysis to eliminate the areas of insufficiency, NHTSA publishes the notice requesting public comment.

After considering the petition and any public comments received, if NHTSA determines that the petition does not contain adequate justification, the administrator denies it and notifies the petitioner in writing. The administrator also publishes in the Federal Register a notice of the denial along with an explanation of reasons. Alternatively, if the administrator determines that the petition contains adequate justification, the administrator grants the petition, notifies the petitioner in writing, and publishes the notice of exemption granted and the reasons for granting it in the Federal Register.

Under the exemption rules, when an entity petitioned NHTSA for a FMVSS exemption, NHTSA would first be required to make a determination that the petition is complete (i.e., that it provides sufficient information for NHTSA to determine whether to grant or deny the exemption). Only upon this initial determination would NHTSA then publish a notice in the Federal Register summarizing the petition and inviting public comment on whether it should be granted or denied. Only then would NHTSA consider the substance of the petition and any public comments to determine whether the petition contains adequate justification to grant the requested exemption. This two-step process led to delays in processing petitions and consequently presented a significant barrier to innovation. Many recognized that the question of whether a petition was “complete” or whether it provided “adequate justification” were mutually exclusive questions. To streamline the exemption process, NHTSA eliminated the requirement that calls for the agency to determine a petition is complete before publishing a summary for public comment.

On December 18, 2018, NHTSA issued a statement announcing that, “the U.S. Department of Transportation’s National Highway Traffic Safety Administration today issued a final rule to streamline the application and review process for vehicle petitions submitted by manufacturers while continuing to prioritize safety for drivers, occupants, and other road users (NHTSA, 2018b).” Under the new rule, the agency will no longer determine whether the petition is complete before publishing the notice in the Federal Register. While NHTSA will still determine whether the petition contains adequate justification in deciding whether to grant or deny the petition, this was intended to enable a faster exemption process. The new rule, it says, will make the review process faster by eliminating that first decision point.

“Existing federal motor vehicle safety standards were developed when all vehicles had a human driver, and prior to the introduction of automated vehicle technologies, which are rapidly evolving,” Heidi R. King, NHTSA Deputy Administrator, explained in the press release, and further noted that, “improvements to transportation safety and efficiency are a key part of reimagining vehicles of the future. This rule [change] improves both the efficiency and transparency of the process to focus on the safety review.” Without the openings provided by exemptions, the auto industry would not be able to move significantly beyond traditional vehicle, regardless of advances in automated technology.

Not all industry stakeholders accepted the premise that NHTSA’s rule changes sufficiently protected safety and have been critical of the agency. The Center for Auto Safety, a consumer-advocacy organization based on Washington DC, stated that NHTSA acted unlawfully by crafting a new temporary exemption process which, in the view of the center, skirts long-standing notice and comment requirements and creates the potential for an incomplete petition (Center for Auto Safety, 2019). The center’s comments call for the review of both petitions to be suspended until NHTSA conforms with their interpretation of the law. The center claims that NHTSA’s issuance of a new temporary exemption rule at the same time as it considered the first applications of exemptions from the FMVSS for the deployment of AVs curtailed public participation in the rulemaking process in favor of expedited approvals for manufacturers who may not yet have demonstrated that their AV technology can meet some level of acceptable safety standards.

On October 19, 2018, the center petitioned NHTSA to immediately mandate the submission of safety information by companies testing automated vehicles system technology on public roads. Because their no uniform data collection process exists to address the scope of public testing and the success, failures, and lessons learned from the testing, NHTSA has missed an important opportunity to create a fact-specific baseline from which to consider petitions for exemptions on a merit basis. This has led to opposition to FMVSS exemption petitions proposed to NHTSA by leading manufacturers for purposes of supporting AV technology testing.

Nonetheless, AV technology companies have used the new rule by NHTSA, officially published on December 16, 2018 as Docket No. NHTSA-2018-0103 entitled Temporary Exemption from Motor Vehicle Safety and Bumper Standards as the mechanism to enable various tests and demonstrations across the U.S. This rule amends “NHTSA’s regulation on temporary exemption from the federal motor vehicle safety standards (FMVSS) and bumper standards to expedite the publishing of notices soliciting public comment on exemption petitions. It does so by eliminating the provision calling for the agency to

determine that a petition is complete before the agency publishes a notice summarizing the petition and soliciting public comment. As amended, the regulation continues to provide that the agency will, as it does now, determine whether a petition contains adequate justification in deciding whether to grant or deny the petition. The intended effect of these changes is to enable the agency to solicit public comments more quickly (NHTSA, 2018a).”

5.5.3 EasyMile Example

Since 2019, EasyMile, a manufacturer of fully automated, self-driving, low-speed, electric powered shuttles, similar to the design of the Olli Bus, has received approval from NHTSA through the exemption process to deploy its shuttles on public roadways in numerous locations across the U.S. Based on press reports detailed below, these deployments included Columbus, OH; Dover, DE; West Valley City, Park City, Farmington, and Salt Lake City, UT; Dallas, Houston, and Corpus Christi, TX; Dublin, CA; Golden, CO; Raleigh, NC; Gainesville, FL; Fairfax, Arlington, and Blacksburg, VA; and Basking Ridge, NJ. The NHTSA exemption allows EasyMile shuttles to transport passengers at 25 MPH or less, ensured operation was restricted to small geographic areas, and required a human attendant in the shuttle at all times to handle unexpected problems.

EasyMile, founded in 2014 and based in Toulouse, France is the manufacturer of the EZ10 shuttle first launched in April 2015. The EZ10 has many of the same attributes of the Olli Bus. The EZ10 is electric and driverless and “boasts a proven track record of over 200 deployments and more than 600,000 kilometers (km) driven in autonomous mode. The EZ10 is currently deployed on public and private roads and more than 25 countries over 4 continents.” EasyMile website states it is “Shared, flexible, and inclusive, the EZ10 is the best solution to solve the first and last mile challenge” and the “[v]ehicle insured worldwide with Allianz (EasyMile, 2020).” The EZ10 is a low-speed shuttle that generally runs at 25 MPH or less, is restricted to small geographic areas and has a human attendant on board to handle unexpected problems.

The EasyMile FMVSS exemptions granted by NHTSA are not published in the Federal Register, on the NHTSA website or at Regulations.gov. However, according to City of Adrian Rising Tide AV Project Grant Proposal submitted on March 21, 2019 to U.S. DOT for Notice of Funding Opportunity Number 693JJ319NF00001 "Automated Driving System Demonstration Grants" by the City of Adrian and EasyMile, “EasyMile is required to get a federal exemption from NHTSA to operate on public roads (as no autonomous shuttle complies with the current FMVSS standards). In October 2018, NHTSA updated their process for granting these approvals, and EasyMile was the first to apply and be approved

for projects via this new process. EasyMile was at the forefront of this change with the Federal Government during this process. This is a testament to the level of experience that EasyMile has deploying autonomous technology around the world and resulting in them as global leaders in this space. They continue to work closely with NHTSA, the Federal Transit Administration (FTA), Federal Highway Administration (FHWA), Volpe, and other branches of the Federal Government and work continually with California, Colorado, and other states as driverless regulations are developed and refined. The updated federal process requires the importer to submit vehicle and project-specific information. Once the application is submitted, the process is estimated to take less than 60 days. To date, EasyMile has successfully imported all of our vehicles (around 20 vehicles) and received approvals for all of projects (over 30 project-specific approvals).”

In addition, since EasyMile is based in France, it must complete a DOT HS-7 declaration form. The form provides that “vehicles temporarily imported for research, investigation, demonstrations or training, or competitive racing events” do not have to be modified to conform to FMVSS. A DOT HS-7 declaration form must be completed for each vehicle imported (NHTSA, 2016b).

Since EasyMile’s DOT HS-7 declaration form is also not published, it is only possible to document the number of deployments of the EasyMile EZ10 in the U.S. based on press reports. On May 20, 2020, the AP reported that NHTSA “told France-based EasyMile to halt passenger operations on low-speed shuttles in 16 U.S. cities after a mysterious braking problem occurred in Columbus, Ohio.” The AP article further stated that “the 12–15 passenger shuttles were halted in Columbus as well as Dover, DE; West Valley City, Park City, Farmington and Salt Lake City, UT; Dallas, Houston and Corpus Christi, TX; Dublin, CA; Golden, CO; Raleigh, NC; Gainesville, FL; Fairfax, Arlington, and Blacksburg, VA; and Basking Ridge, NJ.” This information provides a snapshot of the deployments of the EZ10. It appears that NHTSA has approved 16 EasyMile EZ10 shuttles to operate in projects in 16 cities across 10 states. The AP article further stated that NHTSA “approved EasyMile’s return-to-service plan.” EasyMile developed six corrective actions that were sufficient to reduce the safety risk of a sudden stop and “NHTSA also will review corrective plans for importers that hold permits to run each individual shuttle (AP News, 2020).”

Although EasyMile has achieved several deployments of driverless shuttles in the U.S., the nature and limitations of these deployments leads us to conclude that the current expedited exemption process and DOT HS-7 declaration form do not provide a sustainable regulatory process for the large-scale deployment of AV technology on public roads. The success of EasyMile to operate in the

U.S. under the exemption process represents an important industry milestone. But due to the requirement to maintain a human attendant, we question the ability to assess the true safety of its AV technology. For example, NHTSA in their review of EasyMile, provided no declaration on the safety and efficacy of EasyMile's Automated Driving System's ability to control braking. In order to assess whether the safety of AV technology is equal to or greater than existing motor vehicles, the AV technology must be evaluated in operation without intervention by a human. NHTSA is unable to assess or provide such an assessment at this time. This also signifies that NHTSA is still operating under a safety paradigm of human-in-control of the vehicle, that the exemptions granted to EasyMile did not foster the further advancement of AV technology on public roadways, and that its results would ultimately be of little or application value to the Olli Bus.

5.5.4 Mcity and NAVYA Example

We also researched the policy option of securing a FMVSS exemption from NHTSA as a user and not as a manufacturer. Perhaps the most prominent example in the U.S. is the success of Mcity to deploy the NAVYA shuttle, which is similar in design to the Olli Bus. Mcity is a public-private partnership at the University of Michigan (U-M) formed to manage a 32-acre mock city on the U-M North Campus in Ann Arbor, Michigan as a proving ground for the testing of AVs. The site includes 4.25 lane miles of roadway incorporating signalized intersections, a railroad crossing, a roundabout, a traffic circle, brick and gravel roads, parking spaces, and building facades and mock pedestrians that can be moved and altered to simulate different tests.

Mcity received an exemption in 2017 to deploy two shuttles equipped with AV technology. In June 2018, Mcity launched the first driverless shuttle project in the U.S. with two self-driving shuttles transporting students, faculty, and staff on the U-M campus. The Mcity project was designed to support data collection to understand vehicle performance, roadway interactions, and passenger attitudes. Similar to the Olli Bus Automated Electric Vehicle Campus Demonstration project, its goal was to achieve the ongoing, long-term deployment of driverless shuttles on public roadways. The exemption granted to Mcity supports the deployment of AV technology on the Mcity campus. However, because the NAVYA shuttles were confined to the Mcity campus, the Mcity exemption example did not further inform how the Olli Bus could achieve the wider deployment on public roadways.

The shuttles deployed in the Mcity project were built by NAVYA, a mobility technology company headquartered in Lyon, France. Like the Olli Bus, the NAVYA automated shuttles do not comply with U.S. or Canadian safety standards, were heavier than vehicles covered by applicable regulations for low-speed operation and were not certified to meet applicable FMVSS. For example, the following items required for FMVSS compliance were not present in the NAVYA driverless shuttles: airbags, traditional brake or accelerator pedals, and the standard “driver control interface” (i.e., a steering wheel), among others.

To facilitate a successful deployment, Mcity sought FMVSS exemptions from NHTSA prior to importing the NAVYA shuttles (M-City, 2018). Although Mcity requested the exemption as a user, not as manufacturer, NHTSA’s Office of Vehicle Safety Compliance granted an exemption for use of these automated shuttles on public roads. NHTSA recognized that non-compliance with FMVSS does not necessarily mean a lack of safety. The exemption letter specified three main elements: (1) a general description of the organization requesting the exemption, (2) a summary of the research project for which the exempted vehicle would be used, and (3) the type and nature of the vehicle. While seeking the exemption, Mcity provided NHTSA with a robust analysis from the manufacturer that sets forth the 12 guiding principles outlined in “Automated Driving Systems (ADS): A Vision for Safety 2.0” to aid in the application process.

As Mcity noted in its case study, seeking and obtaining an applicable exemption is not an insignificant undertaking. As the RAND Corporation notes in its study (Fraade-Blanar and Karla, 2017), any company petitioning NHTSA for an exemption will come under more scrutiny than it would deploying a conventional vehicle. For an exemption to be granted, manufacturers must provide proof of insurance and data collected during testing, making exempt vehicles the most vetted cars on the roads. Moreover, manufacturers must report to NHTSA if an exempt car is involved in an accident, adding greater scrutiny.

The waiver process is also cumbersome to NHTSA and requires significant resources and technical capabilities to properly process exemption petitions. Staff resources are limited. So is staff expertise. This raises questions about who does or does not get considered for an exemption, or how long an exemption application takes to be processed. Given the unlimited potential for new waiver exemption requests among AV technology practitioners with each new technological development that needs to be

tested, it is unclear if NHTSA possesses sufficient staff resources to handle the potential demand. The idea that the number of exemptions could be unintentionally limited or slowed due to bottlenecks in NHTSA exposes an important question about which petitions will ultimately be granted, on what basis, and how competing technical claims will be adjudicated.

NHTSA should establish and use performance standards to settle competing claims involving technical merit on a scientific and rigorous basis. No such performance-based standards currently exist. This void presents massive implications. Without technical standards to guide policymakers' decisions to grant or deny exemption petitions, claims cannot be technically substantiated and must be evaluated based on obsolete ideas or, when technological claims surpass known factors, guesses about the future. If the public interest calls for the development of safe AV technology, that interest is served when the process is a technical one. Aside from any normative concerns about fairness and a transparent, equitable regulatory process, this raises the concern that important and meaningful technical AV technology advances could go untested because their petitioners lacked the ability to secure a NHTSA exemption.

This once again leads us to conclude that the current expedited exemption process and DOT HS-7 declaration form do not provide a sustainable regulatory process for the large-scale deployment of AV technology. This is further illustrated by the business decision of NAVYA to end further manufacturing of driverless shuttles, as announced on July 25, 2019 (The Drive, 2019). In explaining why they exited from the market, NAVYA highlighted “the slow movement of legislation and development in the fully AV market and concedes the autonomous shuttle market will remain experimental for the next 24 months until the safety driver is removed.” The number of NAVYA deployments in the U.S. has not been published by NHTSA. However, worldwide, NAVYA reported sale of 18 autonomous shuttle vehicles in the first half of 2019, compared with 36 in the first half of 2018.

“I firmly believe that the autonomous mobility sector represents the future of goods and passenger transportation, as illustrated by the increasing intensification of our ecosystem,” said Navya’s CEO Étienne Hermite. He went on to say:

Its wide-scale implementation is, however, taking longer than anticipated at the time of our initial public offering. The market is still in an experimentation phase, as complete autonomy has not yet been achieved, the regulatory framework has yet to be uniformly established and economic models are continuing to evolve. We have decided to adapt our business model: thus, we will now provide our technology to industrials who want to make their vehicles autonomous [goods and passenger transportation]. Thanks to this new orientation, I am convinced that the teams' commitment and our technological leadership will be decisive assets that will enable us to seize market opportunities and make Navya a world leader in autonomous driving systems (AV International, 2019).

5.5.5 Nuro Example

On March 19, 2019, NHTSA published a notice of receipt of petition for temporary exemption, from Nuro, Inc. in Docket No. NHTSA-2019-0017. Nuro was seeking a temporary exemption from certain requirements in Federal Motor Vehicle Safety Standard (FMVSS) No. 500, which establishes standards for “Low-speed vehicles,” on the basis that an exemption would make the development or field evaluation of a low-emission vehicle easier without unreasonably lowering the safety of that vehicle (NHTSA, 2019b). The vehicle for which Nuro requested an exemption is a low-speed, autonomous, passenger-less delivery vehicle called the R2 that was intended to be operated without any human occupants and thus was designed without seating or human controls. Nuro sought to operate its R2 vehicle as part of a local delivery service for restaurants, grocery stores, and other businesses and needed a NHTSA exemption to execute its business plan. Specifically, Nuro requested exemptions from the requirements in FMVSS No. 500 that its vehicle be equipped with rearview mirrors, a windshield that complies with FMVSS No. 205, and a rear visibility (backup camera) system that complies with FMVSS No. 111. Nuro stated that the absence of human occupants, combined with the vehicle's various safety design features, including the vehicle's Automated Driving System (ADS), make compliance with these provisions of FMVSS No. 500 either unnecessary for, and detrimental to, the safety of pedestrians and cyclists.

After approximately fifteen months, on February 6, 2020, NHTSA announced that it granted Nuro's request for a temporary exemption from certain low-speed vehicle standard requirements. “Since this is a low-speed self-driving delivery vehicle, certain features that the Department traditionally required—such as mirrors and a windshield for vehicles carrying drivers—no longer make sense,” said Secretary Chao. Nuro will be permitted to produce and deploy no more than 5,000 R2 vehicles during the two-year exemption period.

In our analysis of the exemption requirements from the Low-Speed Vehicle standard (FMVSS No. 500), we found that testing a low-speed vehicle on public roadways could only occur without unreasonably lowering the safety of that vehicle. In its exemption request, Nuro was required to prove that, in the absence of human occupants, combined with the vehicle's various safety design features, its Automated Driving System made compliance with the provisions of No. 500 either unnecessary for, or not detrimental to, the safety of pedestrians and cyclists, even though it was designed to be a low-speed vehicle not occupied by a human. This means that, as part of the exemption processes as it currently stands, the applicant must proactively make the case to NHTSA for including innovative features in new vehicles, and that NHTSA shall only grant exemptions when the petitioner can prove that proposed features are as safe as traditional vehicles or safer than current safety standards. In the case of Nuro, the exemption was granted because it did not transport people and because it was a low-speed vehicle (i.e., the safety of low-speed vehicle impacting pedestrians and cyclists can be assessed based on mass and acceleration but not based on evaluating its Automated Driving System). However, neither of these points applies to supporting the deployment of the Olli Bus on public roadways.

As noted previously, in January 2018, GM had applied to NHTSA for a temporary exemption for its driverless all-electric ZEAV vehicle with an ADS (i.e., an AV), from part of each of 16 Federal Motor Vehicle Safety Standards. The ZEAVs would not be equipped with a steering wheel, manually operated gear selection mechanism, or foot pedals for braking and accelerating. If the requested exemption were granted, GM would use the ZEAVs to provide on-demand mobility services in GM-controlled fleets. On March 19, 2019, NHTSA published a notice in the Federal Register regarding that GM had filed a petition seeking an exemption to use fully automated vehicles as part of a ride-sharing fleet it plans to deploy in 2019 (NHTSA, 2019a). In two letters submitted to NHTSA, on May 20, 2019, the Center for Auto Safety urged NHTSA to reject both the Nuro and GM petitions for FMVSS exemptions. The center based its opposition, in part, on the concern that such exemptions constituted an abuse by automotive manufacturers to get around current safety rules and regulations in vehicles that the center believed should remain mandatory, despite the fact that those exact requirements were designed for cars with human drivers, not AV technology. The main concern the center raised was that safety had been sacrificed on the altar of technological innovation. In their interpretation, any exemption allowing

for the open-road testing of unproven technologies with uncertain safety features would relegate the role of consumers to that of human guinea pigs. The center, and others sharing this point of view, perceive safety itself as a deterministic outcome that should not be compromised on any level. They view any potential dangers to human life as too high a cost to justify any risk. Proof of zero risk is the only acceptable condition upon which AV technology testing should be allowed on public roads.

Regardless of the merits and substance of the arguments that the center and other critics of any particular exemption petition might pose, the fact that such substantive and vociferous opposition exists reveals the flaws of a process through which outcomes often reflect contested political considerations rather than solely technical merit. This ultimately shows that AV technology practitioners cannot rely upon the exemption process as a reliable means to achieve sufficient regulatory relief to enable legal deployments on public roads for testing purposes.

Exemptions are not loop-holes or giveaways to the auto industry, and they do not compromise safety, as some critics have warned. It is a misconception to perceive exemptions as waivers from safety requirements. In fact, exemptions are sometimes necessary to enhance safety. The exemption processes forces manufacturers to proactively make the case to NHTSA for including innovative features in new vehicles. NHTSA only grants exemptions when the petitioner can prove that its features are as safe as traditional vehicles or safer than current safety standards. However, this standard poses unique challenges to AVs when current safety standards are not performance-based.

Even new rules in the exemption process that reduced regulatory impediments have not resulted in AV deployments on a broader or more sustainable basis. Since 1994, according to a RAND Corporation study, only eight exemptions have been sought on the basis of developing or evaluating new safety features (Fraade-Blanar & Karla, 2017). NHTSA denied exemptions because the petition failed to show that the new safety feature provided a safety level equal to that of the FMVSS, that the exemption would facilitate testing, or both. The low figure underscores the chicken-versus-egg challenge that AV manufacturers face in demonstrating through the petition process that a feature provides the same level of safety as the FMVSS, or that the exemption would facilitate testing.

In a Catch-22 scenario, it is impossible to show that an AV is as safe as an existing vehicle for two reasons. First, as demonstrated previously, AVs are by definition non-compliant with FMVSS, and therefore cannot be tested on public roads. “For use on public roadways, automated vehicles must meet all applicable FMVSS.” If a manufacturer or other entity wishes to test or operate a vehicle that

would not meet applicable safety standards, “[t]he Agency encourages manufacturers to, when appropriate, seek use of NHTSA’s exemption authority to field test fleets that can demonstrate the safety benefits of fully AVs.” This statement also applies to entities that traditionally may not be considered “manufacturers” (e.g., alterers and modifiers) under NHTSA’s regulations. This precludes the possibility of demonstrating that an AV might be safe according to some baseline of performance standards corresponding to safety.

Second, even if an AV deployment on a public road could be legally undertaken, no performance baseline or standards exist or have been promulgated. Safety performance could be observed and measured but there would be no basis to quantitatively show that such performance met an acceptable threshold for safety.

On February 11, 2020, NHTSA granted Nuro’s petition for a temporary exemption from three provisions of FMVSS No. 500, “Low-speed vehicles (LSV).” NHTSA found that an exemption from the requirement that an LSV be equipped with exterior and/or interior mirrors, be equipped with FMVSS No. 205-compliant windshield, LSV’s backup camera would meet the “Linger Time” requirement of FMVSS No. 111 and an exemption from portions of the FMVSS No. 111 “Field of View and Image Size Test Procedure” and “Image Response Time Test Procedure” would not lower the safety of the Nuro R2X.

NHTSA stated that it has “broad authority and discretion in determining whether granting the petition is consistent with the public interest and Vehicle Safety Act and that it “finds that granting Nuro’s petition is consistent with the public interest and 49 U.S.C. Chapter 301 because an exemption would enable a limited-risk deployment” in terms of vehicle size, weight, and speed, as well as limited operational design domain and fleet size.

5.5.6 Conclusion

The NHTSA exemption process does not provide a solution and does not provide the permanent conditions needed for the sustainable, ongoing deployment of AVs. Although exemptions from existing standards have provided AV technology practitioners with some flexibility in the requirements to comply with FMVSS, they do so only on a temporary basis. Exemptions expire while FMVSS and related enforcement provisions remain codified in law. The U.S. DOT is clear on this matter:

Exemptions provide for limited exceptions to the obligation to comply with the FMVSS in certain circumstances specified in the Vehicle Safety Act. They are not intended to allow indefinite non-compliance for large numbers of vehicles. General exemptions are also not a device to excuse non-compliance with applicable standards simply because doing so would be inconvenient or inconsistent with the manufacturers' preferred vehicle design. Additionally, general exemptions are only temporary—two to three years, with the option for renewal for a similar time period (NHTSA, 2016).

The exemption process is intended to provide manufacturers with more time to achieve compliance. However, the ability of AVs to achieve FMVSS compliance is not a matter of time. AVs will never achieve full compliance with current FMVSS irrespective of how much time is made available to do so. Only a permanent solution will remove the significant obstacle that FMVSS pose to the sustainable deployment of AVs. Proposed solutions which call for the modification of the existing exemption process will still fail because the exemption process relies on traditional methods for evaluating vehicle safety that were designed for human drivers. That is why later in this report we recommend the development and adoption of a new regulatory approach in which AV technology systems are validated and verified to meet a set of incremental, performance-based benchmarks as a basis for demonstrating efficacy and safety.

5.6 Buffalo Principles

Earlier in this report, we summarized the legislative action taken since 2011 by 20 states and 10 executive orders to enable the testing of AV technology on public roadways. As we have documented, such action has had to occur on a state-by-state basis due to the lack of action at the federal level related to AV technology. We highlighted that the only federal action taken thus far has been the U.S. DOT publication of four nonbinding documents from 2016 to 2020 that provide voluntary guidance on AV technology. As a result, the legal and regulatory regime that was first enacted by the U.S. Congress in 1966 through the National Traffic and Motor Vehicle Safety Act, still remains in place today despite dramatic advancements in technology.

As we have demonstrated, the National Traffic and Motor Vehicle Safety Act, which established NHTSA to develop and enforce FMVSS, resulted in a regulatory framework designed to address safety solely from the perspective of a motor vehicle controlled by a human driver. Through our analysis, we have

illustrated how FMVSS are incompatible with AV technology. We further illustrated how FMVSS exemptions offered by NHTSA for testing AVs are only temporary in nature, require a human to be available to take control of the AV at all times and do little to quantify or evaluate the actual safety and efficacy of AV technology which is intended to be controlled by a system instead of a human.

Since the Olli Bus is designed to be operated without a human or human control, until there is permanent action taken by the U.S. Congress or NHTSA to address AV technology, it is impossible for the Olli Bus to be tested legally on public roadways. In fact, U.S. DOT in *Preparing for the Future of Transportation Automated Vehicles 3.0*, published in October of 2018 on page 7 clearly stated that “NHTSA’s current safety standards constitute an unintended regulatory barrier to innovation” for AVs such as the Olli Bus.

Due to the supremacy of the U.S. Congress and NHTSA over all states, including New York, the lack of action at the federal level of government related to AV technology has resulted in a tangible roadblock to the advancement and development of AVs, such as the Olli Bus. Nonetheless, through a compilation of lessons learned from the project, we have identified a new approach that we believe more quickly supports the ability for policy makers to gain a deeper understanding of AV technology necessary for them to take the legal and regulatory action required for the sustainable testing and deployment of AVs. This presents a tangible methodology for how practitioners can continue the advancement of AV technology to work around existing impediments until the necessary legal and regulatory changes are enacted.

This new approach shares strategies and tactics detailed in a paper published by Warren Walker (2000) in which he describes a systematic process for examining complex public policy choices and methods to assist policymakers in choosing preferred courses of action. Walker recognizes that “[i]n most real-world policy situations there are many possible alternatives, many uncertainties, many stakeholders and many consequences of interest. Also, there is usually no single decisionmaker and little chance of obtaining agreement on a single set of preferences among the consequences. As a result, there is no way to identify an optimal solution (Walker, 2000).” To address these issues, Walker summarizes methods to present relevant information to “the parties involved in the policymaking process in a manner that helps them come to a decision.” We believe that the best way to present relevant information to policymakers related to AV technology is through the Buffalo Principles that we define in this section of the report.

The Buffalo Principles are comprised of four key tenets that have been distilled from detailed analysis of the large amounts of evidence generated from the project. To advance AV technology, such as the Olli Bus, the Buffalo Principle detail value of (1) Testing on Private Roads, (2) Slow Speed Testing, (3) Recording Data of Testing, and (4) Integrated Simulation of Testing to offer what we believe are the most impactful public policy lessons learned from the project.

5.6.1 Buffalo Principle Number 1: Testing on Private Roads

The first Buffalo Principle, Testing on Private Roads, demonstrates how to fulfill the critical need to test AV technology in an open-roadway environment by overcoming the fact that AVs are prohibited from operating on public roadways due to non-compliance with FMVSS. This is possible because testing on privately-owned roads is exempt from FMVSS regulatory requirements.

The value of testing on private roads, embodied on the first Buffalo Principle of Testing on Private Roads, is evident by the impact of the two real-world demonstrations of an AV built by Southwest Research Institute (SwRI), held on June 9, 2016 in Saratoga Springs, NY and on June 24, 2016 in Buffalo, NY on public policy makers in the New York State to later enact on April 9, 2017 the New York State Demonstration and Testing of AV Technology legislation. These two demonstrations could not have occurred unless they were conducted in parking lots at both locations since parking lots are deemed private property and exempt from federal, State and local law as it relates to FMVSS.

Our team recommended that the demonstrations occur in parking lots because Section 129-B of the New York State Vehicle and Traffic Law defines a parking lot as "Any area or areas of private property near or contiguous to and provided in connection with premises having one or more stores or business establishments, and used by the public as a means of access to and egress from such stores and business establishments and for the parking of motor vehicles of customers and patrons of such stores and business establishments." Therefore, Section 129-B promulgates that parking lots are private property and as a result are exempt from federal, State, and local law and allows the AV built by SwRI from not complying with FMVSS, so that an AV can be tested without any regulatory limitation. In addition, since New York State had not passed its AV testing legislation until the following year, it was only possible to demonstrate an AV on private property at that time.

Recognition that Section 129-B promulgates that parking lots are private property inspired our team to inquire if the University at Buffalo North Campus, which encompasses over five square kilometers and many miles of roadway within the Town of Amherst, NY, also owns and operates private roadways within its campus. Privately owned and maintained roadways within university-owned property would constitute roadways also exempt from federal, State and local laws as it relates to FMVSS. University at Buffalo officials conducted an internal study to determine which of its roadway were private and determined that at least the service road, a one mile stretch of roadway in its North Campus was private. This provided critical information for our team to recommend a robust testing route for the Olli Bus from the Center for Tomorrow parking lot, to the service road, to the Crofts Hall parking lot round about and back on the service road. In total, this represented a one-mile loop that offered a real-world environment for the testing and evaluation of the Olli Bus.

This public policy analysis laid the foundation for the successful deployment and testing of the Olli Bus for the project. On September 29, 2016, NYSERDA PON 3345 Making Transportation Smart and Sustainable was released. It was determined that the University at Buffalo would respond to this opportunity if a suitable AV technology partner could be identified. Our team approached Local Motors with the request that if we partnered together all data generated from the project would be shared. Through discussions in October and November, a mutual understanding of shared benefits was agreed to between University at Buffalo and Local Motors. University at Buffalo, by owning private roadway and parking lots could provide a real-world testing environment for the Olli Bus and Local Motors would share with University at Buffalo all the data generated from the vehicle during testing. This led to our team to secure a Letter of Commitment from Local Motors on November 28, 2016 that was submitted with the University at Buffalo proposal to NYSERDA for PON 3345 on November 29, 2016.

On March 25, 2017, University at Buffalo received an award letter from NYSERDA indicating that its proposal for PON 3345 was funded. With passage on April 9, 2017, of the New York State Demonstration and Testing of AV Technology legislation there was the hope that this would support the testing of the Olli Bus and the project. Our Team informed University at Buffalo and NYSERDA that, unfortunately, due to FMVSS requirements, the legislation passed by the State of New York did not provide new testing opportunities for the Olli Bus. At that time there was concern among project stakeholders that the project would not proceed due to this regulatory hurdle. Our team recommended to stakeholders that, based on the evidence from the two demonstrations in 2016, that the testing of the Olli Bus could occur on private roads and parking lots. We supported University at Buffalo in securing

a letter from State University of New York (SUNY) to NYSERDA, dated May 15, 2017, that stated: “I am writing you regarding use and testing of the Olli Bus on the University at Buffalo’s (UB) North Campus. This letter is to confirm that UB has the legal authority to test AVs on certain roads that have been determined to be private and therefore not under the jurisdiction of the Department of Motor Vehicles for AV testing approval. In addition to testing on these private roads, UB may also test the Olli Bus in its parking lots, which are defined separately in the law and also are outside of DMV’s jurisdiction.” With this letter, NYSERDA accepted University at Buffalo’s Scope of Work (SOW) and proceed to contract execution for the project on November 16, 2017.

This evidence of relevant public policy information informed the development of first Buffalo Principle, Test on Private Roads. The value of testing on private roads is not limited to AV deployments in New York State. In fact, every state in the U.S., which each share a similar legal construct, could utilize the Buffalo Principle, Test on Private Roads, as a means to achieve AV technology deployments in public roadway settings. All private roads and parking lots are exempt from federal, State and local laws as it relates to FMVSS. This offers unlimited opportunities for testing of AV technology on private roads across the U.S.

In addition, the evidence to support the value of this first Buffalo Principle can be traced to 2004 when the initial civilian testing of AV technology funded by the Federal Government was initiated under the DARPA Grand Challenge (DARPA, 2005). In the report to Congress, DAPRA Prize Authority, Fiscal Year 2005 in accordance with 10 U.S.C. § 2374a by Defense Advanced Research Projects Agency (DARPA) published in March of 2006, it stated that “[o]n March 13, 2004, 15 robotic vehicles attempted the route through the Mojave Desert in pursuit of this goal. The most successful vehicle completed approximately seven miles of the 142-mile route.” This marked the first official Federal Government sponsored deployment of civilian ground AVs.

In order to allow this to happen, the 15 robotic vehicles could only be deployed on private roads due to the limitations of FMVSS. Thus, the section of Mojave Desert selected for the initial Grand Challenge had to be owned by the Federal Government and deemed federal land. As a result, it is exempt from federal, State and local laws as they relate to FMVSS and did not limit the ability to deploy AV technology for the DARPA Challenge. The report also explains that in the following year “40 teams were invited to attend the National Qualification Event (NQE) as Grand Challenge

semi-finalists...the NQE was held from September 28 to October 5, 2005, at the California Speedway in Fontana, California...with a 2.5-mile route included waypoints with associated speed limits and route width.” Again, the California Speedway is private property. Therefore, the 2.5-mile route was considered a private road that was exempt from FMVSS.

Finally, the report details that on “October 5, 2005, DARPA announced the 23 best-performing teams to travel to Primm, Nevada, and competed in the Grand Challenge Event (GCE)...the 132-mile route contained a series of graduated challenges beginning with a dry lake bed, narrow cattle guard gates, narrow roads, tight turns, highway and railroad underpasses...travel surfaces included broken pavement, gravel utility roads, and off-road trails...the route featured more than 50 turns of at least 90 degrees, leaving only a slim margin of error for vehicle navigation systems.” The report noted that DARPA “worked closely with the Nevada Bureau of Land Management to ensure compliance with local environmental and cultural restrictions and obtained a U.S. Fish and Wildlife Service Biological Opinion (in accordance with Section 7 of the Endangered Species Act of 1973, as amended) for the event”; however, DARPA did not have to seek any exemptions or approvals from NHTSA because the 132-mile route was on land considered private.

Overall, the initial deployments in 2004 and more recent AV technology tests demonstrate to policymakers the power of the first Buffalo Principle, Test on Private Roads. The testing on open roads so critically necessary to achieve meaningful advances AV technology can overcome the regulatory impediments posed by FMVSS by conducted them on private roads exempt from federal, State and local laws.

5.6.2 Buffalo Principle Number 2: Test Using Slow Speeds

The second Buffalo Principle, Test Using Slow Speeds postulates that testing AV technology should be conducted at slow speeds. This is advantageous for two reasons. First, vehicles moving at slower speeds pose a much lower safety risk. Second, proposed FMVSS exemptions which involve AV technology tests that will be conducted at slower speeds are more likely to achieve NHTSA approval.

The value of the second Buffalo Principle, Test at Slow Speed, is evident by the fact that the Olli Bus is programmed to have a maximum speed of 25 MPH. It is self-evident that testing of AV technology at slower speeds poses a much lower safety risk. As we detailed in section 4 of this report, the vast majority of FMVSS exemptions for AVs are granted by NHTSA for the testing of slow speed vehicles. NHTSA has granted these exemptions because their analysis has determined that AVs at slow speeds

are as safe as traditional vehicles or operation of AVs at slow speeds are safer than current safety standards. The unique nature of slow speeds is also supported by the fact that NHTSA has promulgated a specific safety standard for low-speed vehicles. As we summarized in section 3 of this report, 49 CFR § 571.500 - Standard No. 500; Low-speed vehicles that a low-speed vehicle is a four-wheeled motor vehicle whose top speed is more than 32 km/h (20 mph) and not more than 40 km/h (25 mph).

Just as the NAVYA, EasyMile, Nuro, and Olli Bus are all slow speed vehicles, a decade earlier, DARPA recognized that slow speeds should be a critical element in evaluating AV technology. Also, in the report to Congress, DARPA Prize Authority, Fiscal Year 2005 in accordance with 10 U.S.C. § 2374a by DARPA published in March of 2006, it stated that the goal of the DARPA Challenge was recognition that:

Autonomous ground vehicles operate in complex, dynamic environments that require layered, context-driven reasoning and sophisticated control strategies. When real-world factors such as inclement weather, difficult terrain, or limited visibility due to dust or nightfall are introduced, the problem of vehicle control at military-relevant speeds can quickly become intractable. While research on individual components or algorithms to address these challenges is valuable, the competition format of the Grand Challenge emphasizes full-system integration and reliable performance at realistic speeds (15-20 mph). Full-system solutions require design trade-offs and integrated solutions, with an emphasis on practicality and cost-effectiveness. Recasting the AV navigation problem in this way has sparked interest in new technologies and kicked off a new generation of innovative approaches.

The DARPA Challenge set realistic speeds of 15–20 MPH reiterating the value of slow-speed testing of AV technology that we have identified as a key tenet of the Buffalo Principles.

In DARPA’s report to Congress goes on to state that “[c]ourse speeds varied from 10 mph in sections deemed unsafe for higher speed, to 40 mph on the dry lakebed. Completing the 132-mile route required approximately 6 hours at the defined course speeds.” In addition, the winning team had the highest average speed of 19.1 MPH with the runners-up having demonstrated average speeds of 18.6, 18.2, and 17.5 MPH, respectively. Further, the DARPA Grand Challenge 2005 Rules published on October 8, 2004 stated on page 22, “A maximum speed limit is specified for each segment of the route. Any vehicle that exceeds the speed limit may be disqualified. A specified speed limit does not imply that it is a safe or achievable speed. Speed limits are specified in the route definition data file (RDDF) and apply to the

route segment defined by the associated waypoint to the next sequential waypoint. Between the start chutes and the first waypoint, vehicles may not exceed the speed limit of the first route segment. In the area where two route segments overlap, the least restrictive (i.e., higher) speed limit applies.” And on page 29, “The route definition data file (RDDF) specifies the official Challenge route. The RDDF is a comma-delimited text file distributed on a PC-formatted CD. Data fields will include waypoint number, waypoint latitude, waypoint longitude, lateral boundary offset, and speed limit (DARPA, 2004).”

In summary, there are several advantages to the slow-speed testing approach embodied in the Buffalo Principle, Test at Slow Speed. First, conducting testing at a slower vehicle speed reduces both the risk and cost of failure. Following the basic laws of physics, when collisions happen at high speeds, the degree of damage and potential loss of life increase exponentially, whereas collisions at slow speeds result in less damage. In addition, the use of slow speeds provides the driving system with additional time for accident avoidance and to make dynamic adjustments in real-time that may also minimize potential damage. Second, the perception of reduced risk resulting from slower-speed deployments may also prove to be a key decision-making factor among policymakers who are motivated by safety concerns. We believe that this was the case when our team secured the necessary approvals for the project to test the Olli Bus on private roads on the North Campus of University at Buffalo. We observed from the various stakeholders for the project that the perception of lower risk made an important difference in their decision-making process. This view is also expressed by Warren Walker in noting that, for most real-world policy situations, there are many possible alternatives and many uncertainties. It is the assurance of greater safety in the testing of AV technology that often proves to be most influential for policy makers, and we have shown that slow-speed testing greatly facilitates this assurance.

5.6.3 Buffalo Principle Number 3: Record Data

In recognizing that the availability of vast quantities of performance and other testing data is a critical to making technical advances in AV Technology, the third Buffalo Principle, Record Data, states that data should be captured and made available to other practitioners to support the ongoing achievement of industry-wide advances.

The value of the third Buffalo Principle, Record Data, is evident by the declaration of U.S. DOT in its initial 2016 AV technology guidance published on page 6 that stated “the data generated from these activities should be shared in a way that allows government, industry, and the public to increase their learning and understanding as technology evolves but protects legitimate privacy and competitive

interests.” In this publication, U.S. DOT goes on to offer on page 13 that “the manufacturer or other entity should address the cross-cutting items as a vehicle or equipment is designed and developed to ensure that the vehicle has data recording and sharing capabilities,” and on page 18 “[d]ata sharing is a rapidly evolving area that requires more research and discussion among stakeholders to develop consensus on data standards. For example, many manufacturers and other entities likely will want the ability to retrieve the data from vehicles they manufacture or sell and store the data for some period of time. The industry as a whole should work together with relevant standards bodies (IEEE, SAE International, etc.) to develop a uniform approach to address data recording and sharing (NHTSA, 2016a).”

In addition, on page 69, U.S. DOT states “[u]sing information gained from the manufacturers and the Agency’s continuing research, DOT will be able to specifically identify effective safety analyses and risk mitigation measures, such as: What metrics and data are needed to assess reliability and measure safety performance and effectiveness; What test procedures and equipment are needed for that purpose; What types of safety problems should a manufacturer consider for each type of automated driving function; and What risk mitigation strategies should a manufacturer consider?” And on page 80, U.S. DOT states,

[a]utomated vehicles will access and generate large amounts of data about the nearby roadway environment and roadway users (e.g., other motorists, bicyclists, and pedestrians), and use those data to make judgments and execute safety decisions. When crashes or near crashes occur, the best source of information for learning the underlying causes will be the vehicle itself—if the vehicle retains the data and a record of relevant decisions it made. To that end, NHTSA believes enhanced event data recorders would be useful to allow the Agency to reconstruct the circumstances of crashes and to gain an understanding of how a vehicle involved in a crash or incident sensed and responded to its driving environment immediately before and during the crash or near crash. Such data could provide insight to the answers to such crash- reconstruction-related questions as whether there were other roadway users nearby shortly before the crash or incident and whether the vehicle correctly and timely identified the other users and anticipated their speed and trajectories (NHTSA, 2016a).

In 2017, on page 14 of Automated Driving Systems 2.0, A Vision for Safety (U.S. DOT, 2017), U.S. DOT reiterated the importance of data recording in stating “entities engaging in testing or deployment are encouraged to establish a documented process for testing, validating, and collecting necessary data related

to the occurrence of malfunctions, degradations, or failures in a way that can be used to establish the cause of any crash. Data should be collected for on-road testing and use, and entities are encouraged to adopt voluntary guidance, best practices, design principles, and standards issued by accredited standards developing organizations.”

Also, in 2018, Automated Vehicles 3.0, Preparing for the Future of Transportation (U.S. DOT, 2018), U.S. DOT on page 50 details that “Voluntary Technical Standards for Automation” which consist of “Technology Areas, Functional Standards Areas and Safety Areas,” that data recording shall be included in Safety Area. On page 52, U.S. DOT under Relevant Standardization-Related Document by Functional Area list SAE J1698 standard for Event Data Recorder and on page 58 under Known Current Standards Development Activities Relevant to Automated Surface Vehicles lists SAE Event Data Recorder Committee and SAE Event Data Recorder Task Force.

In December 2019, U.S. DOT released Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0 and page 3 states “[g]iven that ADS are still currently in the R&D phase and not available for consumer purchase, data on collision rates for ADS under real-world conditions are limited at this time and a standardized vocabulary and methodology for evaluating and regulating their safety is still being developed by NHTSA, State regulators, and other stakeholders.” And goes on to say on page 16, “FHWA is Investigating different roadway/automated driving scenarios with a focus on the data and systems that will be needed to enable ADS to exchange data to successfully navigate challenging roadway scenarios (U.S. DOT, 2019).”

The importance of recording data was implicit in rules, reports and other documentation related to the DARPA Challenges involving the deployment of AV Technology. For example, in its report to Congress in 2005 DARPA detailed on page 6 that “[e]ach team was required to submit a technical paper describing its vehicle system architecture, sensor system, processing system, testing plan, and other technical specifications. The papers were openly published to enable technical interchange among teams and with others in the robotics community.”

The DARPA Grand Challenge 2005 Technical Paper Guidelines published on July 19, 2005 summarized the content of each technical report shall include a description of the vehicle and all key aspects of its autonomous operations including processing, localization, sensing, vehicle control and systems tests. These technical reports were widely circulated and provided key data elements for the later development of numerous AV technology solutions.

Even current federal regulations underscore the importance of capturing data that can inform analysis which leads to functional improvements. Although Title 49: Chapter V, Part 571, Subpart B—Federal Motor Vehicle Safety Standards; Part 563: Event Data Recorders was promulgated in the context of vehicular safety, its provisions clearly demonstrate the principle importance of capturing data, as illustrated in the following passages:

Scope and Purpose: This part specifies uniform, national requirements for vehicles equipped with event data recorders (EDRs) concerning the collection, storage, and retrievability of onboard motor vehicle crash event data. It also specifies requirements for vehicle manufacturers to make tools and/or methods commercially available so that crash investigators and researchers are able to retrieve data from EDRs. The purpose of this part is to help ensure that EDRs record, in a readily usable manner, data valuable for effective crash investigations and for analysis of safety equipment performance (e.g., advanced restraint systems). These data will help provide a better understanding of the circumstances in which crashes and injuries occur and will lead to safer vehicle designs.

Application: Passenger cars, multipurpose passenger vehicles, trucks, and buses with a GVWR of 3,855 kg (8,500 lb) or less and an unloaded vehicle weight of 2,495 kg (5,500 lb) or less manufactured on or after September 1, 2012, if equipped with an EDR; exempted from this part are: walk-in van type trucks or vehicles designed to be sold exclusively to the U.S. Postal Service. This part also applies to manufacturers of those vehicles. However, vehicles manufactured before September 1, 2013 that are manufactured in two or more stages or that are altered (within the meaning of 49 CFR 567.7) after having been previously certified to the FMVSSs in accordance with part 567 of this chapter need not meet the requirements of this part.

The principle of recording and sharing raw data generated from AV technology testing is about making that data available to the public for analysis and review. Allowing researchers and practitioners to access raw data will ultimately accelerate the pace of innovation when the lessons of ongoing deployments inform the design and rigor of future ones. The importance of sharing data across the industry as a means to advance technological breakthroughs is underscored by the fact that Waymo, the leader in AV technology in terms of dollars invested and vehicle miles tested, on August 21, 2019 announced the release of the Waymo Open Dataset, a high-quality multimodal sensor data set for autonomous driving.

In their announcement on the website Medium, Waymo states:

[d]ata is a critical ingredient for machine learning. Our vehicles have collected over 10 million autonomous miles in 25 cities; this rich and diverse set of real-world experiences has helped our engineers and researchers develop Waymo's self-driving technology and innovative models and algorithms. Today, we are inviting the research community to join us with the Available free to researchers at waymo.com/open, it is comprised of high-resolution sensor data collected by Waymo self-driving vehicles. The data set covers a wide variety of environments, from dense urban centers to suburban landscapes, as well as data collected during day and night, at dawn and dusk, in sunshine and rain (Medium, 2019).

The Waymo Open Dataset is one of the largest, richest, and most diverse self-driving data sets ever released for research and contains data from 1,000 driving segments. The website states,

Each segment captures 20 seconds of continuous driving, corresponding to 200,000 frames at 10 Hz per sensor. Such continuous footage gives researchers the opportunity to develop models to track and predict the behavior of other road users. It covers dense urban and suburban environments across Phoenix, AZ, Kirkland, WA, Mountain View, CA and San Francisco, CA capturing a wide spectrum of driving conditions (day and night, dawn and dusk, sun and rain); contains sensor data from five high-resolution Waymo lidars and five front-and-side-facing cameras; includes Lidar frames and images with vehicles, pedestrians, cyclists, and signage carefully labeled, capturing a total of 12 million 3D labels and 1.2 million 2D labels.

Recoding and sharing AV technology data provides the research community with the data needed to support the achievement of substantial technological breakthroughs, it is also a tacit admission by these firms of their inability to achieve such breakthroughs on their own.

For the project, as a result of recoding all the raw data from the 15 sensors on the Olli Bus, University at Buffalo has accumulated one of the richest AV technology data sets in New York State, and this offers tremendous research and development opportunities throughout industry, university, and government.

5.6.4 Buffalo Principle Number 4: Use of Integrated Simulation

The fourth Buffalo Principle, Use of Integrated Simulation, affirms the importance of using computer simulation and modeling as a basis to test the efficacy of AV technology software functions and to discover unforeseen challenges prior to conducting real-world deployments. Using both real-world and augmented AV data in simulated testing environments will help practitioners and researchers to better understand edge cases and deployments at higher speeds to ensure AVs can operate safely in more challenging real-world environments. In contrast, achieving learning about high speeds, challenging driving conditions and edge cases through the trial-and-error of real-world deployments presents high-risks and high costs. A real-world deployment presents a form of verification and validation, not discovery.

The use of integrated simulation is considered standard best practice in AV technology testing because the underlying reality is that the ADS handling the Dynamic Driving Tasks in AVs are software systems. Naturally, best practices for AV technology development and deployments follow the same process and take advantage of the same tools as software development. Verification, validation, traceability, running and testing, among others, are used to determine performance of individual AV software in a test bed environment to predict how the AV itself will perform in a real-world deployment. Integrated simulation allows us to assess the limits and capabilities of a vehicle without having to guess. Only when an AV demonstrates through integrated simulation that it can operate effectively in the rain, for example, should the vehicle be tested in the rain in a real-world deployment where it could come in contact with vehicles driven by humans, pedestrians, and cyclists. In fact, the output of integrated simulations could be used by researchers, or even prospective buyers, as a means for performance measurement given various Operations Design Domains (ODDs).

Each of the documents published by the U.S. DOT as guidance to AV technology industry support this view. For example, U.S. DOT in its initial 2016 AV technology guidance states that “tests should be developed and conducted that can evaluate (through a combination of simulation, test track or roadways) and validate that the HAV system can operate safely with respect to the defined ODD and has the capability to fall back to a minimal risk condition when needed (NHTSA, 2016a).” This perspective was reiterated in 2017, in AV 2.0, in stating that “to demonstrate the expected performance of an ADS for deployment on public roads, test approaches may include a combination of simulation, test track, and on-road testing (U.S. DOT, 2017).” In AV 2.0, the U.S. DOT further indicated that prior to on-road testing, entities are encouraged to consider the extent to which simulation and track testing may be necessary. Further, the U.S. DOT supported that testing may be performed by the entities themselves

but could also be performed by an independent third party. U.S. DOT recommended that entities should continue working with NHTSA and industry standards organizations (SAE, International Organization for Standards [ISO], etc.) and others to develop and update tests that use innovative methods as well as to develop performance criteria for test facilities that intend to conduct validation tests.

In 2018, with AV 3.0 U.S. DOT noted that “standards could provide for a range of potential behaviors—e.g., speed, distance, angles, and size—for surrogate vehicles, pedestrians, and other obstacles that ADS-equipped vehicles would need to detect and avoid. Other approaches, such as computer simulation and requirements expressed in terms of mathematical functions could be considered, as federal law does not require that NHTSA’s safety standards rely on physical tests and measurements, only that they be objective, repeatable, and transparent (U.S. DOT, 2018).” Further, U.S. DOT also defined an approach that seeks to prioritize and enable voluntary data exchanges to address critical issues that could slow the safe integration of ADS technologies (U.S. DOT, 2018).”

In 2020, with the release AV 4.0, U.S. DOT noted that, “National Institute of Standards and Technology (NIST) supports the development and use of measurement science in voluntary consensus standards, conformity assessment, and related tools. This work is enabling the development, deployment, and assurance of ADS. NIST’s Cyber-Physical Systems Program is developing methods for measuring AV trustworthiness (safety, security, resilience, reliability, and privacy) to support performance measurements for ADS. The goal is to enhance existing methods for validating vehicle trustworthiness—for example to support new modeling and simulation capabilities in ADS-equipped vehicles (U.S. DOT, 2019).”

5.6.5 The Nuro Deployment Affirms the Efficacy of the Buffalo Principles

As additional validation of the effectiveness of the Buffalo Principles as a deployment strategy, the methods that other industry practitioners have used to achieve successful AVs deployments closely follow the Buffalo Principles. The Nuro case study examined in section 4 offers a prime example.

Regarding the first Buffalo Principle, Testing on Private Roads, in its Voluntary Safety Self-Assessment it states:

Nuro tested our vehicles on private roads to ensure the software works in practice. Before putting our custom vehicles on public streets, we modified passenger cars with the same sensors and self-driving software as our custom vehicle and put teams of experienced and highly trained safety drivers behind the wheel, to avoid exposing the public to risk while testing the self-driving software. These safety drivers can take over at any time, or even

use a failsafe stop button to disconnect the self-driving system if needed. Once we deploy our fully self-driving, custom vehicles, we will use a remote operator as a backup, able to take control of the vehicles and navigate them to a safe position. Each step in this testing program helps the system learn and improve, and the vehicle must pass critical thresholds before it is allowed to go to the next step (Nuro, 2020).

Regarding the importance of training on private roads, Nuro noted that “before any Nuro vehicles operate in self-driving mode on public roads, we conduct extensive bench testing, computer modeling, simulated testing, and driving on private roads, all using hundreds of common and uncommon scenarios tested thousands of times. Our testing always uses highly trained safety drivers as a backup (Nuro, 2020).” Nuro further explained that its rigorous training for back-up drivers includes:

hours of practice on private roads, [so] these safety drivers are able to remotely monitor a vehicle and take over if required. The training program for remote operation requires operators to proceed through six steps of training, progressing through increasingly difficult courses. Training begins with self-driving, traditional vehicles on private roads and parking lots, with a safety driver in the vehicle as well, able to take over in case of any issues. The remote operators must repeatedly pass defined tests at each stage before moving forward or training on public roads (Nuro, 2020).

For the second Buffalo Principle Using Slow Speeds, Nuro specifically “designed, prototyped, and extensively tested a custom, low-speed, zero-emission, self-driving vehicle in its Voluntary Safety Self-Assessment. It is engineered for short neighborhood trips and for the exclusive purpose of transporting and delivering goods (Nuro, 2020).” Nuro noted that for “[l]ower speed operation: Nuro’s vehicle is designed to operate exclusively at or below 25 miles per hour. That low speed gives us more time to react and prevent collisions. Having no passengers means we can take the extra time to drive carefully and always stay on the side of safety.” Nuro recognized the importance of emphasizing its operations at slow speed as evidence of its safety. “Our reduced mass and low speed will reduce the force of any potential impact relative to a passenger car, and we also designed the vehicle to provide additional pedestrian protection (Nuro, 2020).”

For the third Buffalo Principle, Record Data, in its Voluntary Safety Self-Assessment, we observed that Nuro uses data recording to capture information on trips and surroundings for use in continually improving its self-driving system. In its Voluntary Safety Self-Assessment Report, Nuro emphasized the importance of recording data to make ongoing technical progress and described the elaborate and sophisticated data the Nuro vehicle generated and collected:

Recording what is happening in and around our vehicles powers the machine learning that enables continuous improvement of the self-driving software. By capturing details from our test and real-world drives, we can build simulations to practice challenging situations or evaluate a system's performance, ultimately building a more capable self-driving vehicle. Nuro can then apply the learnings from any one of these vehicles to the entire fleet to improve safety and efficiency. Similarly, we capture data during testing on hardware performance and analyze it to ensure all systems are meeting our specifications. For example, we examine the power supply system to ensure its voltage stays within our tolerances, and if the computing system detects a deviation, this gives us the opportunity to investigate and improve the design. We gather detailed data from onboard sensors, the driving systems, and all software systems throughout every trip, enabling us to recreate key events. Were a collision to occur, we can use these data to understand how the vehicle was moving, what it was perceiving, and what movement it had planned. To ensure we have access to critical logs even if there is damage to computing systems, we also have onboard a high-reliability computer with secure, redundant data storage devices—our equivalent to the airplane's "black box." To protect customer privacy, we also do not personally attribute onboard data (Nuro, 2020).

With respect the fourth Buffalo Principle, Use of Integrated Simulation, the Nuro Team also reiterated the importance of using integrated simulation to achieve technical progress but also to protect the public as a safety measure to lessen the risks of deploying AV technology in conditions with unknown or potentially dangerous outcomes. The use of integrated simulation helps identify which conditions pose safety risks based on the capabilities of the AV to operate in those conditions or based on conditions that have not yet been encountered:

Our approach to validating the Nuro self-driving technology is rooted in our philosophy that we should avoid exposing the public to harm during the development and testing process. Therefore, we use a several step process, including simulation, private-road testing, real-world driving, and accelerated testing. Before deploying unmanned vehicles

on public roads, the software must reliably meet our performance requirements in simulation and private-road testing. Simulating the performance of the self-driving system enables us to validate performance at scale, without exposing the public to risk. Using manned vehicles, we have built up a large set of logged data of real-world driving conditions that we can use to evaluate the performance of our system (and any incremental changes made to the system) by simulating self-driving on all the logged data. We do this both in a large-scale manner, where we use as much data as possible to ensure reliability, and in targeted scenario simulations (accelerated testing, described below), to ensure the vehicle can navigate difficult situations or simulated equipment failures. We then compare the performance against our benchmarks to ensure we are meeting our requirements and advancing towards our goal of being the safest vehicle on the road. Real-world driving validates the accuracy of the simulation, collects data on how the entire vehicle performs under the conditions it will eventually need to handle on its own, and finds additional complex cases to challenge and improve our software (Nuro, 2020).

5.6.6 Conclusion: The Buffalo Principles Provide a Sustainable Basis for AV Deployments

As a means to continue research efforts involving real-world deployments, the Buffalo Principles support New York State’s desire to be a leader in AV technology research and development. The Olli Bus demonstration project brings this goal closer to fruition. However, given the regulatory hurdles and technical challenges this project encountered, achieving the Olli Bus deployment required an exceptional effort. An exceptional effort should not be required. The fact that requiring a massive degree of effort is the industry norm to successfully deploy an AV is an unacceptable condition and demonstrates in stark terms why AV technology has failed to advance. By mitigating these conditions, the Buffalo Principles offer two distinct opportunities: one as guidance to practitioners, the other as guidance for a new regulatory approach.

First, as guidance to industry practitioners, we have identified an approach that can accelerate vital development of AVs and when followed, the Buffalo Principles offer a tangible set of guidance for AV technology practitioners to overcome barriers to sustainable real-world AV technology deployments to enable the research work that will produce insights, learnings, incremental improvements, and

eventually, technological breakthroughs. The successful deployment of the Olli Bus offers tangible proof. By testing the Olli on private roads and parking lots at slow speeds, and in using integrated simulations and recording and sharing data widely, the Olli Bus overcame the State and federal regulatory hurdles that would have otherwise prevented the deployment.

The Buffalo Principles also underscore the fact that all AVs are software systems which develop through integrated simulation in a test bed and then hardened through real-world deployments. This tells us precisely what we need from regulators. The regulation of AVs should be based on how one might regulate software development. Regulators should not regulate the permission of each technical advancement, which has been the current approach. This has required the ongoing mastery of each technical detail as technology advances and is neither practical nor sustainable. Instead, regulators have an opportunity to understand that levels of software efficacy can be quantified to form the basis of performance-based requirements. In this new approach, required thresholds of software efficacy could be defined in regulation that spell out when a real-world AV technology deployment would be allowed or not allowed to occur. This approach could fulfill the need to maintain safety standards while promoting rather than hindering technological advancements.

5.7 Suggested Language for New York State

The deliverables for Task 3 of the project include the development of “Suggested Language for NYS,” where the “[c]ontractor shall draft permanent legislation for NYS to allow for testing and deployment of AVs beyond the April 1, 2018, budget provision.” In this section of the report, we present our Suggested Language for NYS. To achieve the deliverable, we applied the Buffalo Principles strategy detailed in section 5 and found that the Buffalo Principles were effective in achieving rapid action by policymakers.

The development of the Suggested Language for NYS began after the first public demonstration of the Olli Bus. On August 9, 2018, as part of the Fourth Annual Symposium on Transportation Informatics, held at the University at Buffalo, where our team participated in the Organizing Committee, our team and the other members of the project hosted the first public demonstration of the Olli Bus. As part of the demonstration, attendees of the symposium were able to ride in the Olli Bus and gain real-world experience and knowledge of AV technology. This event was widely covered in the local and regional media and many local officials who could not attend the event on August 8, 2018 asked if the project team could schedule other demonstrations so that they could also witness and experience AV technology.

Through this process, the project team hosted a demonstration of the Olli Bus on April 17, 2019 for New York State Senator Tim Kennedy who is the Chairman of the State Senate Transportation Committee. Senator Kennedy was so impressed with the demonstration that he asked how he could help to further the project.

In response to this request, our team prepared a letter to Senator Kennedy, along with other members of the project, detailing our support for the Suggest Language for NYS. This letter was entitled Buffalo Principles Automated Vehicle Study and was dated May 8, 2019. After the background section of the letter which provided an overview of the project, our team detailed the value and opportunity of the Suggested Language for NYS. In the letter we stated:

Despite authorization for testing AVs in New York State beginning in 2017, few companies have taken advantage of the opportunity, apart from two isolated tests by Cadillac and Audi in 2017. The majority of AV testing in the US is occurring in California (CA), Arizona (AZ), Michigan (MI) and Pennsylvania (PA). However, AV testing in these States is only occurring using traditional motor vehicles that have been retrofitted with AV technology. The untapped potential is testing for vehicles that have been designed like Olli to be driverless. This cannot occur until NHTSA develops new FMVSS for AV.

The U.S. DOT published on October 5, 2018 Preparing for the Future of Transportation: Automated Vehicles 3.0 which offered: “There may be no steering wheel, accelerator pedal, brakes, mirrors, or information displays for human use. For such Automated Driving System (ADS)-equipped vehicles, NHTSA’s current safety standards constitute an unintended regulatory barrier to innovation.”

By testing the Olli Bus on private roads and parking lots, our team identified an approach that can accelerate vital development of AVs and make New York a leader in AV Technology research and development. To recap, the four Buffalo Principles for the sustainable real-world deployment of AVs are as follows.

1. **Private Roads:** Test on private roads and parking lots that are exempt from federal, State and local law.
2. **Slow Speeds:** Test at slow speeds of below 25 miles per hour.
3. **Record Data:** Record and store all data generated from AV testing and make that data available to the public for analysis and review.
4. **Integrated Simulation:** Conduct integrated simulation of real-world and augmented AV data to understand edge cases and deployments at higher speeds to ensure AVs can operate safely in more difficult environments before deploying those AVs in the real world.

On March 4, 2019, the Mayor of Pittsburgh issued an executive order (Mayor William Peduto, 2019) outlining his objectives for safe testing of AVs which he called the “Pittsburgh Principles.” Companies including Aptiv, Argo AI, Aurora Innovation, as well as Carnegie-Mellon University and Uber are all testing in Pittsburgh. Our Buffalo Principles can make New York competitive in AV testing as well.

To expand the Buffalo Principles and increase innovation in New York, UB is requesting to increase the number of private roads on UB North Campus designated for AV testing.”

5.7.1 The Introduction of AV Legislative in NYS

In the appendix of the May 8th letter to Senator Kennedy, our team included a draft of the “Suggested Language for NYS,” as illustrated below.

An ACT authorizing the commissioner of transportation to conduct a comprehensive study on designation of private roads on the University at Buffalo North Campus for the purposes of AV technology testing.

THE PEOPLE OF THE STATE OF NEW YORK, REPRESENTED IN SENATE AND ASSEMBLY, DO ENACT AS FOLLOWS:

Section 1. Legislative Intent. The legislature recognizes that the safety and mobility of all citizens is of utmost concern to the State. That AV technology possesses the capability of increasing pedestrian and passenger safety, reduce traffic and congestion and improve the movement of goods and services across the state. That the majority of motor vehicle accidents are due to human error and AV technology may possess the ability to eliminate some of these motor vehicle accidents. That AV technology is unproven and requires greater testing and the State of New York is a testbed for innovation that balances the safety and needs of its public against the need for technological advancement.

The legislature also recognizes that the University at Buffalo has the legal authority to test AV technology on certain roads that have been determined to be private and therefore not under the jurisdiction of the New York State Department of Motor Vehicles for AV technology testing approval. In addition to testing on these private roads, University at Buffalo may also test AV technology in its parking lots, which are defined separately in the law, and also are outside of New York State Department of Motor Vehicles jurisdiction.

For the purposes of this act, the term "AV technology" shall mean the hardware and software that are collectively capable of performing part or all of the dynamic driving task on a sustained basis, and the term "dynamic driving task" shall mean all of the real-time operational and tactical functions required to operate a vehicle in on-road traffic, excluding the strategic functions such as trip scheduling and selection of destinations and waypoints.

In order to increase the routes available on the University at Buffalo North Campus for AV technology testing the New York State Department of Transportation has the knowledge and expertise to review traffic flow on the roadways within the University at Buffalo North Campus to identify roads that could be deemed private without impacting existing traffic conditions in and around the University at Buffalo North Campus.

§ 2. The department of transportation shall undertake a comprehensive study on designation of private roads on the University at Buffalo North Campus for the purposes of AV technology testing. The scope of this study shall include:

1. Review of existing traffic patterns in and around the University at Buffalo North Campus.
2. Determination of the mobility needs of the University at Buffalo students, faculty and staff.
3. Recommendations for which roads within the University at Buffalo North Campus would provide the greatest benefit to AV technology testing and cause the least effect on existing traffic patterns in and around the University at Buffalo North Campus.
4. Methodology to transfer recommended roads to private roads.

§ 3. The department of transportation shall make a report to the governor and the legislature of its findings, conclusions and recommendations no later than one year after the effective date of this act and shall submit with this report such legislative proposals as it deems necessary to implement its recommendations.

§ 4. This act shall take effect immediately.

Our team was pleased that on May 16, 2019, Senator Kennedy introduced our Suggested Language for NYS in its entirety as S. 6052 in the New York State Senate. Shortly thereafter, on July 8, 2019, Assemblywoman Karen McMahan, introduced A. 8460 in the New York State Assembly, which was identical to S. 6052. The bills introduced by State Senator Kennedy and Assemblywoman McMahan codify recognition by the New York State Legislature that AV technology possesses the capability of increasing safety but remains unproven and requires greater testing. It further stipulates that the University at Buffalo has the legal authority to test AV technology on certain roads that have been determined to be private and therefore not under the jurisdiction of the New York State Department

of Motor Vehicles for testing approval. In addition to testing on these private roads, University at Buffalo may also test AV technology in its parking lots, which are defined separately in the law, and also are outside of New York State Department of Motor Vehicles jurisdiction. Thus, the purpose of S. 6052/A. 8460 is to increase the routes available on the University at Buffalo North Campus for AV technology testing and requires the New York State Department of Transportation to identify roads that could be deemed private without impacting existing traffic conditions in and around the University at Buffalo North Campus which would directly increase the testing of the Olli Bus in accordance with the objective of Task 3 of the project.

The Suggested Language for NYS in S. 6052/A. 8460 progressed quickly in the New York Senate and as of March 10, 2020 was in its third reading. Here is a summary of the most recent legislative action for S. 6052 / A. 8460:

S6052-B KENNEDY. Same as A 8460 McMahan.

ON FILE: 06/17/19 Transportation.

TITLE Authorizes the commissioner of transportation to conduct a comprehensive study on designation of certain roads for the purposes of AV technology testing.

05/16/19	REFERRED TO TRANSPORTATION
05/30/19	1ST REPORT CAL.1083
06/03/19	2ND REPORT CAL.
06/04/19	ADVANCED TO THIRD READING
06/13/19	AMENDED ON THIRD READING (T) 6052A
06/17/19	AMENDED ON THIRD READING 6052B
06/20/19	COMMITTED TO RULES
01/08/20	REFERRED TO TRANSPORTATION
03/03/20	1ST REPORT CAL.570
03/04/20	2ND REPORT CAL.
03/10/20	ADVANCED TO THIRD READING

Unfortunately, due to the COVID-19 pandemic, the New York State Senate and Assembly shortened their time in session, starting in April of 2020, which precluded further action on S. 6052/A. 8460.

This outcome is certainly understandable due to the unprecedented circumstances of the COVID-19 pandemic. Nevertheless, this legislative delay does not diminish the remarkable success and impact of the Buffalo Principles to date in facilitating public policy action around AV Legislation, evident in the rapid advancement of the Suggested Language for NYS in 6052/A. 8460.

In fact, according to information published on Legiscan, during the 2019–2020 New York State Legislative Session, only four bills were introduced in the New York State Assembly related to AV technology out of the 22,391 total bills introduced (<https://legiscan.com/NY/datasets>). Thus, AV technology related legislation represents only 0.02 percent of all legislation introduced in the 2019–2020 New York State Legislative Session. For this report, we use the New York State Assembly as the baseline for comparison because it represents an even greater number of elected officials and quantity of pieces of legislation introduced each New York State Legislative Session. The New York State Assembly has 150 members compared to the New York State Senate which has 63 members. The State of New York has a two-year Legislative Session.

The fact that so few bills introduced in the New York State Assembly during the 2019–2020 New York State Legislative Session were related to AV technology, despite the clear need to address regulatory needs, underscores several challenges that the Buffalo Principles were instrumental in helping us overcome. Even more remarkable, of the four bills in the New York State Assembly related to AV technology: A. 1554 sponsored by Assemblyman Clyde Vanel, A. 1808 sponsored by Assemblyman William Mangorelli, A. 2643 sponsored by Assemblyman David Gantt and A. 8460 sponsored by Assemblywoman McMahon, only our team’s Suggested Language for NYS embodied in S. 6052/A. 8460 achieved a “Same As” designation in both the New York State Senate and Assembly. This designation indicates that an identical companion bill was introduced in each House of the NYS Legislature and is a rare occurrence. Securing a Same As bill in both the New York State Senate and Assembly is difficult to do considering that New York State legislative elected officials represent over 18 million constituents with extremely complex and diverse public policy needs and requirements. The achievement of securing a Same As designation for the Suggested Language for NYS demonstrates the value of the Buffalo Principles in their ability to garner broader public policy appeal compared to the legislative approaches evident in A. 1554, A. 2643 and A. 8460 that also related to AV technology.

In the New York State Senate, the value of the Buffalo Principles was even more evident. Only two State Senate bills that related to AV technology were introduced during the 2019–2020 New York State Legislative Session. The first was S. 6052, which embodied our team’s Suggested Language

for NYS, and S. 1779, which was introduced by Senator Luis Sepulveda and failed to achieve a Same As designation or companion bill in the New York State Assembly.

The speed of the introduction of our team's Suggested Language for NYS in the New York State Senate and the relatively short amount of time it took to secure a Same As sponsor in the New York State Assembly is unprecedented. We find it notable that the previous Chairman of the New York State Transportation Committee, Senator Joseph Robach, introduced a bill in 2016 that notwithstanding New York State Vehicle and Traffic Law Section 1226 Control of Steering Mechanism, which is known as the "hands on the steering wheel" provision that requires human hands to be on the steering wheel of a motor vehicle at all times. This bill was passed in the State Senate but never garnered a New York State Assembly sponsor. The existing New York State statute requiring human hands on the steering wheel of a motor vehicle was enacted several decades ago, long before AV technology was ever considered, and was adopted to improve the safety of human drivers. As in the case of FMVSS at the federal level, "hands on the steering wheel" requirement at the State level simply does not apply to the safe deployment and operation of AV technology on public roads.

In 2016, because the "hands on the steering wheel" provision was existing law in the State of New York, it was viewed as an impediment to the advancement of AV technology and was the impetus for State Senator Robach to introduce a bill to remove that impediment. State Senator Robach was seeking to advance AV technology in the State of New York; however, without the tangible experience of riding in a vehicle like the Olli Bus, we believe it was difficult for other elected officials in the New York State Assembly to assess the impact of this legislation. As a result, the 150 members of the New York State Assembly took no action on this bill during the 2016–2017 New York State Legislative Session. In the case of our team's Suggested Language for NYS in S. 6052/A. 8460, the parameters of the value of the legislation as it relates to AV technology are much clearer for policymakers to evaluate. S. 6052/A. 8460 only permits testing on private roads with the expectation that (1) the testing would be slow-speed deployments similar to the Olli Bus, (2) data would be shared, and (3) the testing would support integrated simulation to test higher speed AV technology solutions in the virtual world without ever endangering anyone on the roadways. This is the legislative embodiment of all four Buffalo Principles. In contrast, a bill to permanently allow for AV technology to operate with "hands off the steering wheel" might have been perceived as potentially dangerous, especially when not offered in a context of testing or development, which might have limited its ability to move forward in the New York State Assembly.

5.8 System-Controlled Vehicles

In this section, we summarize key lessons learned from the project and offer additional observations and findings that support further improvements. We entitled this section “System-Controlled Vehicles” to reflect the importance of distinguishing between vehicles operated by humans versus those vehicles whose Dynamic Driving Tasks are controlled exclusively by ADS. This distinction is critical to properly understanding and assessing each type of vehicle’s functional performance and its relative safety. Making this distinction is also a prerequisite to understanding what market conditions enable the research advances required to bring everyday use of AVs to fruition and realize the full extent of their potential benefits. Most importantly, it is our main contention that federal, State and local government policymakers must understand this distinction to remove impediments and create a new legal and regulatory environment that supports the advancement of AV technology.

Through this project, we find that the greatest challenge, therefore, is for federal policymakers and regulators to usher in a new legal and regulatory regime that enables the safe introduction of AV technology onto America’s roads while sustaining the safety and reliability of the public roadways underpinning our vibrant economy. We believe that this is possible through a clear distinction between vehicles operated by humans versus those vehicles controlled by ADS. Such clarity would enable stakeholders to properly identify and enact the FMVSS reforms needed to remove regulatory obstacles to public roadway deployments of AVs without sacrificing safety.

While this action appears understandable and achievable, we have observed that the arcane and technical nature of AV technology has mystified policymakers at all levels of government and, as a consequence, has diminished their confidence to formulate effective legal and regulatory action supporting AV technology development. This lack of effective action continues to be a substantial impediment not only for the development and deployment of the Olli Bus on public roadways but for the advancement of all AV technology in the U.S.

We believe that addressing this challenge and establishing the right public policy approach begins by critiquing the incomplete nature of the technical standards related to AV technology. These standards, based on the inherent assumption of human drivers, are partially responsible for preventing necessary FMVSS reforms by further ingraining the human-at-the-wheel paradigm in the minds of policymakers and industry participants across the entire automotive ecosystem spanning private industry, academia, and government.

5.8.1 Human-Centric Industry Definitions Are Incomplete

The Society of Automotive Engineers is perhaps the most influential standards organization in the automotive industry. According to its website, Peter Heldt wrote an editorial in June of 1902 stating, “Now there is a noticeable tendency for automobile manufacturers to follow certain accepted lines of construction, [and] technical questions constantly arise which seek solution from the cooperation of the technical men connected with the industry. These questions could best be dealt with by a technical society. The field of activity for this society would be the purely technical side of automobiles.” This led to the formation of SAE in New York City in 1905. Then, in its first 10 years SAE began to publish a technical journal and a comprehensive compilation of technical papers, previously called SAE Transactions, which still exist today in the form of SAE International's Journals. Today, SAE has cooperative agreements with organizations across the globe including in Japan, Germany, United Kingdom, Australasia, and India among others. Currently, SAE creates and manages more aerospace and ground vehicle standards than any other entity in the world (SAE, 2020a).

SAE established a standards committee focused on AV technology and in 2016 first published the J3016 “Levels of Driving Automation” standard for consumers. According to the SAE website: “The J3016 standard defines six levels of driving automation, from SAE Level Zero (no automation) to SAE Level 5 (full vehicle autonomy). It serves as the industry’s most-cited reference for automated-vehicle (AV) capabilities (SAE, 2020b).”

The majority of the 29 States that have adopted AV technology-related legislation since 2011 either directly or indirectly cite SAE J3016 “Levels of Driving Automation” in the formulation of their law. U.S.DOT in 2017 adopted SAE J3016 “Levels of Driving Automation” and NHTSA works directly with SAE and refers to these standards as it considers FMVSS exemptions and FMVSS reforms as it relates to AV technology.

According to SAE, the class of vehicles often referred to as Automated Driving Systems (ADS), partially or fully Automated or AVs, and also self-driving cars are, grouped together, as “motor vehicle driving automation systems that perform part or all of the dynamic driving task (DDT) on a sustained basis,” where DDT is “the real-time operational and tactical functions required to operate a vehicle in on-road traffic.” The specific conditions under which a given driving automation system or feature is designed

to function, including, but not limited to, driving modes, is known as the Operational Design Domain. The ODD can incorporate a variety of limitations, such as those from geography, traffic, speed, and roadways, or also physical infrastructure, operational constraints, objects, connectivity, environmental conditions, and zones.

The SAE further defines six levels of vehicle automation. In this taxonomy levels of automation increase in a range from zero to five where “zero” represents a vehicle with no automation and full human control, and “five” represents a fully autonomous self-driving system where humans are strictly passengers.

The SAE definition is accepted across the industry. However, through direct first-hand experience in this project, we find that the human-centric framing intrinsic to this taxonomy is the fundamental limitation of truly advancing AV technology for the Olli Bus and other solutions designed to operate without a human or human controls. In the first place, the numbers of levels are arbitrary, and each level offers no additional information on how to evaluate the safety or efficacy of the Olli Bus. The six levels could just as easily have been 15 levels or even three. The differences from one level to the next are wholly arbitrary and not based on any organizing principle beyond the convenience of how different technologies happened to be grouped. More importantly, the taxonomy is limiting because it defines automation in terms of features in relation to a human driver instead of as the functions in the operation of a system that is in control of the vehicle. This distorts an understanding of Automated Driving Systems as being separate and distinct from vehicles operated by a human driver and has led to understandable confusion and lack of action by policymakers. We believe this distinction is important because it obfuscates rather than clarifies the single most important factor: who controls the vehicle.

A human driver is either operating the motor vehicle or not. Regardless of how well a mechanical function operates, a human driver either controls the Dynamic Driving Task or the human does not. The degree of assistance that a human driver receives from a mechanical feature in the execution of one or more driving functions does not alter the fact of who is in control and is therefore irrelevant as a basis of classification. The amount of automation in a vehicle is a classic case of a difference-without-distinction since a human still controls the vehicle. We argue this is the fundamental reason why there has been no progress from a legal or regulatory perspective on advancing AV technology. It does not matter how it is framed, as we have detailed in this report, all AV technology laws, rules, and regulations are constructed based on the assumption that the motor vehicle is operated by a human with human controls. The levels or degrees of human operation or human control are wholly irrelevant to evaluating the safety and efficacy of AV technology.

5.8.2 System-Controlled Vehicles Versus Human-Controlled Vehicles

To address this fundamental incompatibility, we introduce the term system-controlled vehicle (SCV) to replace incomplete nomenclature across industry, university, and government that has failed to provide either clarity or accurate descriptions of AV technology. This lack of clarity, disseminated into the everyday lexicon, has contributed to the lack of understanding of AV technology and increased the level of fear among many that has caused legal and regulatory inaction. We define a system-controlled vehicle as an adaptive and non-deterministic system that completes all Dynamic Driving Tasks without human oversight or intervention. It is safe to deploy SCVs when there is a level of confidence that both the bounds of performance of the system and the bounds of the control actions that will be performed within and by the system, will achieve desired objectives (i.e., the ability to navigate from point A to point B safely).

We define an Adaptive System as a system that responds dynamically to changing conditions, and a Non-adaptive System is therefore defined as a system that does not respond dynamically to conditions. We also define a Deterministic System as a system whose outcomes for any given input are determined by specified rules and are therefore limited and predictable. It follows that a Non-deterministic System is a system whose outcomes for any given input are not restricted by predetermined rules and are therefore unlimited and unpredictable. A true system-controlled vehicle is both an adaptive and non-deterministic because it autonomously navigates in reaction to its physical environment to achieve its objectives, and the range of reactive actions the system might choose to take is both unlimited and unpredictable rather than scripted and easily definable.

In all motor vehicles registered and operated on the public roadways today, all mechanical functions depend upon the explicit control by a human. A human driver determines the direction to where the vehicle steers, and whether to slow or accelerate. Even so-called automated functions, such as lane assist, which automatically respond to environmental conditions to affect a part of the Dynamic Driving Tasks, are pre-programmed by humans to respond in deterministic ways and implicitly assume a human is in control of the vehicle at all times. Their functional actions are limited and predetermined and thus reinforce the underlying fact that a human ultimately remains in control of the vehicle at all times. Despite the appearance of independent operation, these functions in fact are not mechanically different from a throttle or brake that a human driver controls.

To facilitate a clear understanding of this point, we return to what a vehicle does in the context of the Dynamic Driving Tasks (i.e., the real-time operational and tactical functions required to operate a vehicle in on-road traffic). At its most fundamental level, whether operated by a human driver or AV technology, and regardless of its engine or wheels, a vehicle accelerates, brakes, or steers in relation to its environment to go from point A to point B.

In the case of human control, a driver's independent actions control the vehicle through the ability to see and correspondingly control the wheel and pedals. Drivers also communicate to others through turn signals or honking the horn, etc. Hence, most current regulations focus on achieving safety by imposing standards on how the driver or the vehicle supports a driver's ability to see, steer, accelerate, brake or communicate to other drivers. (The remaining regulations pertain to passenger safety, fuel efficiency, and emissions for air quality.)

In contrast, a system-controlled vehicle operates through three internal software systems a: perception algorithm, planning algorithm, and control algorithm. Working in concert, these automated systems replicate the same Dynamic Driving Tasks of seeing, steering, accelerating, and braking. The vehicle's perception devices (e.g., LIDAR, RADAR, cameras, etc.) send information to the perception algorithm to define the physical elements in the path and surrounding environment of the vehicle. The planning algorithm interprets and devises an appropriate response for what action the vehicle should take next. The control algorithm executes the requisite action through the vehicle's powertrain and mechanical controls which steer, accelerate, brake, or communicate to others (e.g., enact a turn signal, honk the horn, enact V2X communications, etc.).

The ongoing development of technologies to advance SCVs, therefore, can be construed as advances in the performance of each of these three software systems as they related to variations in the Operational Design Domain. Research has shown that advances are achieved through three main components of a testing architecture for developing SCV technology: (1) modeling and simulation, (2) closed-track testing, and (3) real-world testing on open roads.

For any given ODD, whether tested in in a simulation, closed-track, or open-road environment, the effectiveness of an automated system can be measured by how well each of these three systems performs their designated functions. That is, (1) how accurately the perception algorithm perceives the physical environment, (2) how well the planning algorithm interprets the signal and devises an appropriate response, (3) how effectively the control algorithm executes the corresponding vehicle commands

to steer, accelerate or brake, and also (4) how well these systems interact as a whole (in addition to how well any individual component controlled by the system responds and functions, such as a wheel, or a brake pad).

5.8.3 Inadequate Federal Guidance

As noted previously, AV 1.0 embraced the SAE approach of defining AV technology in terms of increasing levels of automation assisting a human driver. AV 1.0 drew a further distinction between Levels 0–2 and 3–5 based on whether an Automated System was primarily responsible for monitoring the driving environment. AV 1.0 defined AV technology system as “a combination of hardware and software (both remote and onboard) that performs a driving function, with or without a human actively monitoring the driving environment,” even though the only distinction that matters is whether or not a human driver is in control of the vehicle, irrespective of how much automated technology is available to assist the driver in any Dynamic Driving Task. The term introduced by AV 1.0, Highly Automated Vehicle (HAV) personifies the inherent human-centric bias that AV 1.0 reinforced across the industry. The fact that the term was never adopted exemplifies the short-comings of the human-centric approach embodied in AV 1.0, and we find that this flaw to be the explanation for why AV 1.0 failed to advance the development of AV technology.

Like its predecessor, the publication of AV 2.0, despite incorporating some elements of helpful guidance, also failed to unleash a wave of AV deployments or corresponding technological breakthroughs because it too did not illuminate a pathway toward AV testing on public roadways on a sustainable basis. Because AV 2.0 sustained the human-centric bias of AV 1.0 by failing to distinguish between human-controlled Vehicles and system-controlled vehicles, AV 2.0 did not consider that the key barrier impeding the AV technology real-world deployments. Policymakers would have otherwise recognized the need to replace FMVSS designed for human drivers with a new regime to accommodate SCVs. This failure of AV 2.0 can be traced to the persistent assumption that a vehicle is something that is built and designed for a human operator who remains present at the wheel, even if the vehicle itself may be operated by an automated system in any given time.

For example, AV 2.0 explicitly calls for industry practitioners to include fallback capabilities for human drivers to be alerted to system malfunctions and even take over driving control when necessary. Further, AV 2.0 encouraged entities to document how they intend to account for all applicable federal, state,

and local laws in the design of their vehicles and ADSs. However, as we have documented in this report, compliance with FMVSS, and thus compliance with “all applicable federal, state, and local laws in the design of their vehicles,” (AV 2.0, p. 15) makes it literally impossible for AVs not designed for a human driver.

It is unclear if other aspects of AV 2.0 helped or had no meaningful impact on advancing AV technology technologies. AV 2.0 did address a number of important areas. For example, regarding crash worthiness, AV 2.0 stated that a mix of vehicles, having different levels of automation, operating on public roads requires one to consider the possibility of another vehicle crashing into an ADS-equipped vehicle, and how to best protect the vehicle occupants in that case. However, the guidance contained in the first section of AV 2.0 was less of a proactive guide than it was a description and affirmation of common industry practice already being followed. Thus, it failed to provide industry practitioners with an actionable path forward for how to approach system safety.

For example, beyond introducing the important idea that AV technology safety and performance should be approached through the lens of systems engineering, the guidance included no further detail or instruction. AV 2.0 noted that AV safety should emphasize software development, verification, and validation, both at the level of individual subsystems, and as part of the entire vehicle architecture. Entities are encouraged to document the entire process, all actions, changes, design choices, analyses, associated testing, and data should be traceable and transparent.” While the ideas inherent in this language clearly suggest a new approach, U.S. DOT failed consider the implications of its own guidance for how it regulates safety and this impedes AV technology deployments.

Even where AV 2.0 was on the right track, it failed to provide the right guidance actually needed. Consider the following passage from AV 2.0 (page 7):

Entities are encouraged to have a documented process for assessment, testing, and validation of their crash avoidance capabilities and design choices. Based on the ODD, an ADS should be able to address applicable pre-crash scenarios that relate to control loss; crossing-path crashes; lane change/merge; head-on and opposite-direction travel; and rear-end, road departure, and low-speed situations such as backing and parking maneuvers. Depending on the ODD, an ADS may be expected to handle many of the pre-crash scenarios that NHTSA has identified previously.

This demonstrates that, although U.S.DOT has identified a promising approach to safety, the lack of performance standards and benchmarks makes the approach an ineffective safeguard. Without established benchmarks to indicate levels of safety and performance, and without a clear process to establish such industry-wide safety and performance benchmarks, an industry practitioner could follow the letter of the guidance without actually deploying a safe vehicle on public roads.

The observation that FMVSS—because they are written with the assumption of a human driver controlling a vehicle—constitute a major regulatory barrier to the advancement of AV technology, is not a novel notion. Countless examples of prominent industry practitioners articulating this point have been presented in important works of research. For example, in an analysis of regulatory exemptions, the RAND corporation noted that FMVSS were written with the assumption that a human would be behind the wheel of the vehicle. With AVs, some standards are outdated, making exemptions a necessity.

We have also seen this point made in official correspondence to and from NHTSA. For example, in 2015, prior to establishing Waymo the following year, Google explained to NHTSA that the FMVSS were promulgated before SDVs [i.e., self-driving vehicles] were even contemplated, let alone a reality. Waymo argued that given this, and given that Level 4 AVs are controlled almost entirely by a self-driving control algorithm, such vehicles should not be expected to have some of the components that are used by human drivers (e.g., the brake and accelerator pedals and the steering wheel). In its response, NHTSA acknowledged the point made by Google, and explained that NHTSA will interpret the “driver” in that context as referring to the self-driving or autonomous control software, and not to any of the vehicle occupants. Yet, despite proof of this recognition by U.S. DOT, AV 2.0 did not revise nor suggest the revision of FMVSS to address the core issue impeding AV technology deployments and advancement. This would only be tentatively addressed in AV 3.0.

Overall, AV 3.0 intended to describe an “illustrative framework of safety risk management stages along the path to full commercial integration of automated vehicles.” However, despite the intention by AV 3.0 that this framework “promotes the benefits of safe deployment while managing risk and provides clarity to the public regarding the distinctions between various stages of testing and full deployment,” our experience with the Olli Bus demonstrated that a lack of clarity has persisted. In fact, AV 3.0 has done little to promote the industry-wide clarity it intended.

This is encapsulated by the fact that the language U.S. DOT adopted to define AVs has still to solidify. In AV 1.0 and AV 2.0, and continued in AV 3.0 among other U.S. DOT guidance publications, the language defining the class of vehicles using automated technologies has shifted but for reasons that made little technical sense. In AV 1.0, U.S. DOT introduced the concept of HAVs based on the misguidedly arbitrary difference that some driving functions are more automated than others. As we have noted previously, this difference was without distinction. U.S. DOT abandoned the term of HAVs in lieu of the term ADS in AV 2.0, as affirmed in AV 3.0, to better recognize that entire driving systems, not just functions, can be automated. However, this has still failed to achieve full clarity. The underlying cause of this lack of clarity once again stems from U.S. DOT's conflation of system-controlled and human-controlled vehicles. As demonstrated in AV 3.0, U.S. DOT continues to view both through the lens of the human-driver paradigm. A key lesson stemming from the deployment of the Olli Bus was the realization that the Olli Bus and all systems devised to control a vehicle's dynamic driving tasks—without a human driver in mind—represent a different paradigm altogether.

This flaw in fundamental thinking pervasive throughout AV 3.0 has undermined U.S. DOT's ability to help industry make any meaningful advancements in achieving sustainable AV technology deployments, much less important technological advances. For example, even as AV 3.0 expressed NHTSA's recognition for the need to revise FMVSS to enable AV technology deployments, U.S. DOT did not address the task. AV 3.0 was not accompanied by any pertinent changes to FMVSS. AV 3.0 affirmed that U.S. DOT did not perceive immediate regulatory changes to be necessary because the "statutory provision authorizing NHTSA to grant exemptions from FMVSS provides sufficient flexibility to accommodate a wide array of automated operations, particularly for manufacturers seeking to engage in research, testing, and demonstration projects." However, as we have noted previously, the NHTSA exemption provided neither the regulatory relief nor a permanent solution to remove regulatory impediments to AV technology deployments.

Other efforts to address the barriers imposed by FMVSS were equally ineffective. As outlined in AV 3.0, U.S. DOT provided for an open, collaborative, and industry-friendly approach to promulgating and revising FMVSS. AV 3.0 noted that "FHWA will continue to work with stakeholders through its National Dialogue and other efforts to address the readiness of the roadway infrastructure to support ADS-equipped vehicles. It is reviewing existing standards to address uniformity and consistency of traffic control devices, such as signage, and plans to update the existing MUTCD." But while this may

be laudable, these actions represent the modifications at the margins of the current regulatory regime that have failed to promote SCV deployments. The lack of progress has not been due to the lack of a democratic rule-making process or a failure to include multiple perspectives in it. Only a wholesale rethinking of the current regulatory regime itself will enable the promulgation of industry rules that ensure safety while supporting technological advancements.

Regardless of the merits of this concern, the issues raised highlight that U.S. DOT has yet to find the balance in how to support industry while ensuring safety. U.S. DOT's challenge emanates in part because it seeks to determine how to regulate ADS operating within the context of a human driver. Because NHTSA needs to ensure safety for automated technologies that assist human drivers in the completion of dynamic driving tasks, it fails to recognize its more fundamental need to also contemplate that system-controlled vehicles present a completely separate class of vehicles as human-operated vehicles, irrespective of how automated or intelligent any of its functions might be.

The best way to support industry while ensuring safety, therefore, would be to establish safety performance standards for the evaluation, testing, and certification of AVs. Unlike standards that assume a human driver, a set of standards applicable to AVs would involve an assessment of the efficacy of how well the systems performed given specified circumstances and at a designated performance threshold. The number and scope of tests would be sufficiently wide to assess different systems and performance across varied ODD. Systems that proved their efficacy by passing such tests would then be certified as safe to deploy on public roadways.

In fact, some aspects of AV 3.0 do suggest that U.S. DOT is open to the adoption of an approach based on establishing performance standards for the evaluation, testing, and certification of AVs. On page 7, AV 3.0 states that, "Other approaches, such as computer simulation and requirements expressed in terms of mathematical functions could be considered, as federal law does not require that NHTSA's safety standards rely on physical tests and measurements, only that they be objective, repeatable, and transparent."

The efficacy of safety standards established for SCVs (i.e., where the vehicle has no human driver so the automated system controls the vehicle) would apply equally to the regulation of technologies used in human-controlled vehicles. Therefore, establishing safety performance standards for the evaluation, testing and certification of AV technology would accommodate NHTSA's need to regulate the safety of automated technologies that assist human drivers in the completion of Dynamic Driving Tasks.

AV 4.0 was a step in the right direction but did not go far enough. In highlighting the goal of Modernizing Regulations as one of its 10 principles, AV 4.0 expresses the federal commitment to “modernize or eliminate outdated regulations that unnecessarily impede the development of AVs.” However, this is offered in the context of reducing regulations that do not address “critical safety, mobility, and accessibility needs,” and the desire to “encourage a consistent regulatory and operational environment.” Further, the principle devoted to ensuring a consistent federal approach refers solely to funding support. It does not refer to promulgating a new regulatory regime to promote national regulatory harmonization around AV technology, nor does it address the requirements of vehicles controlled by systems versus humans. AV 4.0 does not explicitly acknowledge the need for a new regulatory regime despite its recognition of the distinction between Advanced Driver Assistance Systems (ADAS), such as automatic emergency braking, lane departure warning, and adaptive cruise control that assist human drivers to avoid collisions, and Automated Driving Systems in which the ADS fully controls the Dynamic Driving Tasks.

In fact, in explaining the distinction between ADAS from ADS, AV 4.0 notes that the safety impact and effect on collision rates of numerous ADAS technologies (because they are already being incorporated into conventional vehicles) can be evaluated. In contrast, ADS are still currently in the R&D phase, not available for consumer purchase and, as noted previously, not widely deployed on public roadways. Hence, “data on collision rates for ADS under real-world conditions are limited at this time and a standardized vocabulary and methodology for evaluating and regulating their safety is still being developed by NHTSA, state regulators, and other stakeholders.” While U.S. DOT made this distinction in recognition that “advances in these technologies can reduce roadway crashes, fatalities, and injuries and assist the U.S. DOT in managing safety risks along the path to the full commercial integration of AV technology,” we note the larger importance of this distinction as it relates to FMVSS as an essential element underlying Federal Government efforts to support advances in AV technology. While U.S. DOT demonstrates clear awareness of this distinction, it has not yet applied this distinction in a substantive effort to update current FMVSS aside from acknowledging the need to do so.

For example, as noted in AV 4.0, NHTSA is “researching unintended regulatory barriers.” NHTSA acknowledges that, historically, the FMVSS “have been based on the concept of a human operating the vehicle. With the introduction of ADS, the driving tasks are increasingly shifted to the vehicle. The absence of a human driver creates opportunities for vehicle manufacturers to design new vehicle architectures that may remove driving controls, change seating configurations, and establishing new interfaces for occupants.” Despite this acknowledgment, NHTSA is not undertaking the necessary

revising of the FMVSS to accommodate ADS vehicles operating outside the human-controlled paradigm. Instead, NHTSA has “published non-binding guidance to support the automotive industry and other key stakeholders as they consider and design best practices for the testing and safe integration of Automated Driving Systems, along with technical assistance to States and Best Practices for Legislatures,” even though the current evidence has proven this approach to be largely ineffective in producing actual technological advances.

5.8.4 Limited International AV Technology Advancements

Since 2018, the consulting firm KPMG has published an annual AVs Readiness Index (AVRI). KPMG assessed the countries surveyed for their readiness to accept and support AV technology based on 25 different measures within four pillars: policy and legislation; technology and innovation; infrastructure; and consumer acceptance. According to KPMG’s analysis, the Netherlands once again ranked number 1 as it had in the inaugural 2018 AVRI. In summarizing the basis for this finding, KPMG noted that the Netherlands is working on an initiative that would launch huge platoons of driverless trucks to transport flowers on major “Tulip Corridor” routes from Amsterdam to Antwerp and Rotterdam to the Ruhr Valley. KPMG also noted that the Netherlands is securing its lead by doing many things consistently well, including investigating AVs’ use in freight and logistics and passing new legislation (KPMG, 2019).

However, notwithstanding its ranking as the country most conducive to promoting AV technology, the Netherlands still requires human control of all vehicles and still places limits on testing on public roads through an exemption process in policies still grounded in the Human-behind-the-Wheel paradigm. For example, new legislation in the Netherlands specified that “the experimental use of self-driving vehicles will enable companies to apply for a permit to conduct tests with driverless vehicles on public roads, with a human being ready to take command via remote control (Government of the Netherlands, 2020).” Further, the Dutch Vehicle Authority, which is responsible for the admission of vehicles to the public roads in the Netherlands, has the authority to issue exemptions to companies that wish to test self-driving vehicles but only to those who “must first convince and demonstrate that the tests will be conducted in a safe manner.” But safety, as it is defined, requires “having a human being ready to take command via remote control.” Hence, this exemption process resembles the NHTSA exemption process that is hampered by the same Human-behind-the-Wheel paradigm underlying the FMVSS. Due to this same

defect, laws and regulations in the Netherlands, like the FMVSS, will create obstacles to testing on public roadways and will not result in the widescale testing the Ministry of Infrastructure and the Environment intended to achieve when it “opened the public roads to large-scale tests with self-driving passenger cars and trucks (Government of the Netherlands, 2020).”

Interestingly KPMG ranked the U.S. in the fourth position, just behind Norway in third place. With Singapore, which KPMG describes as a “powerhouse of technological innovation,” ranked second behind the Netherlands. Singapore, with its leading university, “has created a test town for driverless vehicles complete with traffic lights, bus stops, skyscrapers and a rain machine that recreates its stormy tropical weather” as the basis for its ranking. While a substantial investment in closed-road testing facilities is laudable, and we have noted the importance of closed-road testing as a critical pillar in advancing AV technology, the rarer and more urgently required research is deployments on public roadways. As we have seen from current efforts, despite its benefits, closed-road testing alone will not produce the breakthrough technological advances required to bring AV technology to fruition.

If KPMG’s analysis of global AVs Readiness Index is correct, the leading nations across the globe in AVs are all still encumbered by human-controlled vehicles frameworks and we do not find any lessons to be learned from the Netherlands, Singapore, or Norway to support the advancement of rules and regulations concerning system-controlled vehicles, which we believe are vitally important to advance AV technology.

5.8.5 Underwriters Laboratories Publishes First AV Standard

Fortunately, through our research for this report, we have found an exciting new development offering a glimpse into the first steps toward identifying and establishing performance standards that industry practitioners could use to assess the safety and functional performance of AV technology. Most notably, on April 1, 2020, Underwriters Laboratories (UL), a nonprofit scientific research organization that conducts global safety certification, published UL 4600, the Standard for Safety for the Evaluation of Autonomous Products as the first-ever set of standards that address the performance of AVs (UL, 2020).

The standards set for the safety certification includes safety principles and processes for evaluating AV technology without human supervision, meaning that the vehicle is fully autonomous. According to UL, there is a need to consider topics such as risk analysis, testing, tool qualification, autonomy validation,

data integrity and human-machine interaction for nondrivers, among others. UL 4600 is technology neutral, meaning that it does not mandate the use of any specific technology in creating the autonomous system, and it also permits design process flexibility.

UL convened “a diverse body of international stakeholders...to participate on the Standards Technical Panel (STP) to develop the document, says the organization. The group proposed content, shared knowledge, reviewed, and voted upon the proposals and ultimately achieved consensus on publishing the first edition of UL 4600. Other stakeholders provided proposals and commentary via the online collaboration platform utilized by UL Standards.” The group included practitioners of AV technology, representatives from state Departments of Transportation, private industry, and other stakeholder organizations. “UL's new standard and their approach to standards development allows for rapid iteration and feedback, which is on pace with what our industry needs," commented Uber ATG's Head of Safety, Nat Beuse. "Driving consensus around some of the safety aspects of SDV development is a priority for Uber and the rest of the STP (UL, 2020)." Furthermore, “UL 4600 does not define performance or pass/fail criteria for safety, nor does it cover road testing or acceptable risk levels. Moreover, the Standard does not set forth requirements for ethical product release decisions or any ethical aspects of product behavior (UL, 2020).”

According to a review of the new standard, Junko Yoshida of EE Times commented: “UL 4600 breaks from conventional perceptions about international standards.” And that “UL 4600 remains technologically neutral. It does not prescribe hardware and software specifications. Instead, it offers safety principles and processes for evaluating autonomous products (Yoshida, 2020).” We note that UL 4600 approach matches the concept that we have introduced in defining a SCV as an adaptive and non-deterministic system that completes all Dynamic Driving Tasks without human oversight or intervention. Just as UL 4600 “offers safety principles and processes for evaluating autonomous products” we detail that a SCV is safe to deploy SCVs when there is a level of confidence that both the bounds of performance of the system and the bounds of the control actions that will be performed within and by the system, will achieve desired objectives.

The STP that developed UL 4600 consisted of 32 members from government agencies, academia, AV developers, technology suppliers, testing and standards organizations, and insurance companies, including representatives from Uber, Nissan, Argo AI, Aurora Innovation, Locomotion, Zenuity, Intel,

Infineon, Bosch, Renesas, Ansys, Liberty Mutual, AXA, and U.S. DOT. We note that these experts have developed a new approach and believe that a clear focus on the development and implementation of rules and regulations for SCV will be complimentary to this standards effort and hasten the deployment of AV technology.

5.9 Conclusion

5.9.1 Summary of Findings

Since 2004, when the initial DARPA Challenge marked the beginning of what many believe was the current AV technology era, the deployment of AVs on public roads in the U.S. has been limited. Despite the 29 states enacting legislation authorizing AV testing on public roads or similar legislation, including the New York State in 2017, the FMVSS first promulgated in 1966 still stand as an imposing obstacle to further advancement of this new technology.

We recognize the effort of U.S. DOT in offering four AV voluntary guidance documents since 2016, and the recent attempts by NHTSA to expedite the FMVSS exemption process for AV technology to provide the federal-level support necessary to harmonize laws and regulations across the U.S. around AV technology. Unfortunately, as we have documented, since FMVSS define safety requirements solely in terms of how well equipment or vehicle operations aid human driving functions, the human-centric nature of human-in-control-of-the-vehicle rules and regulations at the federal level, continue to confound policymakers and regulators in taking the required actions sought by many seeking to develop and commercialize AV technology.

Without federal-level action to reform the FMVSS, either by Congress or NHTSA, the supremacy of the federal rules and regulations over the states limits what New York and every other state is able to enact in terms of AV technology legislation. This directly impacts this project because since the Olli Bus does not meet all FMVSS, as we documented in this report, despite our review of previously enacted AV legislation as required under Task 3, there is no action that NYS can take to authorize the Olli Bus to be deployed on public roads unless FMVSS are reformed at the federal level.

While the incompatibility between FMVSS and the Olli Bus as well as all other AV technology designed for operation without a human remain, we found that the Buffalo Principles provide a tangible pathway for the sustainable deployment of the Olli Bus and similarly designed AV technology. As supported by the success of the rapid advancement of the Suggested Language for NYS that we drafted, the Buffalo Principles provide a viable work around.

Overall, despite global leadership in the development and deployment of AV technology via billions in investments and multiple, largescale efforts spanning private industry, institutions of higher education and research, and federal, state and local government, the technological breakthroughs necessary to realize the full potential of AV technology remain out of reach. In the 15 years since the first DARPA challenge, fewer than 1,500 AVs are in operation today. While many industry practitioners will correctly conclude that achieving breakthrough technical advances requires more testing on public roadways, among other research needs, we argue further that the current legal and regulatory regime itself presents the main impediment to progress. Our findings in each section of this report support this conclusion. It is our contention that only action at the federal level, not action at the state level, not greater funding, nor more advanced engineering, can lead to the market conditions needed to unlock the full potential of AV technology in the U.S.

We find that despite industry-friendly policies and substantial investments at the federal level, in action related to FMVSS reform has proven to be a barrier to AV technology innovation. We believe that at the heart of this issue lies the failure by policymakers and industry experts alike to understand the critical distinction between vehicles designed to be operated by humans versus system-controlled vehicles. The human-at-the-wheel paradigm has had far-reaching implications into public policy. In this paradigm, as we have demonstrated, the idea of human control and vehicular safety are inextricably conflated when in fact they are mutually exclusive and not opposing concepts. Policymakers' determined focus on safety is not misplaced, but the assumption of a human driver inherent in their understanding of safety has prevented the development of laws and regulations supporting the advancement of AV technology. In contrast, a performance-based regulatory regime would otherwise create the market conditions that incentivize and support the activities of industry practitioners, which would in turn enable breakthrough technical advances. Our findings in each section of this report support this finding as well. It is our contention that achieving these favorable conditions requires the federal government to enact a wholly separate body of law and regulation based on system-controlled vehicles, and that exemptions from

and incremental changes to FMVSS will never be sufficient. A new set of laws and regulations designed for SCVs should be focused on establishing standards for vehicle performance while promoting, not undermining, tenets of vehicular safety.

In summary, in section 1 of this report, we detailed the efforts in 30 states to promote advances of AV technology through the enactment of supportive legislation or signing of executive orders. Among the more far-reaching examples we analyzed, these efforts remove important barriers in state and local traffic law to enable deployments while expressing support for AV technology and encouraging public acceptance. Nevertheless, despite the implementation of favorable elements, we concluded that efforts at the state level, regardless of how robust, are ultimately inconsequential to supporting actual deployments. The primacy of federal law, codified in the FMVSS, renders state law as secondary. Industry practitioners seeking to deploy AVs on public roadways for testing or other purposes must look to the Federal Government for enablement. However, the Federal Government transportation policy and safety regulations remain the key barrier.

In section 2 of this report, to date, we note that the U.S. Congress has not passed any legislation that defines AVs or authorizes AV testing. At the federal level of government, the U.S. DOT has been the sole actor in setting federal policy toward AV technology. The first guidance document, “Federal Automated Vehicles Policy: Accelerating the Next Revolution in Roadway Safety.” Then in September of 2017, U.S. DOT released “Automated Driving Systems 2.0, A Vision for Safety,” followed by “Automated Vehicles 3.0, Preparing for the Future of Transportation” in October of 2018 and most recently in January of 2020, it produced “Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0.” We provided a summary of U.S. DOT AV guidance published and highlighted sections most relevant to the project.

In section 3 and section 4 of this report, we explore the implications of the legal and regulatory regime that was first enacted by the U.S. Congress in 1966 through the National Traffic and Motor Vehicle Safety Act and which remains in place today despite dramatic subsequent advancements in AV technology. We illustrated how this current framework, codified in the Federal Motor Vehicle Safety Standards, remains largely responsible for impeding advancements to AV technology in three critical ways.

First, FMVSS were established to address safety from the perspective of a motor vehicle controlled by a human driver and contain numerous provisions detailing corresponding requirements. In our analysis, current FMVSS are incompatible with AV technology controlled by software-based ADS. Second, exemptions from FMVSS offered by NHTSA to enable the testing of AVs are wholly inadequate to support the needs of the industry because such exemptions are temporary and because they each require a human to be available to take control of the AV at all times, despite the fact that such requirements do little to quantify or evaluate the actual safety and efficacy of a technology that is intended to be controlled by a system instead of a human. Third, states are unable to remedy federal regulatory prohibitions due to the supremacy clause expressed in Article VI, Clause 2 of the U.S. Constitution, which renders the legal primacy of FMVSS over any action at the state level, including by each of the 30 states that have enacted AV-related legislation. As a result, industry practitioners seeking to make the necessary technical advances to AV technology must either forego open-road testing or make concessions to requirements that are irrelevant at best but substantial impediments at worst.

In section 5, as a solution to work around the limitations and impediments of the current legal and regulatory environment to undertake the testing on public roadways necessary to achieve technical advances in AV technology, we offered the four Buffalo Principles. As we demonstrated, the principles provide a sustainable strategy to overcome these immense obstacles to provide a way forward for the testing and advancement of any AV technology developed for operation without a human or human controls. The most important way this project helps advance the development of SCVs is in the formulation of the Buffalo Principles. These four principles provide other SCV practitioners with a set of practical steps to overcome barriers posed by FMVSS and legally undertake the real-world testing so critical to advancing AV technology. The Buffalo Principles demonstrate how AV technology can be deployed on public roadways while remaining in compliance with FMVSS by using private roads at slow speeds. The Buffalo Principles further affirm the importance of recording data and using integrated simulations to test and understand the unlimited virtual scenarios prior to real-world deployment.

In section 6 of this report, we illustrated the value of the Buffalo Principles, in chronicling how the Suggested Language for NYS developed by our team was introduced and achieved substantial advancement toward passage in both Houses of the New York State Legislature, especially relative

to other similar legislation. The swiftness of immediate Legislative action for the Suggested Language for NYS underlines the importance of this project and other pilot demonstrations of AV technology in providing policymakers with a first-hand knowledge about SCVs. The direct experience of riding on the Olli Bus had a substantial impact on how people thought and felt about SCV technology.

In section 7 of this report, we introduce the concept of system-controlled vehicles to replace pervasive but incomplete current industry nomenclature that fails to provide either clarity or accurate descriptions of AV technology, and to also address the fundamental incompatibility of assessing the safety and performance of a vehicle controlled entirely by ADS through the lens of the human-at-the-wheel paradigm. Although U.S. DOT has acknowledged this incompatibility in its written industry guidance, and even though federal regulations pose the greatest barrier to advancing AV technology, neither Congress nor the U.S. DOT have exercised their authority to act via new legislation or enacting substantial changes to FMVSS to promulgate a wholly new regulatory regime that supports assessing the safety and performance of system-controlled vehicles. We conclude the report by calling for this necessary action.

5.9.2 New Regulatory Regime

The assumption that having a human-at-the-wheel is required to define a vehicle is the modern equivalent of flat-Earth thinking. Recognizing that vehicles should be understood as a spectrum of increasingly automated operations is the equivalent of recognizing that the Earth revolves around the sun. While this view is technically accurate, it remains incomplete because it still assumes to define vehicles through the paradigm of a human driver. However, recognizing the distinction between an adaptive software-based ADS that exclusively controls DDT versus a vehicle deterministically controlled by a human driver,

irrespective of that vehicle's automation, is the equivalent of recognizing that the Earth, sun, and entire solar system are part of an even larger Milky Way galaxy. Reforming the current legal and regulatory regime to the needs of SCVs, to sustain the analogy, would bring us to the equivalent of apprehending the larger universe.

The notion underlying the above analogy, and in emphasizing the distinction between SCVs versus human-controlled vehicles, is that advancing AV technology depends as much on overcoming people's incomplete understanding of SCVs as on overcoming technical challenges. After all, the current FMVSS that constitute the main impediments to technological innovation simply reflect the choices and understanding of the people who promulgated and sustain them (who, in their minds, had good reason

to do so). Changing any laws and regulations, therefore, begins with winning the hearts and minds of those who influence or determine regulations and policy.

Any current law or regulation grounded in a human-at-the-wheel paradigm, such as current FMVSS, will remain a barrier to advancing AV technology. In our critique, the human-at-the-wheel paradigm also explains why current approaches to overcoming regulatory barriers have failed. The twin objectives of promoting both safety and technological innovation are currently in direct competition. They can only be aligned and met when policymakers and industry practitioners alike shift their thinking to embrace the reality that SCVs are not human-operated vehicles, they are software systems which require their own definition under the law and thus require a completely new regulatory regime.

As we noted previously, the performance of a system-controlled vehicle should be assessed with respect to four observable and quantifiable measures of performance:

1. how accurately the perception algorithm perceives the physical environment.
2. how well the planning algorithm interprets the signal and devises an appropriate response.
3. how effectively the control algorithm executes the corresponding vehicle commands to steer, accelerate or brake.
4. how well these systems interact as a whole (in addition to how well any individual component controlled by the system responds and functions, such as a wheel, or a brake pad).

It follows logically, therefore, that laws and regulations governing SCVs should apply this same understanding in assessing the efficacy of how well a software system achieves its requisite function as a basis for enforcing safety standards. Congress or NHTSA should devise performance-based metrics to assess an ADS in terms of how accurately the perception algorithm perceives its physical environment, how well the planning algorithm interprets signals and devises appropriate responses, and how effectively the control algorithm executes the corresponding vehicle commands to steer, accelerate or brake, in addition to assessing how well the system functions as a whole.

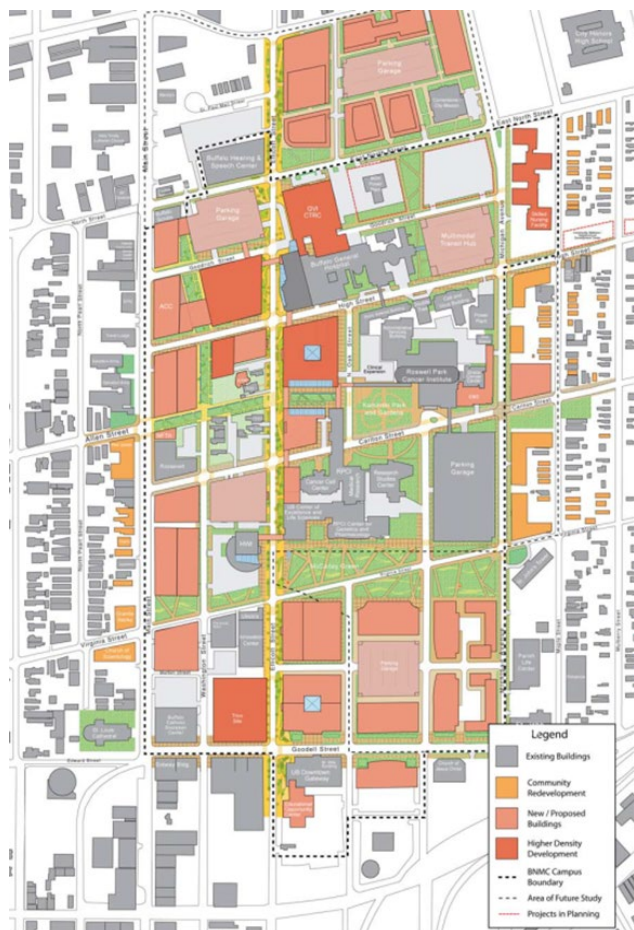
We believe that removing regulatory barriers to SCV technology while designing effective laws and regulations governing SCVs poses the most important task currently facing policy makers regarding mobility and transportation. The success or failure to do so will have far-reaching reverberations throughout the 21st century, much like how the introduction of the horseless carriage did in the 20th century. Nevertheless, defining a new legal and regulatory framework for SCV would exceed the scope of this project. Instead, we hope that the questions and insights raised in the report provide policy makers with the inspiration, insight, and understanding to successfully complete this endeavor.

6 Buffalo Niagara Medical Campus Case Study

6.1 Introduction

The Buffalo Niagara Medical Campus (BNMC) was used to assess the feasibility of Olli to provide “last mile” service from a financial standpoint, as well as for evaluating the likely benefits in terms of cost savings and reduced parking demand. BNMC is a rapidly growing consortium of world-class health care, life sciences, medical education institutions and spin-off companies located in the City of Buffalo. In the last few years, the campus has witnessed dramatic growth both in terms of employment and new construction. BNMC is envisioned by many to bring around a total transformation of the Buffalo downtown area, changing it into a welcoming and thriving place for people to work, shop, eat, and live. Given this, BNMC leadership has been placing great emphasis on sustainable transportation principles and has been pursuing a number of ridesharing and cycling programs to reduce dependency on the single-occupancy private vehicle and improve transportation sustainability.

Figure 38. Buffalo Niagara Medical Campus



BNMC is served by one of the Buffalo's metro rail stations, the Allen/Medical Campus Metro Station. However, once passengers exit the metro rail, there is no easy way to provide door-to-door transportation (i.e., a travel distribution function) to the different destination buildings that comprise the BNMC (see Figure 38 for campus map). This is especially true for the long-range plan for future expansion of the campus. Moreover, the unavailability of a convenient transportation system connecting the BNMC campus elements, along with the lack of parking availability in the area, often prevent BNMC employees from making midday trips for lunch or shopping in the downtown area. Finally, Olli would provide convenient and reliable transportation for employees between BNMC and an adjacent economically disadvantaged neighborhood.

Evaluating the feasibility costs and benefits of Olli for BNMC encompassed the following sub-tasks:

- Assess the mobility needs and service objectives of the medical complex in close collaboration with its principal stakeholders.
- Design the network and routes for the Olli bus to effectively serve BNMC.
- Design the mode of operations for the Olli bus and determine vehicle frequency.
- Derive performance measures from model results. Estimate cost and benefits of operations.

6.2 Estimate Mobility Needs and Demand

The Greater Buffalo Niagara Regional Transportation Council (GBNRTC) completed the Buffalo Niagara Medical Campus (BNMC) and Central Business District (CBD) North Transportation Study in 2017. This study provided an in-depth analysis of over 25 corridors in the area directly surrounding the BNMC. As part of this study, trip generation, mobility needs, and demand have been defined for the BNMC study area. This included hourly distribution and mode share for the major employers and activity centers within the campus. The data presented in this study was refined and used as the baseline estimate for mobility needs and demand for the Olli Case Study.

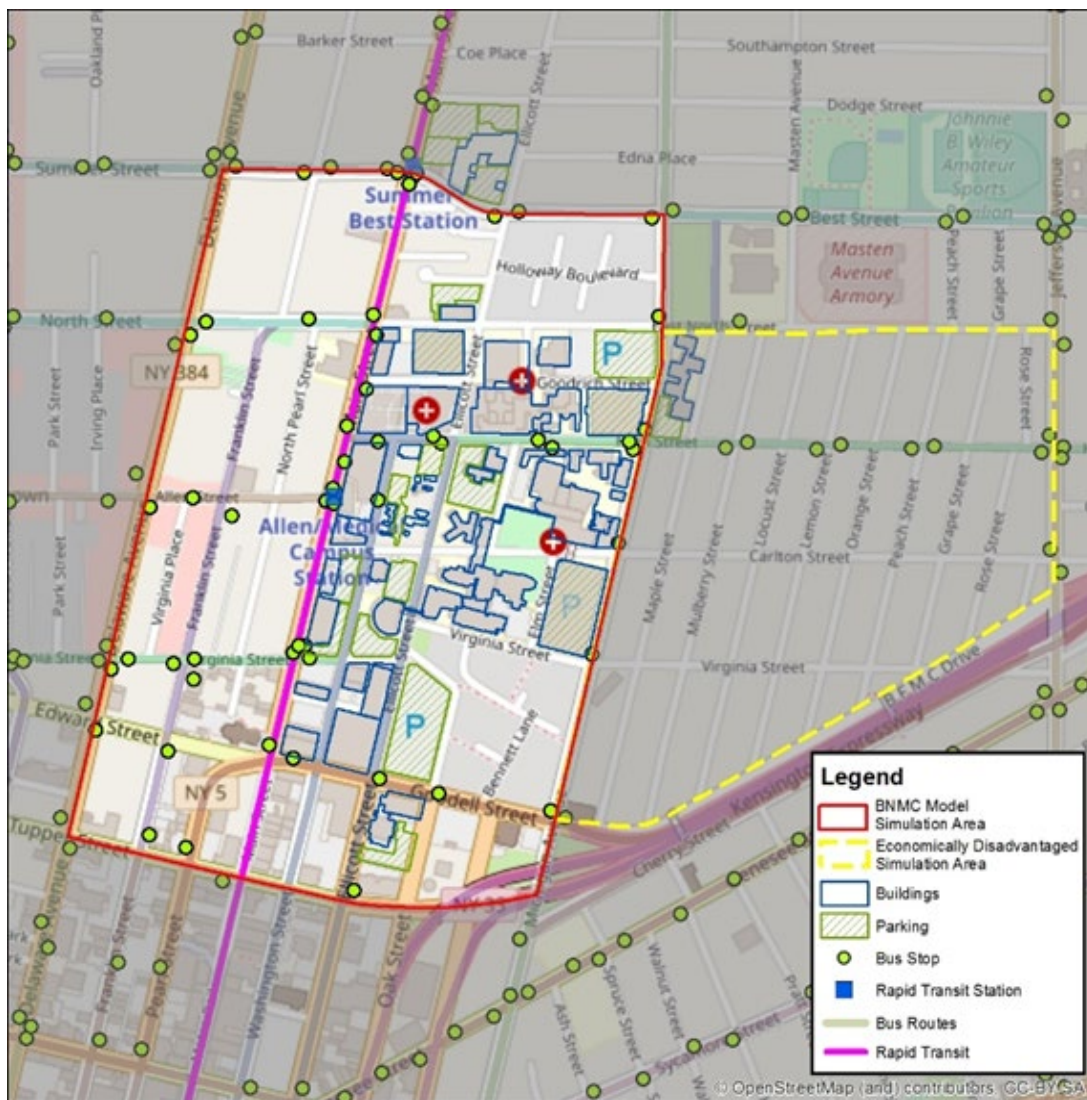
Principal stakeholders were contacted to obtain travel demand data for the BNMC study area.

Stakeholders provided the following travel demand information:

- BNMC provided employment information for major employers on the Buffalo Niagara Medical campus. This included the number of employees per building, employees using transit and other alternative modes to commute as well as the number of employees parking on the campus.
- Niagara Frontier Transportation Authority provided transit ridership information. This included information for the NFTA Metro Allen Street Station and Metro Bus lines that serve the campus. Ridership for spring of 2019 was compiled by BNMC and provided for use by the study team.

- City of Buffalo provided information relative to the existing street infrastructure as well as plans for future improvements on city streets in and around the campus. The city has recently adopted a Uniform Development Code or Green Code that includes complete street elements for various street corridors. These codes would be applied to the streets that Olli would be using.
- GBNRTC provided information relative to travel demand, trip generation, and traffic operations on the campus. Much of this information was obtained as part of the Buffalo Niagara Medical Campus (BNMC) and Central Business District (CBD) North Transportation Study.
- Niagara International Transportation Technology Coalition provided information on regional transportation demand management strategies that would have an impact on future deployment of AVs in and around the campus.

Figure 39. BNMC Case Study GIS



The study team developed a GIS Web Map Application to assemble data sets that contained study area characteristics and mode-share transportation demand. Stakeholders provided the following data sets:

- BNMC building footprint layer
- BNMC parking garage and parking lots layer
- BNMC parking lot entrances layer
- Number and location of on-street parking space
- Number of employees by building
- Number of employees using public transportation
- NFTA ridership numbers for existing LRRT and bus routes by stop location
- Ridership for the on-campus courtesy shuttle as well as the UB shuttle
- Results of Annual Survey that provides mode-share for the campus
- Summary of transit payroll deduction that provides transit dependent population data
- BNMC employee home addresses

Figure 40. BNMC Employee Home Addresses



The following data sets were incorporated into the BNMC Case Study GIS, and the information was used to establish Automated Transit Network (ATN) demand for the campus.

- Confirm activity centers, origins, and destinations
- Potential ridership
- Type of operations included fixed-route and on-call
- Required headways
- Interface with Allen Street/Medical Campus Metro Station
- Service to adjacent economically disadvantaged neighborhoods

Samples of this GIS data are presented in Figure 39 and Figure 40.

6.3 Design Network and Routes for Serving BNMC Mobility Needs

The next step for the BNMC Case Study was to design the ATN and route structure for the BNMC Study Area. The route structure may include fixed routes for peak periods and on-demand service for non-peak periods. Route and service plan design will include the following criteria:

- Address the critical needs for mobility/movement within the facility. These needs were identified through interviews and interaction with BNMC and other stakeholders.
- Identify activity centers in the study area and surrounding community that could be incorporated into the overall service plan.
- Identify potential users for the Olli service. This would include commuters that are employed on the campus as well as transit residents that live in the adjacent economically disadvantaged neighborhoods or adjacent neighborhoods that would utilize Olli to access the BNMC or NFTA Transit System. Since the Olli bus has limited passenger capacity and is not designed for ADA use, BNMC patients were not considered as potential users.
- Formulate a service plan that satisfies strategic goals for enhanced mobility. This includes desired headways and hours of operation.
- Address operational limitations that are presented by the existing city street infrastructure.
- Utilize documented travel speeds and operating endurance for Olli were used in the development of network layouts and station locations.

These criteria were used to develop alternative layouts. Layouts include the network configuration and station locations.

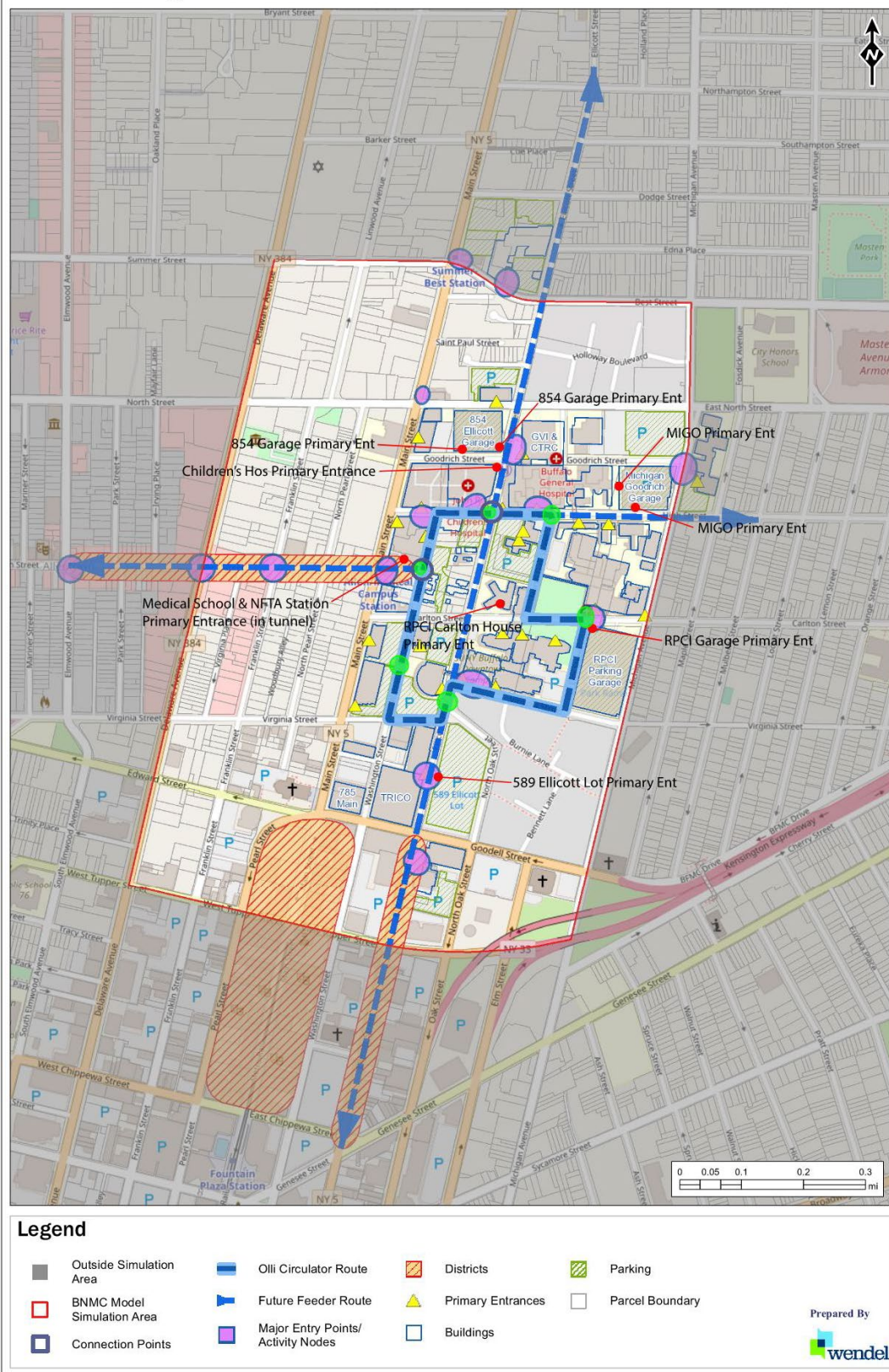
The study team hosted a charrette to solicit stakeholder input and refine the preferred network configuration. The result of the charrette is presented in Figure 41. This network satisfies the criteria the BNMC mobility criteria as follows.

- The BNMC core loop connects entrances to the high traffic buildings such as Oshie Children's Hospital, Buffalo General Hospital, Roswell Park Cancer Institute and SUNY at Buffalo's new Medical School with major parking garages and the NFTA Transit system.
- The network provides a north/south spine that connects to Summer Street NFTA Metro Station and neighborhoods to the north and the city's Central Business District to the south.
- The network provides an east/west spine that connects to the economically disadvantaged neighborhoods to the east and the Allentown neighbor to the west. As shown in Figure 5, many BNMC employees live in these neighborhoods.
- Since Olli would be operating at slower speeds than background vehicular traffic, the route used low-traffic volume streets as much as possible. Where it was necessary to use more heavily traveled streets, modifications will need to be made to construct pull off areas at stops and eliminate parking.

- Street modifications in the corridors would be consistent with the city’s future plans for complete street development in accordance with the Green Code. This would include reallocation of parking lanes to wider sidewalks and bicycle facilities. Potentially, these parking lanes could function as a dedicated travel lane for Olli.
- Operating speeds and battery life were factors used in route design. Long routes would not allow the desired headway without many buses. In addition, long routes would require additional buses to support the system due to the relatively short battery life of Olli buses.
- The selected route provides access to an existing parking garage that could be used as a storage facility for the Olli Bus Fleet.

Ultimately, the study team refined the route system that would be used to develop the model simulation used for the business case. The BNMC core loop was selected for the simulation due to its relatively short length, connectivity to major entrances and activity points and the quality of the transportation demand data that was available for the model.

Figure 41. BNMC Proposed Route Structure



6.4 BNMC Case Study Simulation Model

The goal of this part of the case study work was to build a simulation model of Olli’s suggested operations on BNMC. To this end, the data previously compiled (described in detail in section 6.2) were leveraged, and additional data, particularly on traffic signal timing and exiting traffic volumes on the BNMC network were collected. Information about traffic signal timing was collected by direct observations around the BNMC campus. Traffic signals on BNMC campus were found to be following a pre-timed schedule, which was easily recorded in the field. The simulation model was built using PTV Vissim, which is a microscopic simulation software that offers a complete traffic solution.

6.4.1 Demand for the Simulated Case Study

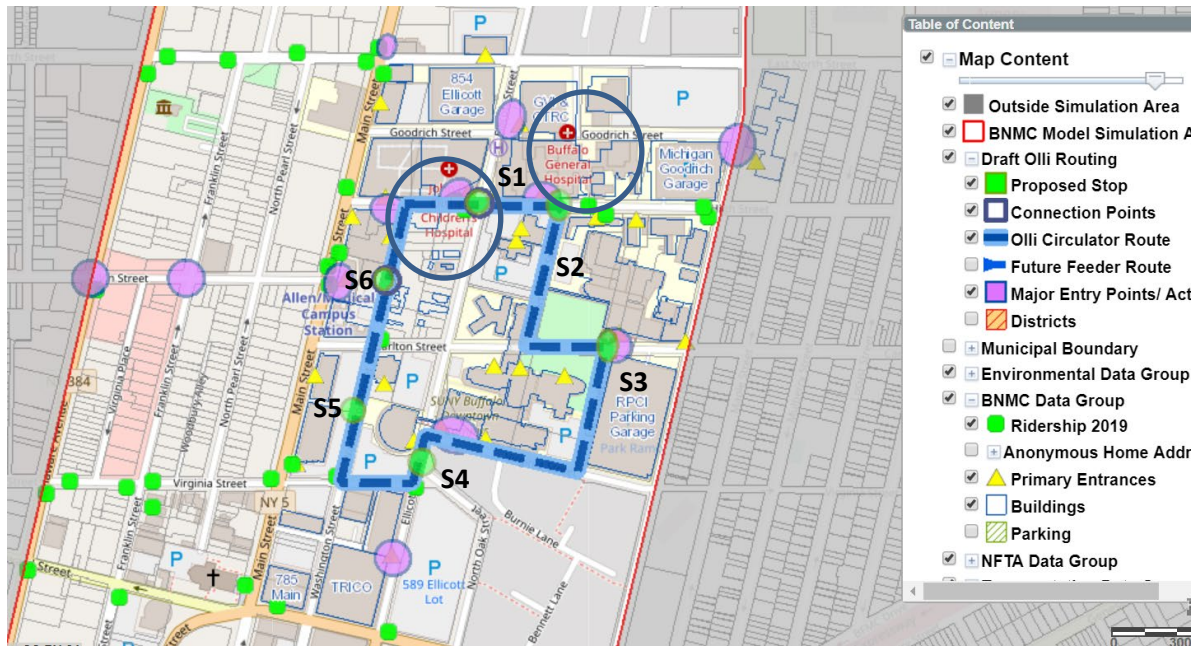
In building the simulation model, we focused on demand from one parking garage to the north of BNMC, indicated as S1 on Figure 42 to the campus’s key buildings around the loop, also shown on Figure 42. That parking lot has a total of 2,000 spots dedicated to BNMC employees. We next looked at the number of employees working in each of the primary buildings (i.e., hospitals, research institutions, and the university’s medical school) to derive a high-level, origin-destination matrix for that demand. The number of employees in each building is shown in Table 26.

Table 26. BNMC Employee Distribution across Buildings

BNMC Building	Number of Employees	Percent of Employees in Building relative to Total Number of Employees
Children Hospital (Ec)	1746	23%
Buffalo General Hospital (Eg)	3522	47%
Roswell Park (Er)	1667	22%
UB Medical School (Eu)	560	8%
Employees Total	7495	100%

Because the location of the northern parking garage we are considering here (indicated by S1 on Figure 42) is close to Children Hospital and to Buffalo General Hospital (shown inside the two circles on Figure 42), we assume that the employees of both the Children Hospital and Buffalo General Hospital would just walk from the garage to their employment location. This leaves the demand between the parking garage and Roswell Park and UB Medical School to be served using Olli.

Figure 42. Locations of Olli's Stations



Based on the assumption above, we used the percentage of employees in each building relative to the total number of employees (i.e., the percentage shown in column 3 of Table 26), to allocate the 2,000 trips from the parking garage to the buildings; therefore, for example, the demand between the parking garage to the north and UB Medical School is calculated according as follows: 2,000 (total demand) x 0.08 = 440 trips. The results are shown in Table 27. As was just mentioned, the demand to be served by Olli is from the parking garage to (1) Roswell Park and (2) UB Medical School, because the other two hospitals (i.e., Children Hospital and Buffalo General Hospital) are quite close to the garage. Given this, the total demand on Olli is equal to (440 + 160) or 600 trips from the Garage to Roswell Park and UB Medical School during the morning peak, and the same during the evening, but in reverse, from the buildings to the garage. Furthermore, we allocate the 600 people to different stops (S2 to S6) according to the percentages of employees in the different buildings around the stops. The results of this are shown in Table 28.

Table 27. Travel Demand from North Parking Garage to BNMC Buildings

	Children Hospital	Buffalo General Hospital	Roswell Park	UB Medical School	TOTAL
North Parking Garage	460	940	440	160	2,000

Table 28. Origin-Destination Matrix for the Olli's Loop

	S2	S3	S4	S5	S6	Total
S1	60	300	120	60	60	600

6.4.2 Simulation Model Assumptions

The following assumptions were made in building the simulation model.

- Employees go to work between the hours of 7:30 a.m. to 10:30 a.m.
- Employees get off from work between the hours 3:30 p.m. to 6:30 p.m.
- Employees' arrival and departure follow normal distribution with a mean time at 9:00 a.m. (for the morning peak) and 5:00 p.m. (for the evening peak) respectively, and with a standard deviation of 30 minutes.
- Lunch time and weekend use is not considered (Olli needs to charge during lunch hour).
- We only consider the passenger demand between the North Garage and Roswell Park and UB's Medical School.
- Employees park on north parking lots and take Olli to work destinations toward the south and follows a circuitous route. The reverse would happen in the evening peak period.

Figure 43. Normal Distribution

Based on the third assumption above, the research team was able to estimate the peak hour demand for each morning and evening peak hour.

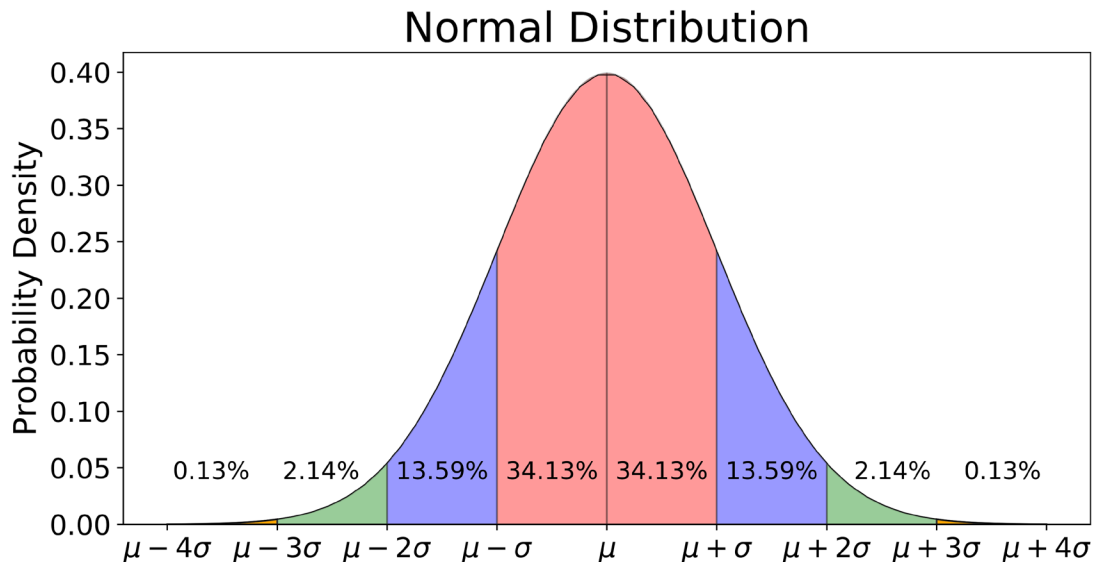


Figure 43 shows a typical normal distribution, which indicates that the range extending from one standard deviation to the left of the mean to one standard deviation to the right (i.e., from $\mu - \sigma$ to $\mu + \sigma$) would contain 34.13% + 34.13% or about 68% of the observations. With the mean assumed to be around 9:00 a.m., and with a standard deviation of 30 minutes, this means that the peak hour for the morning peak would extend from 8:30 a.m. to 9:30 a.m. and would contain 68% of the peak period demand. In other words, the morning peak hour demand would be equal to 0.68 x 600 trips (see section 6.4.1), which is around 400 trips/hour in the morning peak hour and another 400 trips/hour for the evening peak hour (extending from 4:30 p.m. to 5:30 p.m.).

6.4.3 Simulation Model Parameters

The length of the circulator route (L_c) shown in Figure 42 was found to be equal to 1 mile and given an Olli average speed (V_o) equal to 15 mile/hour and a total of six stops (S1 to S6) as shown in Figure 42, the time taken by an Olli shuttle to complete the circular route (T_c) was calculated as shown below.

Equation 6
$$T_c = L_c / V_o + T_s * N_s + T_d \approx 10 \text{ minutes}$$

where T_s is the time spent by Olli at each stop, N_s is the number of stops (6 in our case) and T_d is the delay at the traffic signals encountered along the route.

Now, given the capacity (C_o) of an Olli shuttle, the required size of the self-driving Olli fleet needed to meet a given percentage (P) of the peak demand during the peak hour (D), can be calculated as shown in Equation 7. In that calculation, the capacity of the shuttle was equal to 10 passengers, the peak demand was, as was calculated above, equal to 400 passengers during the peak hour, T is equal to 60 minutes (i.e., an hour), and the percentage of the peak demand satisfied was assumed to be equal to 75% (or 0.75).

Equation 7
$$\text{Fleet Size } (N) = \frac{P * D}{C_o * \frac{T}{T_0}} = \frac{0.75 * 400}{10 * \frac{60}{10}} = 5 \text{ vehicles,}$$

If it is desired to meet the full demand, a total of seven vehicles would be needed, but they would be underutilized for the rest of the day. Given this and to keep the cost down, we assume that it is acceptable to meet only 75% of the demand. This is acceptable because, with five vehicles and a circulation time of 10 minutes, an Olli bus would run every 2 minutes, which would mean that the wait time for a traveler if they cannot get onto an Olli bus would be only around two minutes (which is reasonable).

6.4.4 Simulation Result Analysis

Below we summarize the results from the simulation case study.

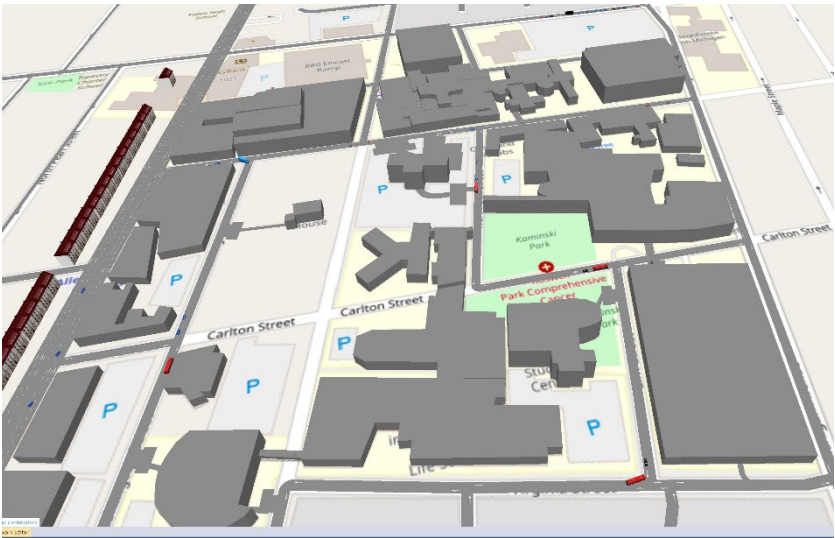
- Each Olli bus takes 10 minutes to finish one loop considering circulating time and time spent at stops, with fleet size of five Olli buses, we would be able to deploy an Olli every two minutes. The fleet would be able to pick up and drop off 300 passengers per hour.
- Based on our simulation result, we found that with fleet size of five Olli buses, we could accommodate a total 300 passengers per hour. This translates to a total of 900 passengers during the morning peak period extending from 7:30 a.m. to 10:30 a.m., and another 900 passengers during the evening peak period).
- Since we assume our primary 600 passengers include employees from UB and Roswell arrive at stations follow normal distribution over the three-hour operation instead of uniform distribution, we can only serve 300 of 400 (or 75% of the demand) during the peak time which is from 8:30 a.m. to 9:30 a.m. and 4:30 p.m. to 5:30 p.m.
- If we increase the fleet size to six Olli buses, we can serve 360 of 400 (90%) during peak time, but that will increase operation cost by 20% (6/5) and result in an underutilization of Olli's capacity during the rest of the day. In fact, outside the peak hour, only 4 vehicles are needed to meet the demand.
- Given this, we recommend an overall fleet size of five Olli buses, considering demand and operational cost.

Figure 44 and Figure 45 show two simulation screenshots.

Figure 44. Two-Dimensional Screenshot of the Simulation Model Output



Figure 45. Three-Dimensional Screenshot of the Simulation Model Output



6.5 BNMC Business Case Analysis

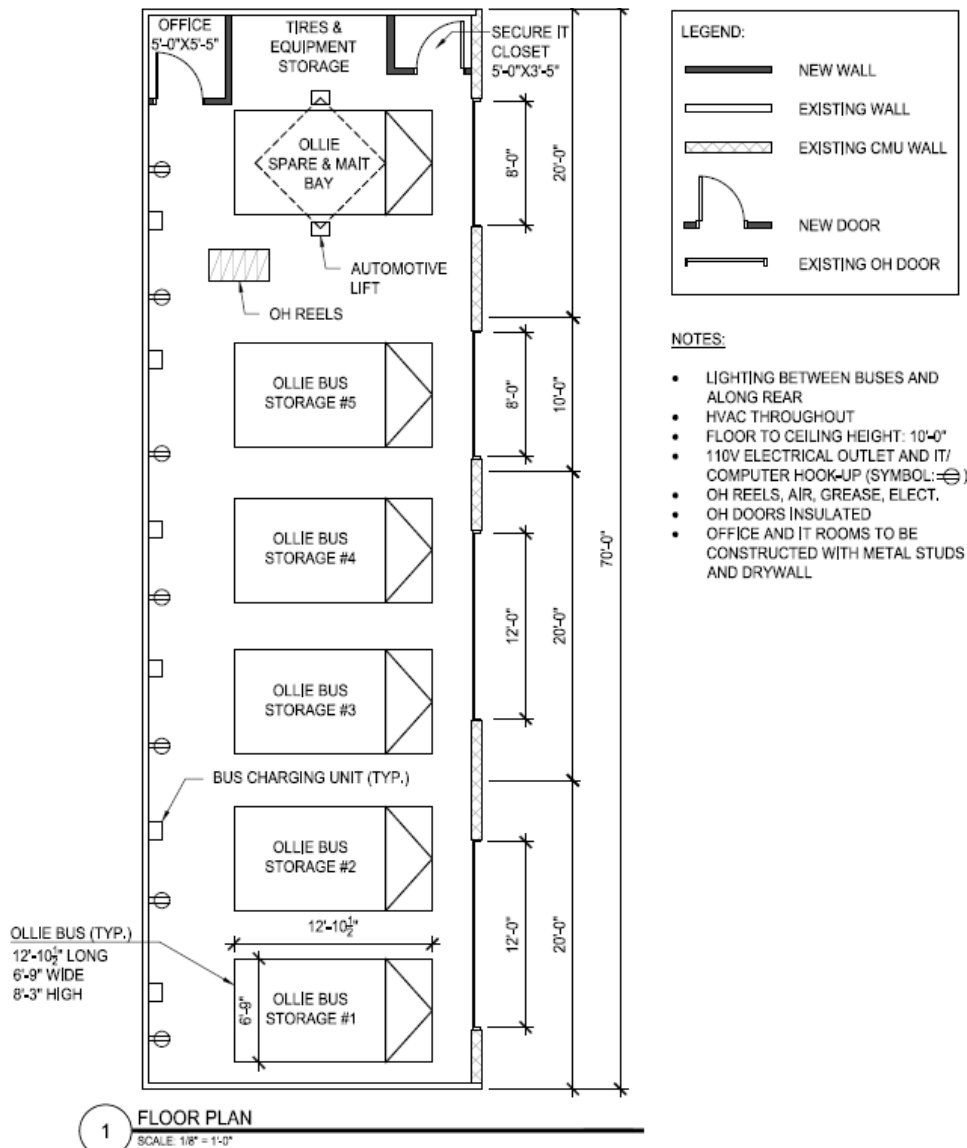
Subsequent to developing the route map—including bus stops and circular pattern—as well as completing the simulation, the research team proceeded to analyze the financial and business case for Ollie’s success on the BNMC. Three approaches to the business plan will be addressed as follows:

- Public plan where all capital and operational costs are covered by the BNMC and patrons ride at no cost.
- Private plan where capital investments and operation costs are made by a private company and there is a fee to ride on the system.
- Public-private partnership where the public entity makes all capital investments while the private operator is responsible for operating cost and a modest fee offsets a portion of the expenses.

The elements of the business model include both capital and operational costs. Note that all costs are in terms of 2020 U.S. dollars.

1. Capital costs acquisition of the Olli shuttles:
Per the bus circulation plan, five Olli shuttles are required with one additional bus for a spare. Local Motors Inc. (LM), manufacturer of the Ollie Bus leases the vehicles to the customers. In discussion with LM representatives, we discussed a five-year lease program. Per LM’s quote, the annual lease payment for the six Olli shuttles is \$660,000 for a total cost of \$3,960,000 for the five-year period. This lease cost includes regular maintenance on the Olli shuttles provided by LM.
2. Capital costs (Olli shuttle garage):
After discussions with the BNMC representative, it was offered that a corner of the Ellicott Garage could be made available for the Olli Bus operation. A plan for the Olli shuttle storage, charging, and maintenance facility is shown in Figure 46. Construction and renovation of this space is estimated to be \$1,000,000.
3. Capital costs (bus shelter):
Weather protection for patrons waiting for the Olli shuttle will require bus shelters. There are six stops as previously discussed, at an estimated cost of \$15,000 each for a total of \$60,000. Note that all bus stops will not require a standalone shelter as some will be part of this existing medical campus.
4. Operational costs (utilities):
Olli shuttles are energized by batteries that require charging. Charging will take place on a regular basis in the Ellicott Garage Maintenance Complex. Annual electric costs are expected to be \$10,000.

Figure 46. Proposed Olli Parking, Charging, and Maintenance Facility



OLLIE BUS STORAGE AND MAINTENANCE FACILITY

BUFFALO NIAGARA
MEDICAL CAMPUS
Project No.: 405609

DATE: 1/28/2020



5. Operational costs (insurance):

Liability insurance for an automatic bus is speculative since experience profiles and accident rates used by insurance companies are nonexistent for this new market. Nevertheless, we did consult with some liability insurance experts and they estimated that liability cost premiums could be as high at \$250,000 per year.

6. Operational cost (personnel):

Two classifications of personnel will be required. The first would be the fleet manager and the second the individual Olli Bus Steward. A steward is a person who would be on each bus and able to drive the bus with the joystick should circumstances require. Both the fleet manager and steward positions would be part-time positions. The estimate for all personnel costs including benefits would be \$200,000.00 per year. If on the other hand, stewards were not necessary this cost would be \$100,000.00 per year.

As a result of the above factors the financial plans for the three scenarios are as follows:

Ollie Bus Lease	\$ 660,000.00
Construction Loan	\$ 225,000.00*
Shelters Loan	\$ 20,000.00*
Utilities	\$ 10,000.00
Insurance	\$ 250,000.00
Personnel	<u>\$ 200,000.00</u>
Total Annual Cost:	\$1,365,000.00/year

Note * Approximate annual costs for five years at a rate of 4.5%

The above would be the annual cost for the public plan where all costs are covered by the BNMC or some other public entity.

Under a private plan and based on a ridership of 270,000 trips per year the breakeven cost per rider would be \$5.05 per trip or with a modest profit, \$5.50 per trip.

A public-private partnership whereby the public entity is responsible for the capital cost with assistance from the State and Federal Government (customary for public transportation providers) and the private entity is responsible for the operating costs, the cost per trip would be approximately \$1.75.

7 References

- Albright, J., Bell, A., Schneider J., and Nyce, C. (2015). "Automobile Insurance in the Era of Autonomous Vehicles," KPMG LLP, Amstelveen, 2015.
- AP News. (2020). "U.S. agency lets self-driving shuttle resume carrying people"
<https://apnews.com/aa26472267a917ad3e0419c76987fa31>
- AV International. (2019). Navya abandons plans to enter fully-AV market" Dan Symonds, July 25, 2019,
<https://www.autonomousvehicleinternational.com/news/business/navya-abandons-plans-to-enter-fully-autonomous-vehicle-market.html>
- Avelar, T. (2015). "Google self-driving car has 1st accident involving injuries," CBC News, 17 July 2015.
- Ben-Akiva, M.E. and Lerman, S.R. (1985). Discrete Choice Analysis: Theory and Application to Travel Demand, Cambridge: The MIT Press.
- Benedetto Piccoli, Dan Work and Benjamin Seibold et al . (2018). Dissipation of stop-and-go waves via control of autonomous vehicles: Field experiments" by May 4, 2017, as found in Transportation Research Part C: Emerging Technologies 2018.
- CBRE Research. (2018). Autonomous Vehicles: Driving Change for Real Estate.
- Center for Auto Safety. (2019). "Center for Auto Safety Calls on NHTSA to Reject GM and Nuro Exemptions from Federal Safety Standards" May 20, 2019, <https://www.autosafety.org/center-for-auto-safety-calls-on-nhtsa-to-reject-gm-and-nuro-exemptions-from-federal-safety-standards/>
- Cole, M. (2014). "Driverless Cars Gain Public Acceptance, Sort Of," The Fiscal Times, 31 July 2014.
- Consortium for Science, Policy & Outcomes at Arizona State University. (2019). "Our Driverless Futures: Community Forums on Automated Mobility," [Online]. Available:
<https://cspo.org/research/driverless-vehicles/>. [Accessed 1 September 2019].
- Cregger, J., Dawes, M., Fischer, S., Lowenthal, C., Macheck, E., and Perlman, D. (2018). Low-Speed Automated Shuttles: State of the Practice. Report No. FHWA-JPO-18-692, U.S. Department of Transportation, Washington, D.C.
- DARPA. (2004). DARPA Grand Challenge 2005 Rules published on October 8, 2004
https://archive.darpa.mil/grandchallenge05/Rules_8oct04.pdf
- DARPA. (2005). Report to Congress.
https://archive.darpa.mil/grandchallenge/docs/Grand_Challenge_2005_Report_to_Congress.pdf
- EasyMile. (2020). EZ10, Accessed June 3, 2020, <https://easymile.com/solutions-easymile/ez10-autonomous-shuttle-easymile/>

- Etherington, D. (2019). 1,400 self-driving vehicles are now in testing by 80+ companies across the US,” June 11, 2019, <https://techcrunch.com/2019/06/11/over-1400-self-driving-vehicles-are-now-in-testing-by-80-companies-across-the-u-s/>
- Fraade-Blanan, L. and Karla, N. (2017). “AVs and Federal Safety Standards” An Exemption to the Rule?” RAND Corporation.
- Gov. Doug Ducey, “Advancing Autonomous Vehicle Testing and Operating; Prioritizing Public Safety,” Arizona Executive Order 2018-04, March 1, 2018, https://azgovernor.gov/sites/default/files/related-docs/eo2018-04_1.pdf
- Gov. John Carney, “Establishment of the Advisory Council on Connected and AVs,” Delaware Executive Order 14, September 5, 2017, <https://governor.delaware.gov/executive-orders/eo14/>
- Gov. David Ige, “AV Testing,” Hawaii Executive Order 17-07, November 22, 2017 <https://governor.hawaii.gov/wp-content/uploads/2017/11/EO-17-07.pdf>
- Gov. C.L. Otter, “Creates the Autonomous and Connected Vehicle Testing and Deployment Committee,” Idaho Executive Order 2018-01, January 2, 2018, https://adminrules.idaho.gov/rules/2018%20Archive/EXOs/2018-01_ExOr_18-2.pdf
- Gov. Paul LePage. (2018). “An Order Establishing the Maine Highly Automated Vehicles Advisory Committee,” Maine Executive Order 2018-001, https://www.maine.gov/tools/whatsnew/index.php?topic=Gov_Executive_Orders&id=776188&v=article2018
- Gov. Charlie Baker. (2016). “To Promote the Testing and Deployment of Highly Automated Driving Technologies” Massachusetts Executive Order 572, <https://www.mass.gov/executive-orders/no-572-to-promote-the-testing-and-deployment-of-highly-automated-driving>
- Gov. Mark Dayton. (2018). “Establishing the Governor's Advisory Council on Connected and Automated Vehicles,” Minnesota Executive Order 18-04, March 5, 2018, <https://www.leg.state.mn.us/archive/execorders/18-04.pdf>
- Gov. John Kasich. (2018) “Establishing DriveOhio as the Statewide Center for Smart Mobility,” Ohio Executive Order 2018-01K, <https://cdm16007.contentdm.oclc.org/digital/collection/p267401ccp2/id/16074>
- Gov. Jay Inslee, 2017. “AV Testing & Technology In Washington State And AV Work Group,” Washington Executive Order 17-02, https://governor.wa.gov/sites/default/files/exe_order/17-02AutonomouVehicles.pdf?utm_medium=email&utm_source=govdelivery
- Gov. Scott Walker, 2017. “Creation of the Governor's Steering Committee on Autonomous and Connected Vehicle Testing and Deployment,” Wisconsin Executive Order 245, https://urbanmilwaukee.com/wp-content/uploads/2017/05/Executive_Order_245.pdf
- Government of the Netherlands. (2020). Self-driving Vehicles, Accessed June 12, 2020. <https://www.government.nl/topics/mobility-public-transport-and-road-safety/self-driving-vehicles>

- Greater Buffalo Niagara Regional Transportation Council; University at Buffalo Regional Institute, The State University of New York at Buffalo. (2019). "MOVING FORWARD 2050," May 2018. [Online]. Available: <https://www.gbnrtc.org/movingforward2050>. [Accessed 1 September 2019].
- KPMG. (2019). AVs Readiness Index. <https://home.kpmg/xx/en/home/insights/2019/02/2019-autonomous-vehicles-readiness-index.html>
- Mayor William Peduto. (2019). Executive Order Self-Driving Vehicle Testing And Operations in the City of Pittsburgh. <http://pittsburghpa.gov/press-releases/press-releases.html?id=2724>
- M-city. (2018). Driverless Shuttle: A Case Study” M-city University of Michigan.
- Medium. (2019). Waymo Open Dataset: Sharing our self-driving data for research” August 21, 2019, <https://medium.com/waymo/waymo-open-dataset-6c6ac227ab1a>
- Mehdi Nourinejad, Sina Bahrami, Matthew J. Roorda. Designing parking facilities for autonomous vehicles. *Transportation Research Part B: Methodological*, 2018; 109: 110
DOI: 10.1016/j.trb.2017.12.017.
- NCSL. (2020). Autonomous Vehicles | Self-Driving Vehicles Enacted Legislation,” last modified on February 18, 2020, <https://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx#enacted>
- NHTSA. (2016a). Federal Automated Vehicles Policy: Accelerating the Next Revolution in Roadway Safety, USDOT.
- NHTSA. (2016b) “Temporary Importations,” July 2016, <https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/tempinfojuly2016.pdf>
- NHTSA. (2018a). Temporary Exemption from Motor Vehicle Safety and Bumper Standards. NHTSA 49 CFR Part 555 [Docket No. NHTSA–2018–0103] RIN 2127–AL97.
- NHTSA. (2018b) NHTSA Issues Final Rule to Streamline Petition Process to Advance Transportation Safety and Innovation” NHTSA, December 18, 2018, <https://www.nhtsa.gov/press-releases/nhtsa-issues-final-rule-streamline-petition-process-advance-transportation-safety>
- NHTSA. (2019a). Notice, “General Motors, LLC-Receipt of Petition for Temporary Exemption From Various Requirements of the Safety Standards for an All-Electric Vehicle With an Automated Driving System,” *Federal Register* 84, (March 19, 2019): 10182-10191, <https://www.federalregister.gov/documents/2019/03/19/2019-05119/general-motors-llc-receipt-of-petition-for-temporary-exemption-from-various-requirements-of-the-of-the-safety-standards-for-an-all-electric-vehicle-with-an-automated-driving-system>

- NHTSA. (2019b) “Nuro, Inc.; Receipt of Petition for Temporary Exemption for an Electric Vehicle With an Automated Driving System” NHTSA, Federal Register, March 19, 2019, <https://www.federalregister.gov/documents/2019/03/19/2019-05121/nuro-inc-receipt-of-petition-for-temporary-exemption-for-an-electric-vehicle-with-an-automated>
- NHTSA. (2020a). Voluntary Safety Self-Assessment,” NHTSA, accessed on June 1, 2020, <https://www.nhtsa.gov/automated-driving-systems/voluntary-safety-self-assessment>
- NHTSA. (2020b). NHTSA Fatality Analysis Reporting System (FARS), accessed on June 12, 2020, <https://www-fars.nhtsa.dot.gov/Main/index.aspx>
- NHTSA. (2020c). “Petitions for Rulemaking Received During This Administration,” NHTSA, accessed June 4, 2020 <https://www.nhtsa.gov/laws-regulations/petitions-nhtsa>
- Nuro Inc. (2020). Delivering Safety: Nuro’s Approach, Accessed on June 12, 2020. https://static1.squarespace.com/static/57bcb0e02994ca36c2ee746c/t/5b9a00848a922d8eaecf65a2/1536819358607/delivering_safety_nuros_approach.pdf
- Office of Highway Policy Information. (2017). “State Motor-Vehicle Registrations”, <https://www.fhwa.dot.gov/policyinformation/statistics/2015/mv1.cfm>
- Roess, R.P., Prassas, E.S., and McShane, W.R. (2014). Traffic Engineering, Boston: Pearson.
- Society of Automotive Engineers (SAE). (2020a). About SAE International”, Accessed May 31, 2020 <https://www.sae.org/about/history>
- Society of Automotive Engineers (SAE). (2020b). “SAE J3016: Levels of Driving Automation”, Accessed May 31, 2020 <https://www.sae.org/news/2019/01/sae-updates-j3016-automated-driving-graphic>
- Standage, T. (2018). Autonomous vehicles are just around the corner”. The Economist.
- The Drive. (2019). Navya Pivots Away from "Experimental" Autonomous Shuttle Business” The Drive, July 29, 2019, <https://www.thedrive.com/tech/29196/navya-pivots-away-from-experimental-autonomous-shuttle-business>
- Underwriters Laboratories (UL). (2020). Underwriters Laboratories Publishes AV Standard, Accessed on May 31, 2020, <https://www.prnewswire.com/in/news-releases/underwriters-laboratories-publishes-autonomous-vehicle-standard-862414512.html>
- USDOT. (2017). Automated Driving Systems (ADS): A Vision for Safety 2.0” (AV 2.0), USDOT.
- USDOT. (2018). Preparing for the Future of Transportation: Automated Vehicles 3.0, USDOT.
- USDOT. (2019). Automated Vehicles 4.0 Ensuring American Leadership in Automated Vehicle Technologies” USDOT.

Warren, W. (2000). Policy Analysis: A Systematic Approach to Supporting Policymaking in the Public Sector". *Journal of Multi-Criteria Decision Analysis*.

Yoshida, J. (2020). "Safe Autonomy: UL 4600 and How It Grew," Accessed on April 2, 2020, <https://www.eetimes.com/safe-autonomy-ul-4600-and-how-it-grew/#>

Appendix A. NYS AV Testing and AV Legislation

Sections 1 to 3 of Part FF of Chapter 55 of the laws of 2017 delivered to the Governor on April 9, 2017 enacted the New York State Demonstration and Testing of Autonomous Vehicle Technology legislation, subsequent amendments in Part H of Chapter 58 of the laws of 2018 delivered to the Governor on April 2, 2018 and amendments in Part M of Chapter 58 of the law of 2019 enacted on April 12, 2019.

A.1 Sections 1 to 3 of Part FF of Chapter 55 of the Laws of 2017 Delivered to the Governor on April 9, 2017

Section 1. a. Notwithstanding the provisions of section 1226 of the vehicle and traffic law, the New York state commissioner of motor vehicles may approve demonstrations and tests consisting of the operation of a motor vehicle equipped with autonomous vehicle technology while such motor vehicle is engaged in the use of such technology on public highways within this state for the purposes of demonstrating and assessing the current development of autonomous vehicle technology and to begin identifying potential impacts of such technology on safety, traffic control, traffic enforcement, emergency services, and such other areas as may be identified by such commissioner. Provided, however, that such demonstrations and tests shall only take place under the direct supervision of the New York state police. Such demonstrations and tests shall take place in a manner and form prescribed by the commissioner of motor vehicles including, but not limited to: a requirement that a natural person holding a valid license for the operation of the motor vehicle's class be present within such vehicle for the duration of the time it is operated on public highways; a requirement that the motor vehicle utilized in such demonstrations and tests complies with all applicable federal motor vehicle safety standards and New York state motor vehicle inspection standards; and a requirement that the motor vehicle utilized in such demonstrations and tests has in place, at a minimum, financial security in the amount of five million dollars. Nothing in this act shall authorize the motor vehicle utilized in such demonstrations and tests to operate in violation of article 22 or title 7 of the vehicle and traffic law, excluding section 1226 of such law.

b. For the purposes of this act, the term "autonomous vehicle technology" shall mean the hardware and software that are collectively capable of performing part or all of the dynamic driving task on a sustained basis, and the term "dynamic driving task" shall mean all of the real-time operational and tactical functions required to operate a vehicle in on-road traffic, excluding the strategic functions such as trip scheduling and selection of destinations and waypoints.

§ 2. The commissioner of motor vehicles shall, in consultation with the superintendent of state police, submit a report to the governor, the temporary president of the senate, the speaker of the assembly, and the chairs of the senate and assembly transportation committees on the demonstrations and tests authorized by section one of this act. Such report shall include, but not be limited to, a description of the parameters and purpose of such demonstrations and tests, the location or locations where demonstrations and tests were conducted, the demonstrations' and tests' impacts on safety, traffic control, traffic enforcement, emergency services, and such other areas as may be identified by such commissioner. Such commissioner shall submit such report on or before June 1, 2018.

§ 3. This act shall take effect April 1, 2017; provided, however, that section one of this act shall expire and be deemed repealed April 1, 2018.

A.2. Amendments in Part H of Chapter 58 of the Laws of 2018 Delivered to the Governor on April 2, 2018

Section 1. Subdivision a of Section 1 of Part FF of Chapter 55 of the laws of 2017, relating to motor vehicles equipped with autonomous vehicle technology, is amended to read as follows:

a. Notwithstanding the provisions of Section 1226 of the vehicle and traffic law, the New York state commissioner of motor vehicles may approve demonstrations and tests consisting of the operation of a motor vehicle equipped with autonomous vehicle technology while such motor vehicle is engaged in the use of such technology on public highways within this state for the purposes of demonstrating and assessing the current development of autonomous vehicle technology and to begin identifying potential impacts of such technology on safety, traffic control, traffic enforcement, emergency services, and such other areas as may be identified by such commissioner. Provided, however, that such demonstrations and tests shall only take place under the direct supervision of the New York state police, in a form and manner prescribed by the superintendent of the New York state police. Additionally, a law enforcement interaction plan shall be included as part of the demonstration and test application that includes information for law enforcement and first responders regarding how to interact with such a vehicle in emergency and traffic enforcement situations. Such demonstrations and tests shall take place in a manner and form prescribed by the commissioner of motor vehicles including, but not limited to: a requirement that a natural person holding a valid license for the operation of the motor vehicle's class be present within such vehicle for the duration of the time it is operated on public highways; a requirement that the motor vehicle utilized in such demonstrations and tests complies with all applicable federal motor vehicle safety standards and New York state motor vehicle inspection standards; and a

requirement that the motor vehicle utilized in such demonstrations and tests has in place, at a minimum, financial security in the amount of five million dollars. Nothing in this act shall authorize the motor vehicle utilized in such demonstrations and tests to operate in violation of article 22 or title 7 of the vehicle and traffic law, excluding section 1226 of such law.

§ 2. Section 2 of Part FF of Chapter 55 of the laws of 2017, relating to motor vehicles equipped with autonomous vehicle technology, is amended to read as follows:

§ 2. The commissioner of motor vehicles shall, in consultation with the superintendent of state police, submit a report to the governor, the temporary president of the senate, the speaker of the assembly, and the chairs of the senate and assembly transportation committees on the demonstrations and tests authorized by section one of this act. Such report shall include, but not be limited to, a description of the parameters and purpose of such demonstrations and tests, the location or locations where demonstrations and tests were conducted, the demonstrations' and tests' impacts on safety, traffic control, traffic enforcement, emergency services, and such other areas as may be identified by such commissioner. Such commissioner shall submit such report on or before June 1, 2018 and June 1, 2019.

§ 3. Section 3 of Part FF of Chapter 55 of the laws of 2017, relating to motor vehicles equipped with autonomous vehicle technology, is amended to read as follows:

§ 3. This act shall take effect April 1, 2017; provided, however, that section one of this act shall expire and be deemed repealed April 1, 2019.

§ 4. This act shall take effect immediately.

A.3. Amendments in Part M of Chapter 58 of the Laws of 2019 Enacted on April 12, 2019

Section 1. Section 2 of Part FF of Chapter 55 of the laws of 2017 relating to motor vehicles equipped with autonomous vehicle technology, as amended by Section 2 of Part H of Chapter 58 of the laws of 2018, is amended to read as follows:

§ 2. The commissioner of motor vehicles shall, in consultation with the superintendent of state police, submit a report to the governor, the temporary president of the senate, the speaker of the assembly, and the chairs of the senate and assembly transportation committees on the demonstrations and tests authorized by section one of this act. Such report shall include, but not be limited to, a description of the parameters and purpose of such demonstrations and tests, the location or locations where demonstrations and tests were conducted, the demonstrations' and tests' impacts on safety, traffic control, traffic enforcement, emergency services, and such other areas as may be identified by such commissioner. Such commissioner shall submit such report on or before June 1, 2018, June 1, 2019, and June first of each year this section remains in effect.

§ 2. Section 3 of Part FF of Chapter 55 of the laws of 2017 relating to motor vehicles equipped with autonomous vehicle technology, as amended by Section 3 of Part H of Chapter 58 of the laws of 2018, is amended to read as follows:

§ 3. This act shall take effect April 1, 2017; provided, however, that section one of this act shall expire and be deemed repealed (initially the repeal date was set to April 1, 2019 and then to 2021).

§ 3. This act shall take effect immediately.

Appendix B. Annual Report by NYS Commissioner of DMV

June 1, 2018

The Honorable Andrew Cuomo
Governor
State of New York
State Capitol
Albany, New York 12224

Dear Governor Cuomo:

New York State has long stood at the forefront of cutting-edge technological advancement and continues to raise the bar through the State's pioneering AV testing pilot program. The evolution of automotive development, particularly in the area of autonomous driving, has the potential to make our roadways safer for all and save lives. Capitalizing on our spirit of innovation, leading researchers have turned to New York to help lead the way.

Together, the Department of Motor Vehicles (DMV) and New York State Police have proudly overseen the pilot program, which began in May 2017. Authorized as part of the State Fiscal Year (SFY) 2017-2018 enacted budget, the legislation created a year-long pilot which allowed entities to apply to DMV and State Police to test or demonstrate AV technology. Most recently, the pilot program was renewed for another year as part of the SFY 2018-2019 enacted budget.

Applications may be submitted by manufacturers of AV technology, or companies creating such technology working in conjunction with manufacturers. All vehicles have to comply with federal safety standards and all applicable New York State inspection standards. A person holding a valid driver license must be present in the driver's seat at all times while it is operated on public highways. The legislation also requires companies to submit a report on their demonstrations or tests to DMV. DMV, in cooperation with the State Police, is also required to submit a summary report of the pilot program to the Governor and legislature.

The program's first year was underscored by demonstrations by Audi of America and Cadillac. New York's first AV demonstration was conducted by Audi of America, where the manufacturer showcased SAE Level 3 AV technology to officials in Albany, New York. This demonstration was soon followed by Cadillac's demonstration which launched the nation's first cross-country, hands-free drive from Cadillac's global headquarters in New York City; the trip continued outside of New York and crossed 16 states and Washington, D.C. ultimately ending in California.

As prescribed in Part FF of Chapter 55 of the Laws of 2017, I am transmitting the required summary report of those AV tests conducted in New York State this past year. The participating companies were required to report details of tests to the State including the purpose, date and location of the AV tests as well as impacts on safety and traffic control.

Summary of 2017-18 AV Tests/Demonstrations

Testing Entity	Purpose of Tests	Date of Tests	Location of Tests	Impacts on Safety
Volkswagon Group of America Inc. dba Audi of America Inc.	To showcase the company's level 3 automated driving technology to NYS officials	6/19/2017	Multiple trips occurred over a seven-hour period; the vehicle traveled approximately 170 miles in the Albany area	The company reported that the technology performed as expected with no safety issues
General Motors Company	To showcase the hands-free capability of the Super Cruise system and allow participants to use and experience the technology	9/25/2017	Nine vehicles were operated in NYC from Battery Park, along the FDR Parkway, and across the George Washington Bridge into NJ en route to Washington DC as the national kick-off of the Super Cruise technology	The company reported that no safety issues relating to the system were reported

If you have any questions or concerns, please contact me. Thank you.

Sincerely,

Theresa L. Egan
 Executive Deputy Commissioner
 NYS Department of Motor Vehicles

TLE:alm

NYSERDA, a public benefit corporation, offers objective information and analysis, innovative programs, technical expertise, and support to help New Yorkers increase energy efficiency, save money, use renewable energy, and reduce reliance on fossil fuels. NYSERDA professionals work to protect the environment and create clean-energy jobs. NYSERDA has been developing partnerships to advance innovative energy solutions in New York State since 1975.

To learn more about NYSERDA's programs and funding opportunities, visit nyserda.ny.gov or follow us on Twitter, Facebook, YouTube, or Instagram.

**New York State
Department of Transportation**

50 Wolf Road
Albany, NY 12232

telephone: 518-457-6195

dot.ny.gov

**New York State
Energy Research and
Development Authority**

17 Columbia Circle
Albany, NY 12203-6399

toll free: 866-NYSERDA
local: 518-862-1090
fax: 518-862-1091

info@nyserda.ny.gov
nyserda.ny.gov



NYSERDA
Department of
Transportation

State of New York

Andrew M. Cuomo, Governor

New York State Energy Research and Development Authority

Richard L. Kauffman, Chair | Doreen M. Harris, President and CEO

New York State Department of Transportation

Marie Therese Dominguez, Commissioner