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# Project 568: Driver training for Shared Autonomy Systems using Mixed Reality

Rahul Mangharam (0000-0002-3388-8283)
Helen Loeb (0000-0001-5762-2044)

*Final Report – July 2025*

**Technical Report Documentation Page**

| **1. Report No.**<br>568 | **2. Government Accession No.** | **3. Recipient's Catalog No.** |
|---|---|---|
| **4. Title and Subtitle**<br>Driver training for Shared Autonomy Systems using Mixed Reality | | **5. Report Date**<br>July 31st, 2025 |
| | | **6. Performing Organization Code** |
| **7. Author(s)**<br>Rahul Mangharam<br>https://orcid.org/0000-0002-3388-8283<br><br>Helen Loeb<br>https://orcid.org/0000-0001-5762-2044 | | **8. Performing Organization Report No.** |
| **9. Performing Organization Name and Address**<br>University of Pennsylvania<br>Jitsik | | **10. Work Unit No.** |
| | | **11. Contract or Grant No.**<br>Federal Grant # 69A3552344811 / 69A3552348316 |
| **12. Sponsoring Agency Name and Address** | | **13. Type of Report and Period Covered**<br>Final Report (July 1, 2024 – June 30, 2025) |
| | | **14. Sponsoring Agency Code**<br>USDOT |
| **15. Supplementary Notes**<br>Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. | | |

| **16. Abstract** | | | |
|---|---|---|---|
| This research project aims at assessing the potential of Virtual Reality for driver training. | | | |
| **17. Key Words**<br>Mixed Reality, Virtual Reality, Driver Training, Driver's Ed. | | **18. Distribution Statement**<br>No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161. | |
| **19. Security Classif. (of this report)** | **20. Security Classif. (of this page)** | **21. No. of Pages**<br>19 | **22. Price** |

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

# Contents

# 1. Project Overview

This project is a continuation of a Year-1 deployment project which engages with different vulnerable driver communities - teens who are learning to drive and seniors who are experiencing loss of cognitive capabilities.

This research consists in the development and assessment of a virtual reality Driver Training system with augmented reality pass through where a 16 year-olds and patients with compromised cognitive capabilities can sit in a stationary real vehicle and use mixed-reality to learn driving skills and get exposed to increasingly challenging driving scenarios. Sensors are strapped onto the steering and brake/gas pedals of their car and capture driver movements that are fed back into the simulation. The windshield and windows are overlaid with a VR generated driving simulator scenario. As a result, the driver is sitting in a real vehicle with AR passthrough showing the steering wheel and the driver’s hands, but the risky driving scenarios are simulated. The goal of this system is to develop a simulator that can be retrofitted in any car so novice drivers can train at home in a safe way and experience risky scenarios that cannot be demonstrated in real-life.

Mixed-reality or XR means VR with AR passthrough. So some visual elements are VR and others are camera passthroughs of reality.

The Problem: The high costs of elder care, both to the individual and the government, combined with the demographic shift towards an increasing number of older adults as a percentage of the overall US population is creating a major healthcare crisis. The number of senior citizens in the US in 2030 will be twice that of 2000, leading to a shortage of working-age caregivers and putting increased pressure on labor costs. Equally important is maintaining, or preferably ameliorating, the quality of life of a growing elderly population. Maintaining elders’ autonomy is correlated with increasing quality of life and autonomy enhancement is correlated with improving functionality. Driving is typically a symbol of autonomy. The revocation of driving privileges is often the first step taken by families worried about cognitive decline and emerging dementia of the older adult. Dementia including Alzheimer's disease is a chronic, progressive syndrome that is characterized by a reduction in the ability to perform daily activities, e.g. a cognitive decline with increasing unpredictability and psychological symptoms. Dementia affects about 5 million people in the USA and 35 million worldwide. Coincidentally, Autonomous Vehicles (AVs) are a game-changing AI and robotic solution that can enable older people to maintain independence. For this technology to be effectively deployed, Safety and Trust are however key. Older people, but also caregivers and clinicians need to view the technology as safe and trustworthy. To realize this potential, a robust shared autonomy strategy is needed. The term shared autonomy is an oxymoron, but it embodies the tension observed as caregivers, clinicians, and patients negotiate the need to trust the autonomous system and the desire to stay in control. This research project aims to address the question on how to mediate autonomy between participating actors to allow the human control of the system up to their level of performance and autotune the degree of intervention by the machine to maintain safety.

Approach: To these ends, we propose the development of an interactive imitation learning system for safe human autonomous systems. The system is trained by an expert for multiple levels of performance following a curriculum. When the system is deployed with a human non-expert user (e.g. an older driver), the safe by construction neural network controller ensures safety at any level of performance (see figure on the left). This enables the system to personalize its capabilities to suit the human partner while ensuring safety from any mismatches in the expectations of the controller and that of the human user. The AVs will therefore learn how the user desires to share autonomy and ensure the system does not reach an unsafe state under all operating conditions and inputs from the human.

# 2. The physical framework

## 2.1 Steering wheel and pedals

While a Logitech G920 system was originally selected in the first phase of the project for its ease of deployment and low cost, an early pilot at the driving school Driven2Drive location in Bala Cynwyd showed that this system had negative aspects. The relative position of the brake pedal vs the gas pedal made it hard for users to brake in an emergency situation. In addition, the steering wheel was perceived as too light with poor force feedback. The research team opted for a Fanatec system that is commonly used for racing simulators. A pilot conducted in April and June 2025 showed that this system was a better representation of real vehicle controls.

## 2.2 Mixed Reality Headset

To deliver the mixed reality driving simulation experience, the research team opted for a Meta Quest 3 headset. The Meta Quest 3 is a standout mixed reality headset thanks to its blend of powerful hardware, immersive capabilities, and user-friendly design. It features full-color passthrough with high-resolution cameras, allowing users to seamlessly blend digital elements into their physical environment. This enhances productivity, gaming, and creative applications, making the headset more versatile than traditional VR.

Powered by the Qualcomm Snapdragon XR2 Gen 2 chip and offering 8GB of RAM, the Quest 3 delivers smoother performance, better graphics, and faster load times. Its redesigned lenses offer improved clarity and a wider field of view compared to its predecessor, the Quest 2. The form factor is slimmer and more comfortable, making extended use more enjoyable.

Another major strength is its standalone functionality—no PC or external sensors are required, although it can also connect to a PC for more demanding VR titles. The Meta Quest ecosystem provides access to a large and growing library of apps and games, including titles that leverage the mixed reality capabilities.

Meta has also prioritized hand tracking and intuitive user controls, which contribute to a more immersive experience. Altogether, the Meta Quest 3 offers an accessible, high-quality gateway into mixed reality for both new and experienced users.

## 2.3 Extra features

In addition to the basic car controls, the research team added various features to ensure users would actually feel immersed in an actual vehicle. The following features are part of the simulation:

- car seat and seat belt

An actual car seat was retrieved from a junkyard and sanitized. This car seat provides height control. It allows users to adjust distance to the pedals and steering wheel. A frame was constructed using Treq hardware to install a real actual seatbelt to the simulator. The action of putting on a seatbelt is indeed an essential part of the training of a novice driver.

- Vibration seat

For a better representation of a driver's sensations, a vibration seat cover was installed on the car seat. The SRS U-Shake6 is a high-fidelity vibration seat pad designed for racing and flight simulators. It integrates six tactile transducers positioned around your seat—front-left, front-right, rear-left, rear-right, center, and sub—each driven by its own channel. Vehicle telemetry routes engine vibrations to center/sub and more nuanced effects (e.g. suspension, ABS, traction loss) to the four corners for spatially accurate feedback

- Fans

One of the caveats of Virtual Reality is the absence of physical cues to users, as it relates to speed. While the images displayed in the headset accurately represents driving past buildings and trees, the lack of acceleration and deceleration can generate driving simulator sickness. As a remediation technique, two fans were installed in either side of the steering wheel to blow air at the user. The fan has a USB port and is directly connected to the simulator PC. The air flow strength is therefore adjusted to reflect the vehicle speed during the driving simulation.

# 3. Development tools

## 3.1 Game Engine

The research team opted for Unity 3D for scenario development. Unity 3D is a good candidate for driving simulation due to its flexibility, powerful rendering engine, and wide range of features tailored for real-time 3D development. It offers cross-platform support, allowing developers to deploy simulations on PC, VR, and mobile devices. Unity's robust physics engine (based on NVIDIA PhysX) accurately simulates vehicle dynamics, collisions, and terrain interaction—critical for realistic driving experiences.

With a large asset store and an active developer community, Unity makes it easy to integrate third-party vehicle controllers, road systems, and AI traffic. Developers can customize everything from weather effects to sensor simulations (e.g., LiDAR or cameras), which is essential for training autonomous vehicles or conducting research.

## 3.2 Script Language

Unity also supports C# scripting, enabling fast development cycles and real-time updates. Combined with tools like Unity ML-Agents, it allows for advanced scenarios like reinforcement learning in driving. Microsoft Visual Studio was used for scenario development through the use of C# scripts. The tight integration of 3D modeling with scenario scripts allow for robust control of the driving experience for novice drivers.

# 4. Driving scenarios

## 4.1 Familiarization

Since many users have little familiarity with Virtual Reality a familiarization phase was built into the software to gradually expose novice drivers to the technology. Familiarization is essential in VR driving simulation to help users adjust to the virtual environment and controls, reducing disorientation and simulator sickness. It allows drivers to build confidence, understand the system's feedback, and adapt to differences from real-world driving. Gradual exposure improves comfort and performance, especially for new users or trainees. The research team therefore built a 10 minutes driver, at low speed, with few turns to allow students to adapt to controls and visual representation. A pilot of 2 months at the Driven2Drive driving school further validated this choice.

## 4.2 Driving curriculum

The main asset for a driving simulator for training is its ability to safely expose novice drivers to a collection of driving scenarios such as stop and go traffic, merging on the highway for a left lane exit, inclement weather, aggressive drivers… In addition, the simulator can be an effective tool to raise awareness of the dangers of texting and driving, especially for teenage drivers who still need to develop muscle memory and acute hazard recognition.

The research team developed driving simulators with progressive difficulties. The features are described below:

| | **Total driving time (mn)** | **82** | | |
|---|---|---|---|---|
| **Level** | **Description** | **Time To complete (mn)** | **Hazards** | **Inclement weather** |
| 1 | Focus on keeping speed that is written on the signs | 5 | No | No |
| 2 | Focus on gently stopping and stopping very close to the stop line. | 5 | No | No |
| 3 | Focus on using turning indicators every time you change a lane or change direction | 4 | No | No |
| 4 | Turnaround, big roundabout, 45 mph drive, pedestrians | 8 | No | No |
| 5 | Pedestrians, living area (residential area, tight car park, fog simulation, small roundabout | 10 | Fog | Fog |
| 6 | Part 1 of 2 exam route, medium traffic, big roundabout, one way street | 10 | Fog | Fog |
| 7 | Part 2 of 2 exam route, medium traffic, small roundabout, turn arounds, stop signs, living area (residential) | 10 | No | No |
| 8 | Free drive around the city you choose what you want to learn | 15 | No | No |
| 9 | Hard level, 7 dangerous situations that require high reaction and skill to pass | 15 | 7, including car backing out of driveway without looking | Fog, Ice |

## 4.3 Driving assessment

A driving assessment was developed by the research team to assess the driver's skills. These skills are tested in level 6 and level 7 of the simulator software suite. Currently only pedal and steering wheel actions are assessed. As a future development, the research team anticipates the upgrade to a Mixed Reality headset with eye tracking abilities. This feature will enable hazard recognition assessment which is critical for all drivers safety.

# 5. Work in Progress

## 5.1 Prototype

A view of the complete driving simulator shows the hardware choices with the real vehicle car seat, Treq hardware frame with seat belt pole, vibration seat cover, fans, triple monitor setting. The prototype has been largely tested through a three month period (April to June 2025) with students from the Bala Cynwyd location of the Driven2Drive driving school.

## 5.2 Deployment

The Virtual Reality Driving simulator is available in self-service at the Bala Cynwyd location of the Driven2Drive driving school. A dedicated calendar is available online to allow students to book the simulator for training.


# 6. Results & Challenges

## 6.1 Results

The research team development has been validated by the adoption by the Driven2Drive driving school for its students. Data from each student is currently logged so as to enable a solid assessment of the simulator for driver training.

At this point, the research team has identified two segments of the population that are especially eager to use a Virtual Reality driving simulator:

- People living with physical disabilities.

  The simulator has been deployed at the Special Needs Driving School manage by the Community Independence Solution in San Antonio, Texas

- People with high anxiety and people living with cognitive disabilities.

The research team visited with the Lehigh Valley center for Independent Living in Allentown, Pennsylvania, which sought help to provide driving training services to a community of people who depend heavily on driving for employment.

## 6.2 Challenges

One of the main challenges for using Virtual Reality for driving simulation has been the weel known phenomena known as simulation sickness. VR users experience simulation sickness in driving simulations due to a sensory mismatch between what the eyes see and what the body feels. In VR, users see motion—like turning or accelerating—but their inner ear doesn't detect corresponding physical movement, causing confusion in the brain. This conflict triggers symptoms such as nausea, dizziness, and disorientation. Contributing factors include low frame rates, high latency, abrupt camera movements, and unrealistic vehicle physics. Driving simulations often involve frequent motion changes, making the problem worse. Reducing latency, improving frame rate, and using motion cues can help minimize discomfort and improve the overall VR driving experience.

## 6.3 Future Work

The next steps of the development will be the further validation of both the driving platform and the existing scenarios through a partnership with the Driven2Drive collaboration. The most important asset of the simulation is the ability to safely expose drivers of all skills, including people living with disabilities, to a collection of driving scenarios so they can safely develop the proper attention span and motor skills.

Once the software and scenarios are validated, the research team hopes to move the Virtual Driving experience to an actual vehicle. A VR driving experience in an actual car offers unmatched realism and immersion. Sitting in a real vehicle provides accurate tactile feedback from seats, controls, and pedals, enhancing muscle memory and spatial awareness. Combined with VR visuals, it creates a safe yet convincing environment for training, testing, or entertainment without real-world risk. It's ideal for practicing complex maneuvers, learning advanced driving techniques, or simulating hazardous conditions like fog or icy roads. This setup bridges the gap between traditional simulators and real driving, offering a powerful, cost-effective solution for education, research, and experiential marketing in automotive industries.

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# 8. Collaborators and Research Students

## 8.1 Collaborators

- Xiaoxia Dong, Prof. University of Pennsylvania
- Erick Guerra, Prof. University of Pennsylvania
- Mike Coraluzzi, Project Manager
- Ronit Tehrani, CEO Driven2Drive
- Mike Peretz, Marketing Consultant
- Jaime Hernandez, Virtual Reality Developer
- James Megarioris, Hardware Engineer

## 8.2 Students

University of Pennsylvania
- Rajnish Gupta
- Sahil Mangaonkar

Drexel University
- Benjamin Loeb
- Ramon Diaz
- Abhiskek Raj
- Kartikeya Yadav
- Prashanna Subedi
- Connor McGovern

Community College of Philadelphia
- Anthony Hyacinth

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# Addendum RSS2024 paper

The following paper was published by the University of Kentucky through its 2024 Proceedings.

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2024 Road Safety & Simulation Conference
Improving Decisions Through Safety and Simulation Tools
Lexington, KY, USA
October 28-31, 2024

## Driving Simulation for Driving Education: Can Mixed Reality do it?

**Helen Loeb, Chase Leibowitz, Ronit Tehrani, Jaime Hernandez**

*Dpt of Engineering, Jitsik, 276 Barwynne Rd Wynnewood, PA 19096, helen.loeb@jitsik.com*
*Dpt of Engineering, Jitsik, 230 Glenmoor Rd, Gladwyne, PA 19035, chase.leibowitz@duke.edu*
*Driven2Drive Driving School, 131 Montgomery Ave, Bala Cynwyd, PA 19004, ronit@driven2drive.com*
*Dpt of Engineering, Jitsik, 276 Barwynne Rd, Wynnewood PA 19096, jaimevazz@gmail.com*

### Extended Abstract

**Introduction:**

Motor vehicle crashes continue to be one of the primary causes of preventable death for US teenagers. Per the National Safety Council, 5,565 people died on US roads in accidents involving a young driver in 2021–a 9.8% increase from the 2020 total of 5,069 [1]. A primary cause for these statistics is the inexperience of teenage drivers [2,3]. Current training methods are unable to adequately expose teenagers to dangerous driving scenarios in a safe manner.

Technological innovations offer new opportunities to solve this problem. The emergence of Mixed Reality at a low cost can help place students in dangerous situations so as to accelerate their exposure to risky situations and train awareness and muscle memory. Driving simulators can be traced back to the 1950s with Aetna's Drivotrainer, a motion picture training system [4]. Several generations of simulators have followed which used multiple monitors to deliver a workable Field of View . Yet, the lack of realism and affordability has, until recently, restricted the use of driving simulation technology to manufacturers and universities. New Virtual Reality (VR) and Mixed Reality (MR) technologies present an opportunity to affordably place students in high-pressure scenarios. The work we highlight below covers a pilot experiment in a driving school where a cohort of 23 student drivers experimented with Jitsik's MetaDrive XR simulator.

**Methodology:**

Our research team built a driving simulator consisting of a Meta Quest 3 MR headset paired with a Logitech 920 steering wheel and pedal set. The goal of the study was to assess the perception of Mixed Reality in the context of driving education. A parallel parking scenario was chosen for its interactive nature to test the usability, intuitiveness, and efficacy of the simulator. The task required the driver to check mirrors, turn his/her head in all directions, and change between forward and reverse gears. The task of parallel parking is often the first skill assessed on state driving tests. It is often feared by students. The simulator's MR technology lets participants see their hands, feet, and steering wheel while driving, while a virtual gear stick lets participants intuitively switch gears.

The test was administered at the Bala Cynwyd location of the Driven2Drive driving school to a cohort of 23 participants aged 16-30 (12 males, 11 females). Following the simulation, participants completed a 5-point Likert scale survey, asking how much they agreed or disagreed with a series of statements (1: strongly agree, 5: strongly disagree). The questions assessed how immersive the simulator was, how intuitive it was, how useful it was, how fun it was, how helpful it was to driving education, and whether or not it would be more effective if delivered in a vehicle.

**Findings:**

The Likert scale resulted in the following mean scores:

| | Immersive | Intuitive | Useful | Fun | Helpful | Effective in Vehicle |
|---|---|---|---|---|---|---|
| MEAN SCORE: | 2.21 | 2.29 | 2.08 | 1.75 | 1.63 | 1.88 |

The mean score for each statement landed in the "somewhat agree" category, with participants agreeing most strongly that the simulator would be helpful in drivers' education. 86% of participants agreed or strongly agreed that the simulator would be helpful in education. Conversely, only one participant disagreed. The modes for how useful the simulator was, how fun it was, and how helpful it would be were all "strongly agree." A correlation matrix shed more light on which factors of the simulation were interrelated and how strongly they influenced each other.

| | Immersive | Intuitive | Useful | Fun | Helpful | More Effective in Vehicle |
|---|---|---|---|---|---|---|
| Immersive | 1.00 | 0.71 | 0.79 | 0.52 | 0.63 | 0.37 |
| Intuitive | 0.71 | 1.00 | 0.78 | 0.62 | 0.54 | 0.40 |
| Useful | 0.79 | 0.78 | 1.00 | 0.76 | 0.67 | 0.54 |
| Fun | 0.52 | 0.62 | 0.76 | 1.00 | 0.55 | 0.38 |
| Helpful | 0.63 | 0.54 | 0.67 | 0.55 | 1.00 | 0.52 |
| More Effective in Vehicle | 0.37 | 0. Oh 40 | 0.54 | 0.38 | 0.52 | 1.00 |

How useful the simulator was perceived, was strongly correlated with its immersivity, intuitiveness, and degree of fun, with correlation coefficients of 0.79, 0.78, and 0.76 respectively. A moderate correlation was found between all other variables. The strongest average correlation (0.71) was found between how useful the simulator was and all other metrics.

**Discussion:**

The findings from this experiment shed light on the efficacy of driving simulation in education. The Likert scale data revealed that most participants strongly agree that it would be helpful in driving education. The lowest scores were averaged under "agree," in how immersive and intuitive the simulator was. These two scores were strongly correlated with how useful the simulator was. As the simulation improves in those areas, its efficacy will also improve. Designing simulators with that in mind will be imperative in the future.

**Conclusion:**

The facts presented in this pilot deployment of the Jitsik MetaDrive XR simulator at the Driven2Drive driving school helps us assess the perception of Mixed Reality simulation among driving school students. Qualitative data obtained from post-simulation surveys show that students anticipate the MetaDrive XR simulator can be effective in driving training.. The correlation analysis shows how improvements in immersion and intuitiveness will further improve the simulator’s efficacy.

Keywords: driving safety; simulation; virtual reality; mixed reality; driver’s education; teenage drivers

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