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Transportation Safety Training in Rural Areas: An Exploration of Virtual Reality and Driving Simulation in Driver Response and Awareness

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16. Abstract

This research evaluates the effectiveness of using simulated virtual reality driving environments to improve transportation safety in rural areas. The transportation accident fatality rate is more than double the national average in rural areas and highlights an important opportunity to address these challenges through improved safety protocols and investment. A review of the literature revealed high frequency scenarios that contributed the most to fatality or injury accidents. Virtual reality driving simulations were created based on these high frequency events using a rural roadway of interest identified with the assistance of the Missouri Department of Transportation. Scenarios considered weather-related conditions, such as flooding or snowfall, along with wildlife crossings, as part of the virtual training. Engineering managers in state or county departments of transportation can use this research to develop training protocols with community planners in rural regions.

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Table of Contents

Disclaimer vi
Abstract vii
Chapter 1 Literature Review 1
1.1 Work Zones 1
1.2 Wildlife Crossing 2
1.3 Roadway Design and Geometry 3
1.4 Speeding Behavior 4
1.5 Inclement Weather 5
Chapter 2 Methodology 7
2.1 Field Observation 8
2.2 Data Acquisition 14
2.3 Road Modeling – Designing 17
2.3.1 Trees/ Vegetation 17
2.3.2 Highlands and Lowlands 17
2.3.3 Creeks 17
2.3.4 River 18
2.3.5 Traffic signs 19
Chapter 3 Results and Discussion 23
3.1 Snowfall 23
3.2 Flooding 24
3.3 Animal Crossing 25
3.4 Blind Curves 26
Chapter 4 Conclusions 28
References 29

List of Figures

Figure 2.1 Layout of Methodology 7
Figure 2.2 Snapshot of Route N (During Field Survey) 9
Figure 2.3 Area of periodic Flooding 10
Figure 2.4 (a-b) Meramec River 11
Figure 2.5 (a-b) Blue Spring Creek 12
Figure 2.6 (a-b) Hills/Farmland 13
Figure 2.7 Location of Route N via Google Earth 14
Figure 2.8 Blue Springs Creek Crossing Route N (Area of Periodic Flooding) 15
Figure 2.9 Meramec River - Route N (Area of Periodic Flooding) 15
Figure 2.10 Whites Creek Crossing Route N (Area of Periodic Flooding) 16
Figure 2.11 Topography of Route N via ArcGIS 16
Figure 2.12 Scene View of Creek 18
Figure 2.13 Scene View of Meramec River 19
Figure 2.14 Scene View of Wildlife Crossing 20
Figure 2.15 Simulated Virtual Reality Roadway with a Car 21
Figure 2.16 Simulated Car Sliding on Roadway 21
Figure 3.1 Simulated Snowfall 23
Figure 3.2 Flooded Creek Simulation 25
Figure 3.3 Deer Animation Script 26
Figure 3.4 Example Blind Curve in the Simulated Environment 27

List of Abbreviations (optional)

Analysis of Variance (ANOVA)

Available Sight Distance (ASD)

Federal Highway Administration (FHWA)

Geographic Information System (GIS)

Mid - America Transportation Center (MATC)

Missouri Department of Transportation (MoDOT)

National Highway Traffic Safety Administration (NHTSA)

Three Dimensional (3D)

Transportation research international documentation (TRID)

Virtual Environment for Reactor Analysis (VERA)

Virtual Reality (VR)

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Abstract

This research evaluates the effectiveness of using simulated virtual reality driving environments to improve transportation safety in rural areas. The transportation accident fatality rate in rural areas is more than double the national average. This statistic highlights an important opportunity to address these challenges through improved safety protocols and investment. A review of the literature revealed high frequency scenarios that contributed the most to fatality or injury accidents. Virtual reality driving simulations were created based on these high frequency events using a rural roadway of interest identified with the assistance of the Missouri Department of Transportation. Scenarios considered weather-related conditions, such as flooding or snowfall, along with wildlife crossings, as part of the virtual training. Engineering managers in state or county departments of transportation can use this research to develop training protocols with community planners in rural regions.

Chapter 1 Literature Review

The rate of traffic accidents has resulted in a huge loss of lives and properties globally. It is a problem that results in physical, emotional, and mental damage to the victims and their families. These accidents also cause economic loss to the governments and the people, costing them billions of dollars per year. In the United States alone, with 19% of the population living in rural areas, the rate of traffic fatalities in rural areas is twice the rate of urban areas (National Highway Traffic Safety Administration, 2020), and rural roads cover 43% of total roadway fatalities (Federal Highway Administration [FHWA], 2020).

Many researchers have conducted studies to improve transportation safety using various methods like driving simulators, real-life/real-time experiments, and virtual reality (VR) applications, among others. However, only a few studies have considered evaluating the effectiveness of these methods in providing or improving transportation safety, especially in rural areas. Some of the research studies used VR or driving simulators to assess drivers' behavior to find causes of road fatalities in work zones, wildlife crossings, inclement weather, bad roads, large farm vehicles/implements, road geometry and other primary and precipitating driving conditions.

1.1 Work Zones

Various metrics were applied by researchers; however, one study performed an experimental evaluation of work zone barrier capacity using a medium-fidelity full-scale driving simulator to assess driver performance on freeways (Banerjee, & Jeihani, 2019). The Federal Highway Administration has in its record that for every 5.4 minutes of the day, one work-zone crash occurred in America (FHWA, 2015). The work zone barriers used included cone pylons, concrete jersey barriers, and metal barriers. Sixty-Five people participated in the experiment and the traffic volumes were based on level of service C. Banerjee et al. (2019) observed that drivers deviated away from concrete jersey barriers, and from the center of the lane, which negates driver behavior in a previous study on an arterial road. The authors concluded utilizing a single factor analysis of variance (ANOVA) which pointed out a statistically significant difference between the mean speeds of vehicles across all barriers and across metal barriers for individuals of age 35 and above against other age groups (Banerjee, & Jeihani, 2019). Another paper focused on validating the use of driving simulators to determine the impact of temporary traffic control devices in a work zone at night (McAvoy, Schattler & Datta, 2007). A combination of field study with six sites and a simulator study with 127 participants was conducted. Speed studies were carried out in three separate locations in the freeway work zone; they included the beginning of the work zone near the transition area, the middle of the work zone, and the end of the work zone near the downstream taper. McAvoy et al (2007) evaluated the data with an analysis of variance test to compare driver performance in the field versus the simulator. The study concluded that driving simulators may not replicate the mean speeds observed in the field because of driver's perceived risk of work zones at nighttime (McAvoy, Schattler & Datta, 2007).

1.2 Wildlife Crossing

In the study by Stanley et al. (2006) evaluated the effectiveness of enhanced wildlife advisories on drivers' behavior using simulated driving environments to reduce animal-vehicle collision. Traffic accidents involving collision with animals are becoming a major concern as human activities are gradually interfering with wildlife. Measures such as fences and wildlife passage creation have proven to be effective in reducing animal-vehicle collision. However, due to the inflated cost and maintenance requirement for these fences, other alternatives are of high interest to transportation agencies. In a different study, a variable message sign and two standard signs, one with a flashing beacon, were used in the simulations to alert drivers when they are approaching areas known for animal crossings. The standard signs displayed the text "NEXT 20 MILES" and the variable message sign displayed the text "ANIMAL CROSSING NEXT 20 MILES BE ALERT". The standard sign with a flashing beacon influenced drivers more than the standard sign without the beacon and caused a significant reduction in speed. The variable message sign in combination with a standard sign and flashing beacon was identified as the most promising advisory system combination because it provided the highest level of adherence, which led to the fewest collisions (Stanley, Hardy, & Lassacher, 2006).

1.3 Roadway Design and Geometry

Road geometry is another factor affecting road users in ways such as available sight distance, among others. A research study was carried out by Bassani, Catani, Salussolia, & Yang (2019) to examine the impact of available sight distance on driver behavior along rural highways using a driving simulator. Available sight distance (ASD) is an underlying factor in principles of road geometry and is used by road designers to ensure road safety, yet designers do not know the effect of a specific ASD on the longitudinal and transversal behavior of drivers involved in negotiating curves. Bassani et al. studied the longitudinal behavior of drivers along rural highway curves with limited visibility. A driving simulator was used to recreate, design, and test sight conditions on three tracks with several combinations of radii and sight obstructions. The setup included a minimum available sight distance of 56.6 m. Traffic barriers, speed limit signs, vegetation and other road factors that could alter the perception of drivers were removed from the simulation. Results showed that speed and trajectory dispersion from the lane centerline linearly depend on ASD in the investigated range of curve radii. Bassani et al. suggests that when encouraging drivers to incorporate good behavior, road designers should adjust the available sight distance. Overall, to develop safe driving conditions, this study suggests ASD should be designed such that it is slightly greater than the required sight distance, since excessive ASD values can potentially encourage drivers to drive at inappropriate speeds.

In another study, Lee et al. (2011) addressed problems associated with roadway design and geometry with the aid of driving simulators (Lee, McGehee, Brown, Richard, Ahmad, Ward, Hallmark & Lee, J. 2011). Though driving simulators can be a helpful system for field research, their capacity to support traffic engineers and geometry designers in addressing issues related to road design projects is yet to be confirmed. In this study, Lee et al. discussed a framework focused on design by which driving simulators can be useful to road design engineers. There are several drawbacks associated with the use of driving simulators for roadway design including perceptual differences among road safety researchers and engineers. To address this, Lee et al. conducted interviews with engineers to resolve differences in perceptions and identify other issues simulators might address. Another drawback is that most simulators are defined as "high fidelity". Lee et al. gains clarity on simulator fidelity during their study and links it with road design issues through a survey on simulators and simulator characteristics. The third identified drawback is that the data collected by traffic engineers do not match the data from simulators. This can be traced to insufficient simulator fidelity but can also be a result of traffic engineers and simulator researchers having different goals for using simulators. Overall, the issues associated with using driving simulators in addressing roadway design result from both technical and communication challenges.

1.4 Speeding Behavior

Research conducted by Montella, Galante, Imbriani, Mauriello, and Pernetti (2014) utilized virtual environment for reactor analysis (VERA) high-fidelity dynamic-driving simulator to examine the continuous speed profiles of different drivers on a two-lane rural highway. Many studies designed models to predict operating speed and evaluate drivers' speed behavior to enhance consistency in design of old and new roads. Most of the models were built based on spot speed data assuming constant operation speed throughout the horizontal curves and acceleration and deceleration on tangents. Montella et al. designed an experimental route consisting of the successions of 20 tangents, 1000 m in length and curves with radius of 400 m. It was observed that along the curve, the speed was not constant, and the rates of deceleration were significantly more than the rates of acceleration. After analyzing each driver's behavior, 85% of driver-speed reduction was more than two times the operating-speed reduction in the tangent-to-curve transition. Montella et al. also deduced that there is potential to identify supplementary design inconsistencies and safety related issues as it would add crucial information to the operating speed profile analysis.

1.5 Inclement Weather

A 2020 study conducted by Wang, Zhang, Feng, Sze, Hu, and Wang was designed to achieve three goals. The first goal was investigating the effect of driver physiological performance on speed considering the level of visibility under fog conditions and the horizontal and vertical alignment of a rural road. The second goal was to measure the relationship between these variables. Lastly, they calculated the maximum acceptable speed that matched the driver's physiological tolerance threshold. The study was conducted with 30 participants using a driving simulator. The relationship between normal heart rate, driving speed, visibility, radius, and gradient were measured using a multiple linear regression model. Results obtained showed that normalized heart rate was affected by driving speed, visibility, radius of curvature and gradient.

In general, the study revealed a substantial association between the drivers' physiological performance and driving speed under fog conditions.

Most of the research studies focused on driver behavior in different scenarios using simulated environments. However, it is particularly important to investigate the effectiveness of these methods by comparing the results of the Virtual Reality experiment and Driving Simulator study. The results from our experimental comparisons can be used for further study on transportation safety. Engineering managers in state or county departments of transportation can also use this research to develop training protocols with community planners in rural regions.

Chapter 2 Methodology

The aim of this research is to evaluate Virtual Reality and driving simulators in improving transportation safety in rural areas and compare the results to determine which method is most effective. The research project focuses on a sample location in rural Missouri. Figure 2.1 shows the layout of the methodology used to accumulate data, build a road model (simulated virtual reality environment), and conduct the driving experiment to determine the most effective method between virtual reality or driving simulators. Performing a literature review was the first step in the process, which involved a comprehensive review of published papers relevant to the subject of transportation safety in rural areas using databases such as Transportation Research International Documentation (TRID), Google Scholar, and Transportation Research Record, among others. Secondly, the modeled road was surveyed and a field observation was carried out in a location prone to periodical flooding in Missouri. The third step involved collecting data for measurements of land elevation and other features using ArcGIS Pro and Google Earth. In the next step, the road was designed using Unity (a cross-platform game engine/real-time development platform) based on the real location with various features identified during the field study. Lastly, the experiment was conducted by recruiting drivers from the university (university students with valid driver's license).

Figure 2.1 Layout of Methodology

2.1 Field Observation

A rural area was selected for the experiment based on suggestions given by an Area Engineer from the Missouri Department of Transportation in Central District St. James, MO. The recommended location, Route N in Crawford County, was selected due to the presence of deer migration, blind curves, and its proneness to periodical flooding. Route N connects to I-44 in Bourbon and runs southeast before connecting to Route 185 in Washington County. During the visit to our selected site, three locations were identified as having a high frequency and long duration of flooding. These locations were Route N at Blue Springs Creek (crossing), Route N just west of Meramec River, and Route N at Whites Creek (near the Crawford/Washington County Line).

Route N and the locations listed above were photographed so they can later be used to create the virtual simulation. A general view of Route N (Figure 2.2) was taken for an initial reference example. Three deer were seen crossing the road during the survey of the roadway, and so deer were chosen to be incorporated into the virtual model. In addition, the locations in the surrounding environment were recorded. These locations include but are not limited to trees and vegetations in a flood prone area (Figure 2.3), the Meramec River (Figure 2.4), a few creeks (Brazil Creek, Whites Creek, Blue Spring Creeks) (Figure 2.5), a few lakes (Bluff Lake, Von Hoffman Lake), hills, farmlands, and bridges (Figure 2.6).

Figure 2.2 Snapshot of Route N (During Field Survey)

Figure 2.3 Area of periodic Flooding

(a)

(b)

Figure 2.4 (a-b) Meramec River

(a)

(b)

Figure 2.5 (a-b) Blue Spring Creek


(a)


(b)

Figure 2.6 (a-b) Hills/Farmland

2.2 Data Acquisition

ArcGIS and Google Earth were used as databases for further study of Route N. The geographic landscape of Route N (Figure 2.7) and areas of periodic flooding (Figure 2.8 - 2.10) were acquired from the Google Earth database. The elevation data of the roadway were obtained using ArcGIS (Figure 2.11). The data collected was then used for the design of the model.

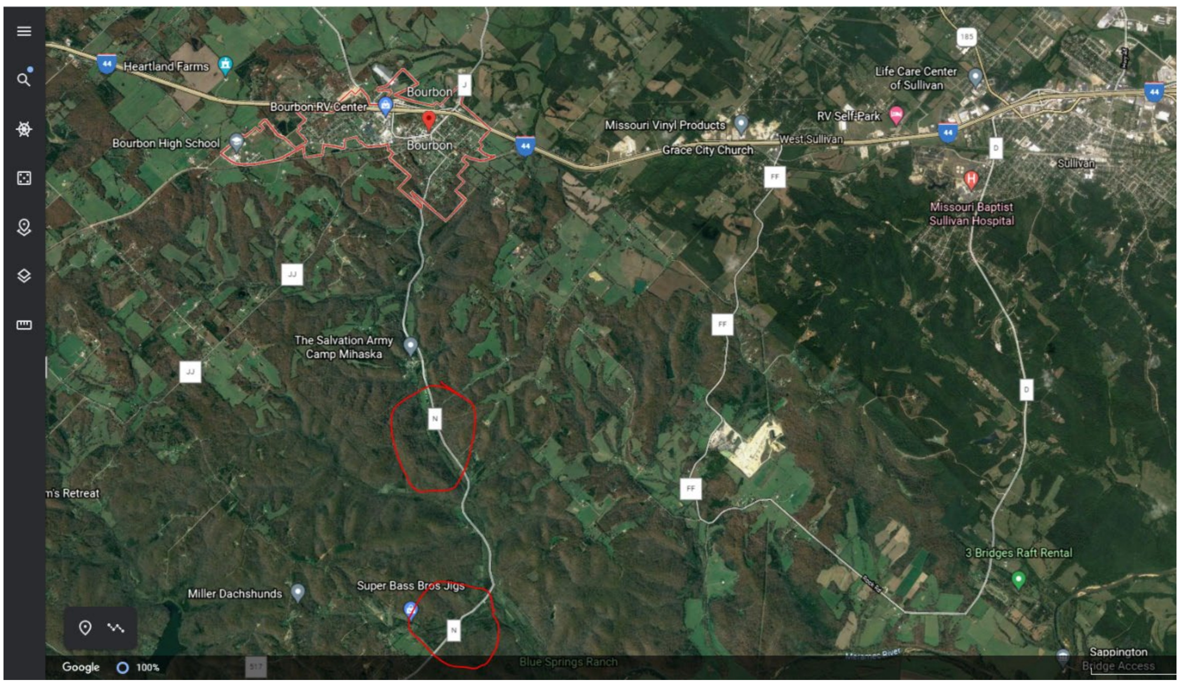

Figure 2.7 Location of Route N via Google Earth

Figure 2.8 Blue Springs Creek Crossing Route N (Area of Periodic Flooding)

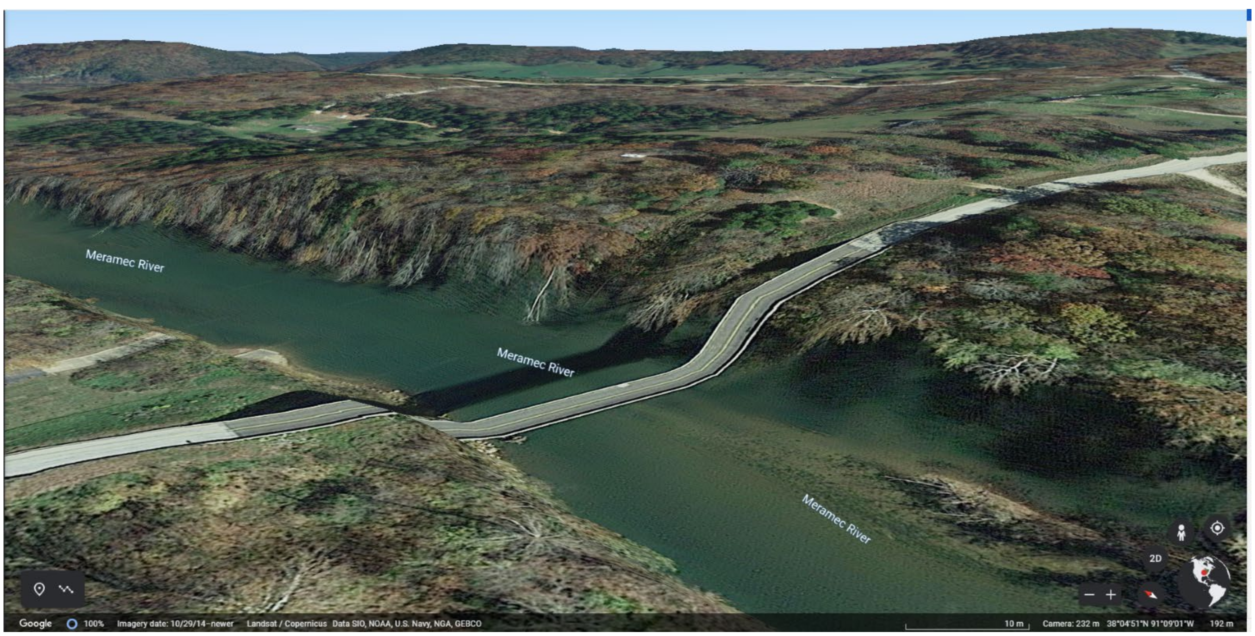

Figure 2.9 Meramec River - Route N (Area of Periodic Flooding)

Figure 2.10 Whites Creek Crossing Route N (Area of Periodic Flooding)

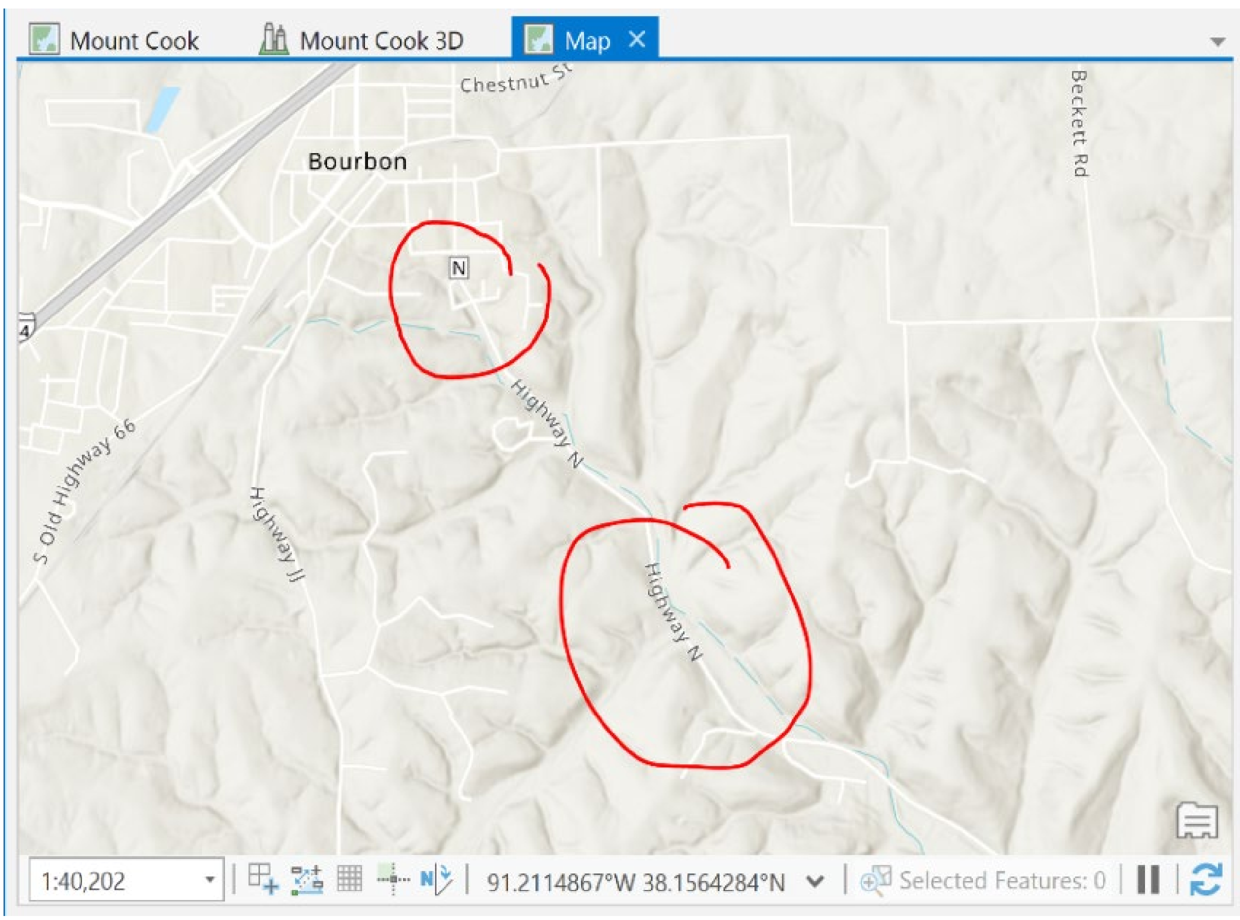

Figure 2.11 Topography of Route N via ArcGIS

2.3 Road Modeling – Designing

In this research project, Unity Real-Time Development Platform (3D) was used to model the site and Visual Studio with C# was used to modify and program the controls for the simulation. The first step was to design the roadway using parameters obtained from the database and field observations. The second step was to define the features of the environment by adding trees and vegetation, traffic signs, highlands and lowlands, creeks, and rivers.

2.3.1 Trees/ Vegetation

The trees used in this simulated environment were purchased from a developer via the Unity Asset Store. Two 3D trees with ambient occlusion were selected for this project because they are similar in shape and height to the trees found along Route N. In the environment model, trees were placed all through the simulated road to model the selected portion of Route N. Figure 2.12 shows the image of the simulated environment with trees along the road.

2.3.2 Highlands and Lowlands

During the field survey, farmlands, barns, hills, and low plains were observed (Figure 2.6) but after careful consideration, the researchers decided to exclude those features in the simulation. Hills and plains with farmlands had little significance to the purpose of the project and they were absent along the part of Route N chosen and merged.

2.3.3 Creeks

The field survey in combination with tools like Google Earth and ArcGIS revealed creeks along Route N named Brazil Creek, Whites Creek, and Blue Spring Creek. For this experiment, Whites Creek and Blue Spring Creek were chosen. The rationale behind the decision was that these two creeks are known for periodic flooding and they both cross Route N during flooding stages. Figure 2.12 shows a creek crossing Route N at the beginning of a potential flood occurrence.

Figure 2.12 Scene View of Creek

2.3.4 River

Figure 2.13 shows Meramec River in the simulated environment of Route N; metal guard rails were used on the side of the road, on the bridge, and over the river to mirror barriers on the bridge at Meramec River. The researchers decided to raise the level of the water at the river to make the river visible to drivers and to represent rising water level because of flooding or potential flooding.

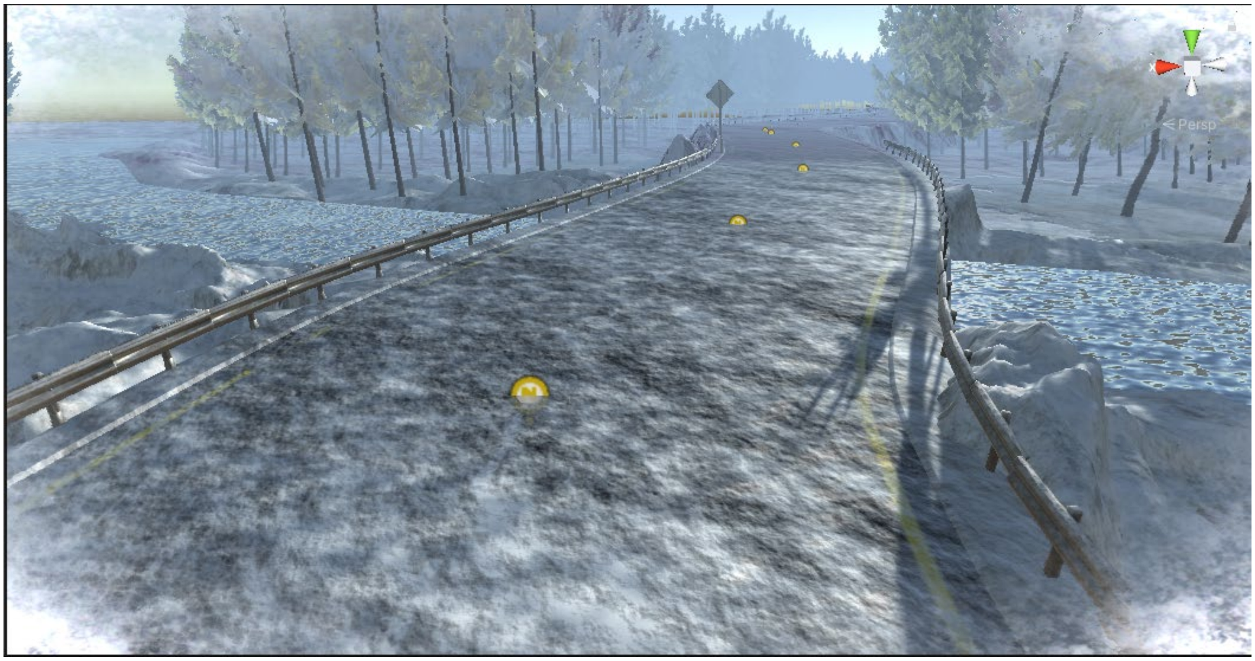

Figure 2.13 Scene View of Meramec River

2.3.5 Traffic signs

Traffic signs were chosen and placed along the road based on drivers' needs. None of the signs were placed according to standards or based on the exact signs found on Route N. They were chosen to inform drivers about road hazards ahead. Signs detailing road geometry and speed limits were implemented along the simulated road to enhance drivers' experiences. Figure 2.14 shows three traffic signs: animal crossing, slippery road, and curve road to the left. The animal crossing sign was chosen to alert drivers of the potential crossing of animals, the slippery road sign was installed to inform drivers about the flooding road conditions and minimize accident risk. The left curve sign was placed to inform drivers of the path's geometry and encourage them to reduce speed.

Figure 2.14 Scene View of Wildlife Crossing

Finally, a realistic 3D car was imported into the simulated virtual reality roadway for the driving experiment. The simulation places the operator in third-person view of the car on the roadway (Figure 2.15). To increase the realism of the simulation, responses are added as road conditions and environmental features are updated, such as flood conditions causing the car to slide more (Figure 2.16).

Figure 2.15 Simulated Virtual Reality Roadway with a Car

Figure 2.16 Simulated Car Sliding on Roadway

For this research project, the two techniques of using virtual reality and driving simulators were applied to conduct the transportation safety experiment and the results from both were compared for further analysis.

The next stage in this research project, experimentation, determines which of the above methods of evaluation is the most effective.

Chapter 3 Results and Discussion

The hazards particular to the studied site were modeled. They include snowfall, flooding, animal crossing, and blind curves.

3.1 Snowfall

The first hazard simulated in the model was snowfall. It is widely known snow and ice heavily contribute to yearly accidents due to the reduced friction it causes between tires and the road, as well as reducing driver vision and road visibility through fog. The asset used to achieve Figure 3.1 (simulated snowfall) is called Global Snow and it allows for adjustments to snow intensity, size, and other features. The simulation was done by attaching the Global Snow script to the Main Camera in the Multipurpose Camera Rig. For the experiment, the researchers enabled terrain marks and footprints to show marks when the car drove through the snow filled road and when brakes were applied. This study looked at these indicators to mark when the driver would slide off the road due to speeding or delayed braking.

Figure 3.1 Simulated Snowfall

3.2 Flooding

A picture representing a flooded creek in Route N is shown in Figure 3.2. Flooding was chosen as a hazard because Route N is known to flood periodically at specific locations. For this experiment, it was important to understand driver behavior in a flooded environment. Drivers were expected to stop when they approached a flooded road because of potential underwater hazards and the lack of information regarding water levels in the simulated environment. Though drivers were not expected to proceed or drive through the flooded area, the researchers wanted to know drivers' perceptions of the flooded area and the water level, as well as the decision to drive-through or halt made by each driver. In modeling a flooded creek, this study created a stagnant water portion over the path where the creek crosses the road. This was achieved by applying three layers of stagnant water using an asset purchased from the Unity Asset Store called Standard Asset (Water4AdvancedReflection). This flood simulation was applied to the two creeks in the simulated environments (Blue Spring and Whites Creeks). It excluded Meramec River flooding because the average flooding scenario increased the water level at the Meramec but did not necessarily make it overflow the riverbank.

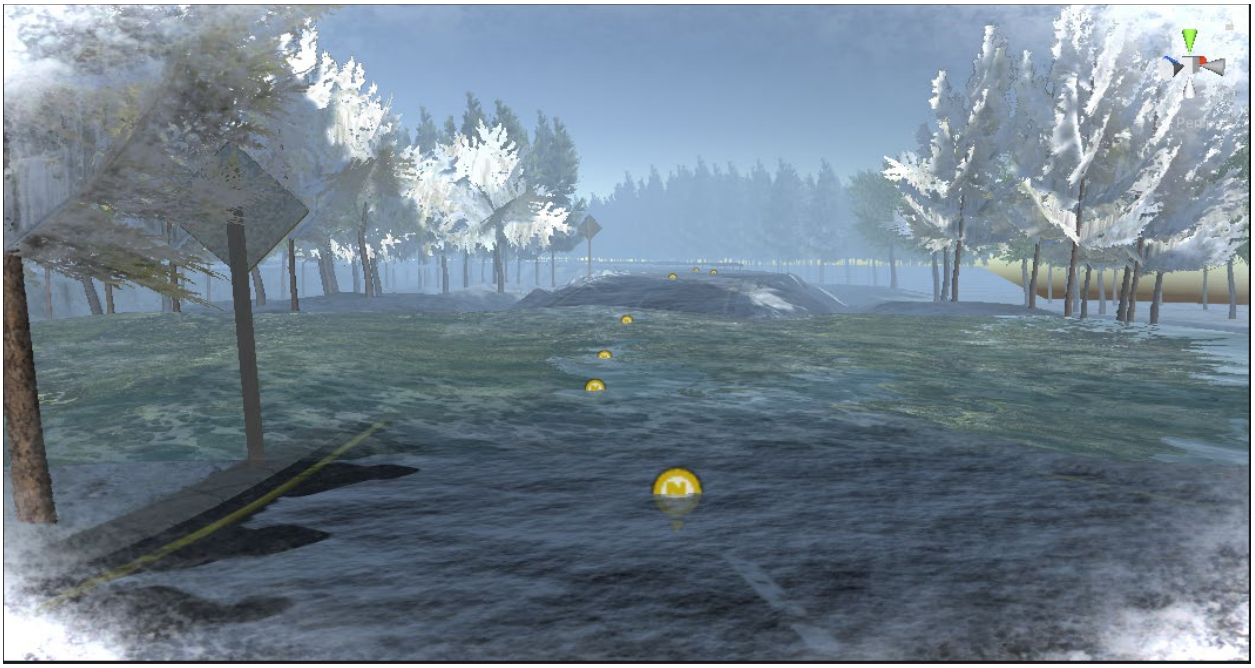

Figure 3.2 Flooded Creek Simulation

3.3 Animal Crossing

This experiment incorporated deer in the simulation due to the presence of three deer crossing Route N during the site survey (Figure 2.14). The asset Deer Animated was purchased from the Unity Asset Store and contained a variety of available animations. Among the animations were idle state, eating, walking, jumping, and galloping. The animations were achieved by writing scripts (performed in C# on Visual Studio shown in Figure 3.3) using key binds to trigger the desired action. Researchers were interested in documenting drivers' behaviors when deer crossed the road. To assess the drivers' behavior, the following metrics were given: A) adherence to the animal crossing sign; in this case the researchers looked for change in speed, deceleration or acceleration, or constant speed by drivers; B) If drivers halted when they saw the deer, the researchers wanted to know the rate of deceleration and the distance between the car and the deer when the driver fully stopped; and C) In a case when the driver hit the deer, the researchers were interested in driver speed at the time of the accident, driver perception in relation to the when they saw the deer, and available sight distance.

```
Miscellaneous Files                                    Deer
using UnityEngine;
using System.Collections;

public class Deer : MonoBehaviour {
    public Animator deer;
    private IEnumerator coroutine;
    public ParticleSystem dust;
    public ParticleSystem dustgallop;
    // Use this for initialization
    void Start () {

    }

    // Update is called once per frame
    void Update () {
        if (Input.GetKey(KeyCode.S))
        {
            deer.SetBool("idle", true);
            deer.SetBool("walking", false);
            deer.SetBool("turnleft", false);
            deer.SetBool("turnright", false);
            deer.SetBool("trotting", false);
            deer.SetBool("trotleft", false);
            deer.SetBool("trotright", false);
            deer.SetBool("galloping", false);
            deer.SetBool("eating", false);
            deer.SetBool("jumping", false);
            deer.SetBool("galloping", false);
            dust.GetComponent<ParticleSystem>().enableEmission = false;
            dustgallop.GetComponent<ParticleSystem>().enableEmission = false;
        }
        if (Input.GetKey(KeyCode.W))
        {
            deer.SetBool("walking", true);
            deer.SetBool("backward", false);
            deer.SetBool("trotting", false);
            deer.SetBool("galloping", false);
            deer.SetBool("eating", false);
            deer.SetBool("up", false);
            deer.SetBool("idle", false);
            deer.SetBool("jumping", false);
            dust.GetComponent<ParticleSystem>().enableEmission = false;
            dustgallop.GetComponent<ParticleSystem>().enableEmission = false;
        }
```

Figure 3.3 Deer Animation Script

3.4 Blind Curves

The last hazard considered, blind curves, was an effect of the road geometry and environment. On Route N, the researchers drove through blind curves in which the trees and vegetation on the side of the road completely obstructed the driver's view around the curve (Figure 3.4). For safety, the researchers positioned a right curve sign in the simulation to alert drivers of the road geometry. This part can be used to assess driver behavior and whether they adhere to signage and slow around the curve.

Figure 3.4 Example Blind Curve in the Simulated Environment

Chapter 4 Conclusions

Virtual reality (VR) and traditional driving simulators with simulated virtual environments are effective for improving transportation safety in rural areas. The simulation was developed using the Unity Real-Time Development Platform and was based on Route N in Bourbon, Missouri. Several hazards particular to this route were modeled in the simulated environment to enhance the evaluation of driver behavior along the route. The dataset used to develop the model was gathered from Site Surveys, ArcGIS, and Google Earth.

The built simulation assisted in evaluating VR systems and driving simulators for improving transportation safety. The simulation can be modified to fit future needs of simulated road projects through the addition of trees, vegetation, and hills to adjust how much of the environment can be viewed, and traffic signs for realism and to guide the user through the simulation. These additions could help is new evaluations of road visibility and reaction times.

Hazards provided a challenge to the evaluated drivers. With the software, snow and ice could be toggled to both limit visibility and to make steering the virtual vehicle more difficult. The water levels in the creek and the river could be adjusted by a simulation operator to simulate a flooded roadway or a roadway about to be topped. Deer crossing the roadway could also be triggered by a simulation operator to block the path of the vehicle. These hazards could have been used individually or in combination to challenge both the decision-making skills and reflexes of the evaluated drivers within the simulation.

The flexibility of the simulation allows future users of the model to create specific scenarios. In addition, the model can be used by engineers in state or county departments of transportation to determine the effectiveness of road designs, for training purposes, or community planning activities.

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