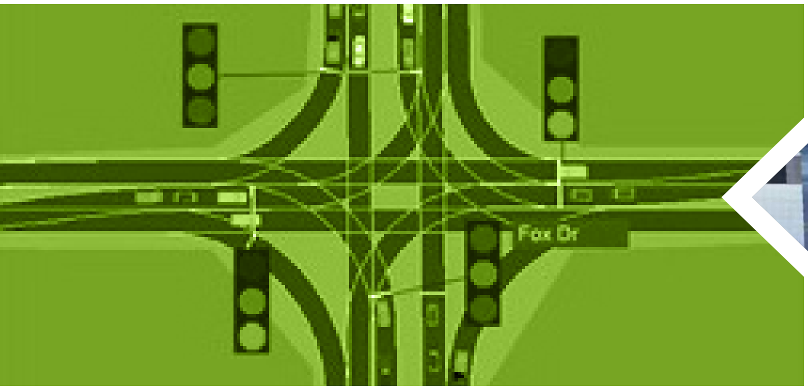
EXPLORATORY ADVANCED RESEARCH

The Exploratory Advanced Research Program

Learning About Driver and Pedestrian Behaviors Through Connected Simulation Technology

RESEARCH SUMMARY REPORT



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Notice

Quality Assurance Statement

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16. Abstract This research summary report provides a description of research carried out to improve the understanding of connected simulated technology and how to expand the study of interactions between drivers and pedestrians, impacting the creation of technologies involving safety and mobility. This project resulted in the development of mixed-mode connected driving and pedestrians with the use of graphical avatars, representing the live actions and movements of drivers and pedestrians. Additionally, new methods of scenario control and data analysis suited for multiparticipant simulation research were created.		
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SI* (Modern Metric) Conversion Factors

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	654.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millimeters	mL
gal	gallons	3.785	meters	L
ft^3	cubic feet	0.028	meters	m^3
yd^3	cubic yards	0.765	kilometers	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9	Celsius	°C
		or (F-32)/1.8		
		ILLUMINATION		
fc	foot-candies	10.76	lux	lx
ft	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yard	yd^2
ha	hectares	2.47	acres	mi
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	mililiters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candies	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	ft
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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List of Abbreviations

3D	three-dimensional
DIS	Distributed Interactive Simulation
EAR	Exploratory Advanced Research
FHWA	Federal Highway Administration
HMD	head-mounted display
NADS	National Advanced Driving Simulator
PDU	protocol data unit
PET	post-encroachment time

Introduction

As our Nation's roadways increase in connectivity and complexity, a challenge emerges to maintain road safety and mobility for all users. Examining how vehicles and pedestrians share the road is one key way to improve road safety, especially in light of increased pedestrian deaths as a result of motor vehicle crashes. In 2018, there were 6,283 reported pedestrian fatalities due to car crashes, the most since 1990.(1) Additionally, in 2017, there were 783 pedalcyclist deaths, accounting for 2.1 percent of all traffic fatalities (37,133) that year.(2)

The Federal Highway Administration's (FHWA) Exploratory Advanced Research (EAR) Program has been supporting research that examines simulated traffic interactions between drivers and pedestrians to better understand how they communicate with each other and the resulting impacts on driver and pedestrian behaviors. The University of Iowa conducted a research project that used real-life drivers and pedestrians along with simulated vehicles and pedestrians in a connected driving simulation.

The researchers successfully created a connected simulation environment, linking a pedestrian simulator and a driving simulator by bridging differing software systems—a large technical challenge of this project. This significant step in simulation technology research can be expanded to include other simulators, such as a bicycle simulator or additional real-life drivers and pedestrians.

The research team created a customized software system that allowed various simulation platforms to talk to each other and share pertinent data. They also created a virtual residential world from the National Advanced Driving Simulator's (NADS) visual assets where simulated and real-life participants can interact.

To study the interactions between a driver and a pedestrian, the Iowa team created life-like avatars by first creating three-dimensional (3D) articulated models of different people. For the real-time simulation, a participant's motions were captured in simulation, communicated through the network to connected simulation nodes, mapped onto a 3D model, and then rendered in real time.(3)

The researchers then used a scenario along residential streets for the connected simulation study, which involved a pair of participants—a real driver and a real pedestrian (via their avatars)—along with computer-controlled vehicles and pedestrians. The Iowa team then ran analyses from the pairs of participants interacting in the virtual world, revealing significant differences in driver/pedestrian interactions. Real-life drivers and pedestrians would interact with each other, with simulated pedestrians, and with computer-controlled vehicles. The research participants influenced each other's behaviors. Real-life drivers slowed down for real-life pedestrians more often than for simulated pedestrians. Likewise, pedestrians were more likely to cross in front of a real-life driver than a vehicle controlled by a computer.

Project Overview

Researchers from NADS, the Hank Virtual Environments Lab, and the Visual Intelligence Laboratory collaborated on the project “Developing Connected Simulation to Study Interactions Between Drivers, Pedestrians, and Bicyclists” at the University of Iowa.

The project had three aims:

- To develop novel technology for connecting real-time driving and pedestrian simulators.
- To develop the 3D avatars that would inhabit the connected virtual world, representing the real-life pedestrians and drivers in order for them to virtually “see” each other.
- To design and conduct a research experiment at NADS with 14 pairs of participants ranging from ages 25 to 45, with one driver and one pedestrian in each pair.

The researchers created a virtual residential setting and focused on how drivers and pedestrians behave at pedestrian crossings, both at an intersection and at a mid-block. The researchers analyzed the probability of certain driver and pedestrian behaviors as well as how often other behaviors occurred.

Figure 1. Photo. The driver's view of the road approaching a mid-block crossing. ©*The University of Iowa.*

The Connected Simulation System

Creating the connected simulation architecture involved connecting various simulation platforms and computer systems. This is known as interoperability, an issue that has long challenged simulation researchers who have been creating multi-driver connected simulations for military use since the 1980s and in the private sector since at least 1997.(4) Three standards and architectures which help support interoperability include the Distributed Interactive Simulation (DIS) standard,(5) the High-Level Architecture standard,(6) and the Test and Training Enabling Architecture.(7) Yet even with these helpful standards, to successfully create connected simulations, interoperability between differing platforms continues to be a difficult hurdle to clear.

To better solve the interoperability issue for this novel simulation system, the Iowa team chose the commercially available DIS platform, which helps to provide a peer-to-peer-type configuration. Specifically, researchers utilized a customized protocol data unit (PDU) implementation that allows for various elements of the system to talk to each other.

Within the PDU framework are three different objects that add to the virtual world or scene of the connected simulation architecture:

- External dynamic objects represent the driver simulator.
- Artificially intelligent dynamic objects can be a preset trajectory or a programmed vehicle.
- Pedestrian dynamic objects represent the pedestrians in the pedestrian simulator, as well as the avatar of the driver.

Simulators included in this connected simulation system were the NADS-1, the NADS miniSim™ (a more compact version of the NADS-1), the Hank pedestrian simulator, and the Hank bicycling simulator, with the latter two using Unity 3D gaming software.

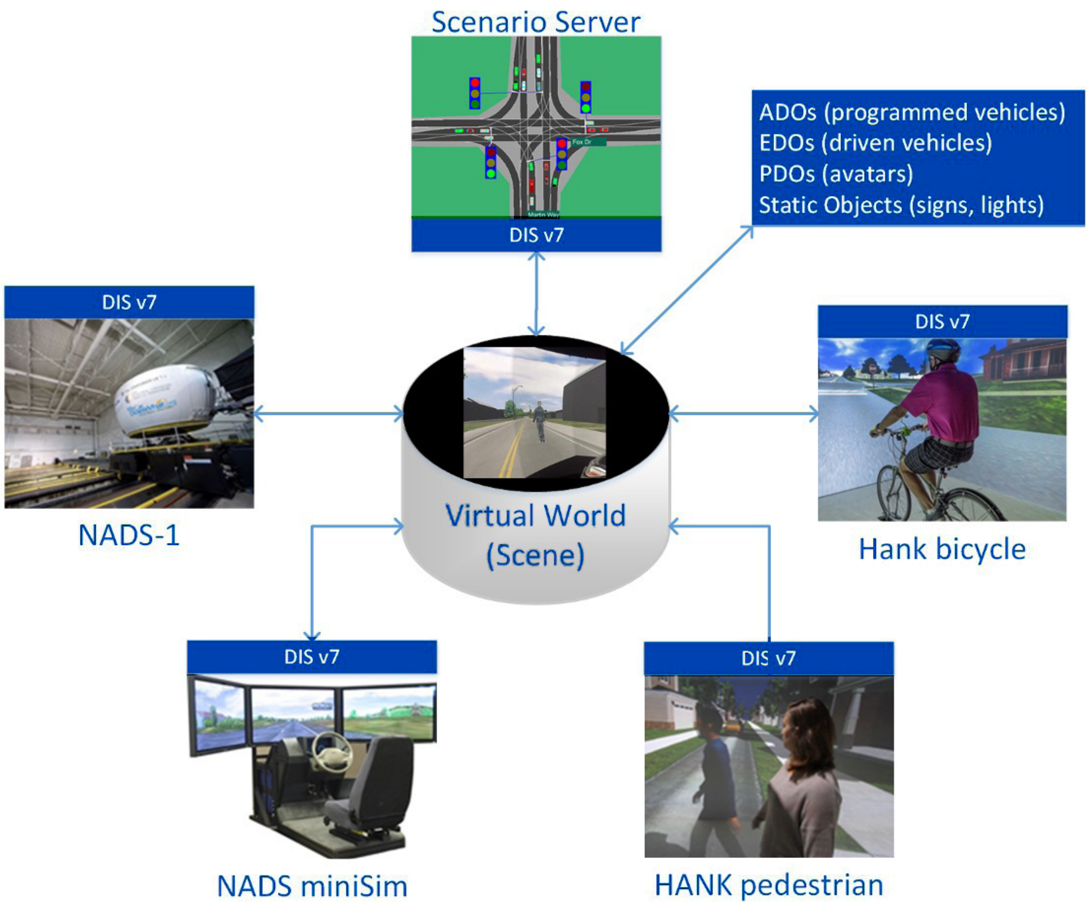

Figure 2. Composite diagram. Iowa connected simulation architecture. ©*The University of Iowa.*

Creating a Common Virtual Interactive World

The connected simulation system requires a common place for all the participants in their separate simulators to virtually interact. The Iowa team created a residential scenario based on NADS visual assets, which were then exported to the Unity platform. The NADS simulators used 3D models and texture to depict the visual environment while the simulation was being run.

The researchers created the terrain models within a two-dimensional editor called the Tile Mosaic Tool. The tiles themselves are controllable, reproducible, and reusable elements and are used for items such as signs, buildings, or terrain. But to convert these models into 3D models so that all participants can view the same virtual world required an intricate process of converting them for use in the Unity 3D platform.

Avatars

To truly examine how drivers and pedestrians see each other in the virtual world, the Iowa team created avatars that represented and could be seen by both the driver participant and the pedestrian participant. Researchers went through an extensive process of character modeling and establishing real-time motion capture to create these avatars. Participants wore small trackers on their wrists, ankles, and waists. The pedestrians wore six trackers with a head-mounted display (HMD), while the drivers wore three. As a participant took a step, his or her pose was calculated using the positions of the trackers and HMD.

To bring these avatars into this virtual world on the Unity platform, they needed to be configured to human models. University of Iowa researchers used a third-party model. The digital avatar that is rendered in the NADS simulators is also a third-party model. These two models varied greatly, so the researchers mapped the more complicated model onto the model used in the NADS simulators. This allowed the smallest possible version of the avatar parameters to be sent across the network to scale up the simulation in the future. This customized avatar was sent into the pedestrian simulator, so the participants were able to see themselves virtually. The driver's avatar was also sent to the pedestrian simulator (the driver's upper body). These avatars were calibrated with the tracker information sent from the participants.

Figure 3.Photo. Participant wearing a virtual reality head-mounted display in the pedestrian simulator. ©*The University of Iowa.*

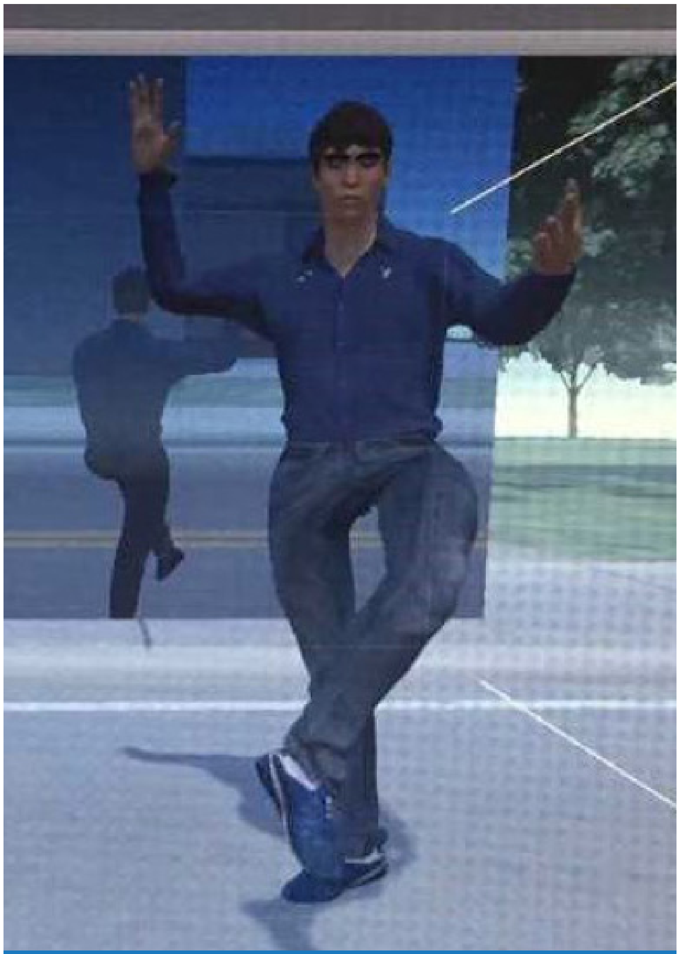

Figure 4. Computer generated image. Pose computed using the calibrated model, rendered in the virtual environment. ©*The University of Iowa.*

Experiments

After creating the connected simulation system and avatars, the Iowa team tested the feasibility of this technology to examine how a driver and a pedestrian would react in real time. The experiment's focus was on the interaction between drivers and pedestrians, specifically when a pedestrian attempted to cross a road in front of vehicles.

The researchers developed two scenarios. In the first one, a pedestrian crossed the street at an intersection with a crosswalk. In the second scenario, a pedestrian crossed at the mid-block with a crosswalk with yield-to-pedestrian signs present. The driver participant would encounter both real and simulated pedestrians, and the pedestrian would encounter a real driver via their avatar along with simulated traffic. With the simulated traffic, the real pedestrian would encounter two simulated vehicles and the avatar of the real driver, who would also be in between the simulated vehicles. After the real pedestrians encountered the three cars, they were teleported to the next crosswalk ahead of the real driver.

When the real driver hits a trigger point, the simulated pedestrians would begin crossing the road, creating an expectation that the pedestrian would always attempt to cross in front of the vehicle. In turn, simulated vehicles were programmed to perform specific behaviors at the intersection and at the mid-block. Specifically, they often did not yield appropriately to the pedestrian, which created the expectation for the real pedestrians that a vehicle may not stop when they cross. The real driver expected the pedestrian to cross first, while the real pedestrian expected the driver to move first. To examine the interaction between a driver and a pedestrian, the driver drove along normally while the pedestrian crossed as often as he or she was able to (vs. waiting for all three vehicles to pass).

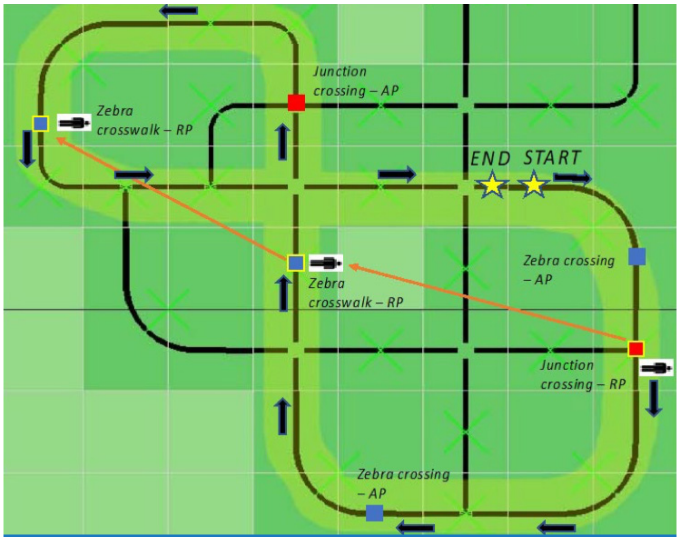

Figure 5. Illustration. Top-down view of drive environment and pedestrian crossings. RP represents real pedestrian and AP represents simulated pedestrian. Red arrows represent teleportation of real pedestrian from one location to another. Black arrows represent the direction of vehicles along the route. ©*The University of Iowa*.

Twenty seven adults, ranging from ages 25 to 45, participated in this study (15 females and 12 males). All participants had U.S. driver's licenses and received $30 per role, with roles randomly assigned. When the participants arrived at NADS, an experimenter explained the study, facilitated questions, and obtained signed consent. Participants, usually four in a group, were then set up as driver and pedestrian pairs.

Researchers measured the heights and the arm reaches of the driver participants. Then they were taken to the NADS-1 driving simulator. To create the avatar for motion tracking, the driver participants were outfitted with trackers on their wrists and ankles and a headset. After calibrating the avatar, the driver completed a five-minute practice drive before the experiment with the real pedestrian commenced. The drivers were given instructions to drive 25 mi/h and to drive normally and to brake gradually when they came to a stop.

Pedestrians also had their heights and arm reaches measured for avatar calibration. Trackers were attached to their wrists, ankles, and waists. They also wore a headset tracker. A microphone was attached to the pedestrian's collar to capture anything he or she said. After calibrating the avatar, the participants were taken to the virtual environment to familiarize themselves with crossing roads virtually. For simplicity's sake, the avatar had a generic male body.

Experiments (Cont.)

After completing the practice session, the participants were told that they would see three oncoming vehicles and that they should see how many times they could cross the virtual roadway back and forth without being hit by a vehicle. After the pedestrian participants crossed the road and the three vehicles had passed through the intersection, the pedestrian participants were told to close their eyes so they would be teleported to the next location. (Teleporting allowed the pedestrian to cross a street elsewhere in the simulation without having to walk long distances.) When the driver completed his or her portion of the study, the research assistant would end the pedestrian's session.

Afterward, both driver and pedestrian participants were given a questionnaire that asked them whether they were able to tell who the real pedestrian was and who the real driver was, and how they were able to make that determination. Only 38 percent of drivers and 43 percent of pedestrians said they were able to tell the difference between the real and simulated pedestrians and drivers, respectively. The majority of drivers found that the pedestrians looked and behaved normally. Yet 43 percent of the pedestrians said that the drivers behaved as expected. For both groups of participants who believed that pedestrians and vehicles behaved unexpectedly, they attributed this to the continuous movement of both, meaning they most likely interacted with the simulated versions of pedestrians and vehicles.

After the questionnaire, the principal investigators asked the driver and pedestrian participant pair if and how they were able to tell who the real driver and the real pedestrian were, using this feedback to adjust the experiment.

Researchers analyzed various measures to examine interactions with the participants and the simulated pedestrians and vehicles.

For the real pedestrians, the researchers used the following four measures:

1. Decision to cross: Did the pedestrians cross when they encountered each real and simulated vehicle?
2. Number of crossings: How many times did the pedestrian cross in front of each real and simulated vehicle?
3. Looks toward vehicle: When the real pedestrians crossed the roadway, how many times did they look toward a vehicle?
4. Gestures toward vehicle: When the real pedestrians crossed the road, how many times did they make a hand gesture toward a vehicle?

The Iowa research team also examined measures that involved both real drivers and real pedestrians:

1. Researchers recorded all collisions between real pedestrians and real or simulated, as well as collisions between real and simulated pedestrians and real drivers.
2. Researchers recorded vehicles slowing and stopping, crossings made by real pedestrians in front of real and simulated vehicles and their subsequent slow downs, as well as real and simulated pedestrian crossings made in front of real vehicles. Slowing down was registered at a speed of less than 5 mi/h. Stopping was registered at a speed of less than 1 mi/h.
3. Researchers measured each crossing a real pedestrian made in front of both real and simulated vehicles, along with the vehicle speed and distance at the moment when a pedestrian crossed. In turn, for each real driver, the researchers recorded the vehicle speed and distance for each moment when both the real and simulated pedestrian initiated crossing a street.

The researchers also had one exclusive measure for real drivers, which is called the post-encroachment time (PET). When both a real or simulated pedestrian crossed in front of a driver, PET was measured, which is defined as the time between when the pedestrian exits the lane of the vehicle and the vehicle enters the crosswalk.

Analysis and Results

With mixed-effects logistic regression and linear regression analyses, researchers examined categorical measures (e.g., the likelihood of a real pedestrian crossing at the mid-block vs. at an intersection) and continuous measures (e.g., the vehicle speed at a crossing initiation).

Categorical Results

For z values, if the absolute value of z is greater than 2, then the variable is found to be significant. For p values, if p is found to be equal or less than .05, then the measure is found to be statistically significant.

- Real pedestrians were more likely to cross in front of a real vehicle vs. a simulated vehicle (with z = crossing type, $z = -2.25$, $p < .01$) as well as crossing at an intersection vs. the mid-block, and effect of vehicle type, (with $z = -2.44$, $p < .05$) (see figure 6).
- Out of 162 crossings, only 13 collisions occurred with real pedestrians, with 100 percent of them occurring with simulated vehicles. Collisions were more likely to happen at mid-block crossings vs. intersectional crossings (see figure 7). Real drivers had no collisions with either real or simulated pedestrians.
- From the real pedestrian perspective, real vehicles typically slowed down at both the junction and mid-block crossings, while simulated vehicles slowed down at intersections but only slowed down about half of the time at the mid-block (see figure 8).
- Real and simulated vehicles were more likely to slow down at junctions vs. at mid-blocks.

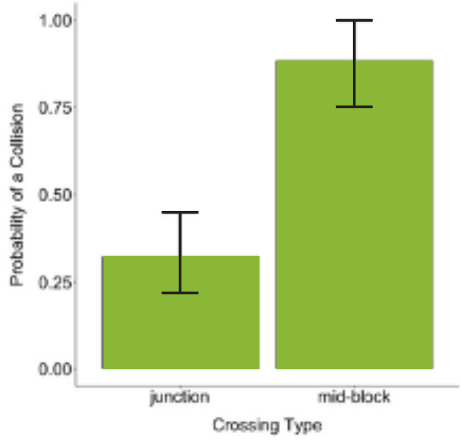

Figure 7. Estimated probability the real pedestrian had a collision with the simulated following vehicle when crossing at junction ~~and~~ mid-block crosswalks. ©*The University of Iowa.*

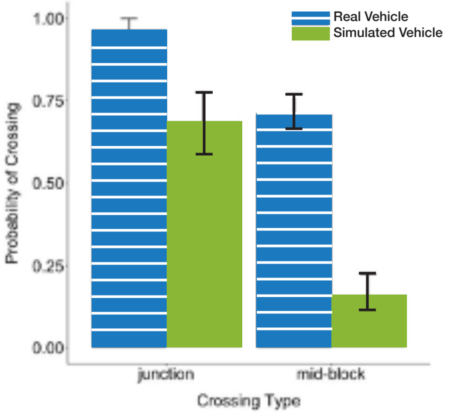

Figure 6. Estimated probability of the real pedestrian crossing in front of the real and simulated vehicle at junction and mid-block crosswalks. ©*The University of Iowa.*

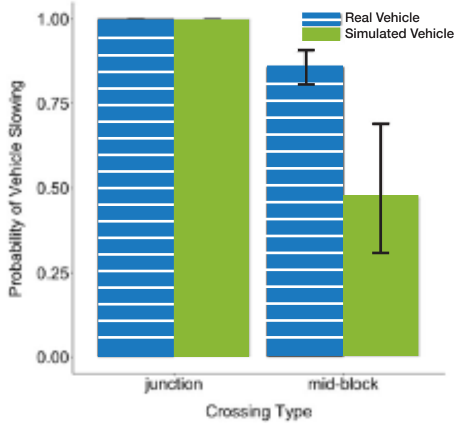

Figure 8. Estimated probability that the real and simulated vehicles slowed down when the real pedestrian crossed at mid-block and junction crosswalks. ©*The University of Iowa.*

Continuous Measurement Results

- Real pedestrians made more mid-block crossings in front of real vehicles vs. simulated vehicles but made similar numbers of intersectional crossings in front of real vehicles and simulated vehicles (see figure 9).
- Real drivers slowed down for longer periods of time:
  - At intersection crossings vs. mid-block crossings ($t = -4.42$, $p < .0001$).
  - In comparison to simulated vehicles at mid-block crossings ($t = -1.90$, $p = .06$).
  - For real pedestrians vs. simulated pedestrians ($t = -3.84$, $p < .0001$).
- Both real and simulated vehicles were further away from the mid-block when real pedestrians initiated their crossings (with z = crossing type, $z = -4.19$, $p < .001$, see figure 10).
- As real pedestrians initiated crossings, both real and simulated vehicles were traveling at greater speeds when approaching the mid-block than at intersections ($z = 6.25$, $p < .001$, (see figure 11).
- For both real and simulated vehicles, and at both junction and mid-block crossings, real pedestrians gave around three to four glances to vehicles as they crossed (see figure 12).
- At both types of crossings, real pedestrians rarely made gestures towards either type of vehicles, with real or simulated drivers (see figure 13).
- Real drivers entered the crosswalk sooner after real pedestrians than simulated pedestrians (see figure 14).

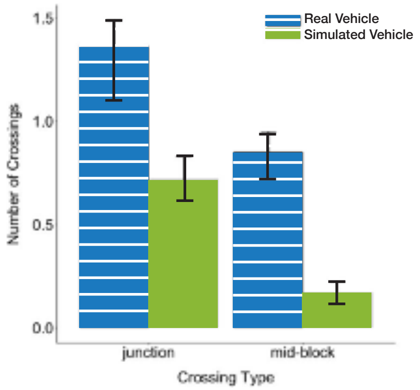

Figure 9. Estimated number of crossings real pedestrians made in front of real and simulated vehicles at junction and mid-block crosswalks. ©*The University of Iowa.*

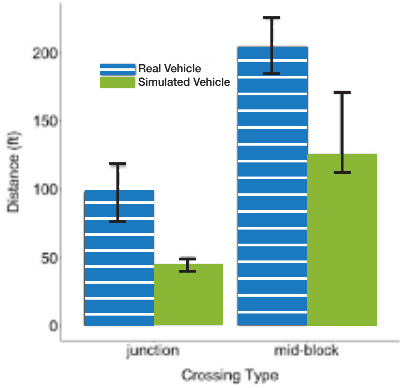

Figure 10. Estimated distance of real and fake vehicles to junction and mid-block crosswalks when the real pedestrian initiated a crossing. ©*The University of Iowa.*

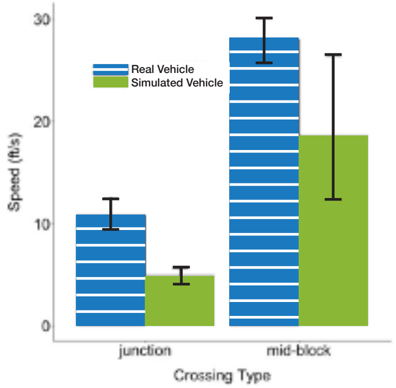

Figure 11. Estimated speed of real and simulated vehicles when the real pedestrian initiated a crossing at junction and mid-block crosswalks. ©*The University of Iowa.*

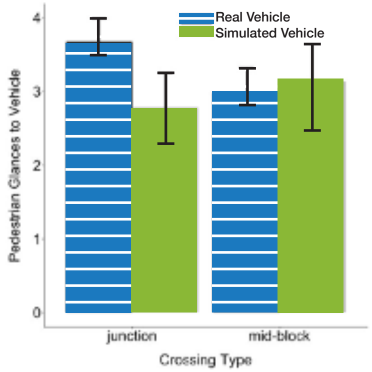

Figure 12. Estimated number of glances real pedestrians made toward real and fake vehicles at junction and mid-block crosswalks. ©*The University of Iowa.*

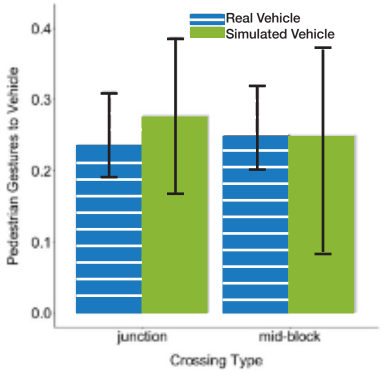

Figure 13. Estimated number of gestures real pedestrians made toward real and simulated vehicles at junction and mid-block crosswalks. ©*The University of Iowa.*

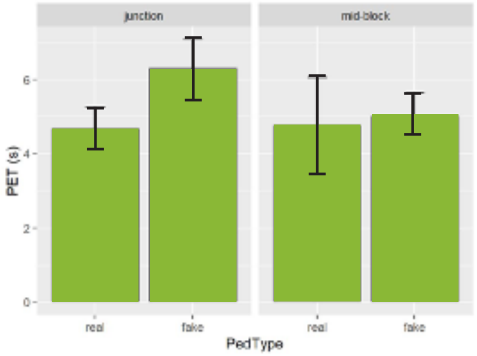

Figure 14. Mean post-encroachment time of the real driver at junction and mid-block crosswalks after the real and simulated pedestrian exited the lane. ©*The University of Iowa.*

Conclusions and Future Research

The University of Iowa demonstrated that connected simulation technology could be utilized with heterogenous platforms by mapping data onto various systems to facilitate communication between them. Specifically, researchers connected a pedestrian simulator and a driving simulator which had their own different software systems and avatar platforms. Avatar technology is a growing field of study and the innovations are rapidly improving, which may make it even easier to accomplish in the future what University of Iowa researchers achieved in this research project.

Based on this connected simulation technology, the researchers explored the relationship between glances and gestures that pedestrians may make towards oncoming traffic as they attempt to cross a roadway. This study was facilitated by the use of 3D avatars which the Iowa team customized for this research project.

Although participants stated that they were unaware of who the real participants in comparison to the simulated ones were the majority of the time, their performance showed that they influenced each other without knowing it. These results suggest that real study participants do behave differently with each other than with simulated pedestrians and vehicles.

Connected simulation technology research endeavors could be expanded to include more remote simulation sites, more simulators and study participants, and higher quality avatars. FHWA will continue to explore the benefits of connected simulation as it relates to improving the safety and mobility of our Nation’s roadways.

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