The Use of Emerging Virtual Reality Technology in Road Safety Analysis: The Hook-Turn Case

Abstract: The Hook Turn (HT), which is rarely seen outside of the Melbourne CBD, Australia, is used to reduce congestion in narrow road spaces shared with trams. Australia allows people from 44 nations to convert their home country driving license to an Australia license without a driving test. Many visitors have never heard of the HT and find it difficult to adopt this new traffic rule for the first time. From this aspect, investigating how inexperienced drivers encounter the HT is important for safety reasons. To address this issue, the Human in Virtual Reality in the Loop Simulator (herein called the Hi-VRiIS) is developed to evaluate the level of safety of people’s driving behavior. Hi-VRiIS is an integrated platform consisting of Vissim and Unity3D with VR based Human-in-the-loop simulation and equipped with driving devices to ensure a better driving experience. This research presents the development of Hi-VRiIS and conducts driving experiments to investigate how non-experienced drivers respond to a completely new road condition. The experimental results are compared with micro-simulation outcomes (here, Vissim). The results show that a human-driven car has a higher accident risk than computer-driven cars. The trajectories from these are statistically different ($t= 2.823$, $p= 0.008$, $\alpha= 0.01$ in the case of Time to Collision $\leq 1.5$). Participant responses to a post experiment survey found that the Hi-VRiIS was realistic (3.88 out of 5.00) and this can help beginner drivers (3.50 out of 5.00). The Hi-VRiIS can be utilized for safety-related research as well as driver training.
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ABSTRACT

The Hook Turn (HT), which is rarely seen outside of the Melbourne CBD, Australia, is used to reduce congestion in narrow road spaces shared with trams. Australia allows people from 44 nations to convert their home country driving license to an Australia license without a driving test. Many visitors have never heard of the HT and find it difficult to adopt this new traffic rule for the first time. From this aspect, investigating how inexperienced drivers encounter the HT is important for safety reasons. To address this issue, the Human in Virtual Reality in the Loop Simulator (herein called the Hi-VRiLS) is developed to evaluate the level of safety of people’s driving behavior. Hi-VRiLS is an integrated platform consisting of Vissim and Unity3D with VR based Human-in-the-loop simulation and equipped with driving devices to ensure a better driving experience. This research presents the development of Hi-VRiLS and conducts driving experiments to investigate how non-experienced drivers respond to a completely new road condition. The experimental results are compared with micro-simulation outcomes (here, Vissim). The results show that a human-driven car has a higher accident risk than computer-driven cars. The trajectories from these are statistically different (t= 2.823, p= 0.008, α= 0.01 in the case of Time to Collision ≤ 1.5). Participant responses to a post experiment survey found that the Hi-VRiLS was realistic (3.88 out of 5.00) and this can help beginner drivers (3.50 out of 5.00). The Hi-VRiLS can be utilized for safety-related research as well as driver training.

Keywords: Human-in-the-loop, Virtual Reality, Hook-turn, Vissim, Unity3D
INTRODUCTION

The hook turn (HT) has been used in the CBD, Melbourne, Australia, which has the largest tram network in the world, with a total network length of more than 200 km (1). The tram tracks are located in the middle of the road resulting in a narrow road space shared with other vehicles so that it is unlikely for right-turning vehicles to occupy dedicated lanes and signal phases.

According to the statistics (2), a record number of people will come to Australia in 2019 on the back of strong growth from education and business-related travel. Plus, the ratio of growth for first visitors has been increasing for the last 8 years. Drivers in Australia use a left-hand drive which accounts for 31.5% (75 countries out of 240 countries) of drivers worldwide. Drivers from some nations that drive on the right-hand side have never experienced hook turns in their own countries. Even worse, driving licenses from sixteen countries, such as Bulgaria, South Korea, Czech Republic and more, can be converted to an Australian driving license without any driving test if the driver is over 25 years of age (3).

Most licensed drivers from the aforementioned countries find it very difficult to drive in Melbourne’s CBD since many intersections require specific driving maneuvers (4). One of the maneuvers is the HT for turning right at specific intersections. Without prior knowledge, people would assume the usual right turn, just like any other intersection, but they would be in breach of the road rules. This research was initiated from this concern to ascertain the degree of driver risk.

To evaluate this traffic condition without compromising the safety, a Human-in-the-Loop VR embedded simulator (Hi-VRiLS) is suggested to evaluate the level of safety from people’s driving behavior. Human-in-the-loop (HITL) is defined as a model that requires human interaction with machines and allows the user to change the outcome of the process in the simulation. This HITL concept has been published and developed for more than five decades. Most literature to date has focused on the integrated operation of humans and machines, which has been tested and verified (5). Researchers have recently started integrating HITL with Virtual Reality (VR) (6). The research shows that HITL with VR becomes a significantly useful tool for analyzing various conditions because the embedded simulation background is easily changeable, and it can test what cannot be tested in the real-world due to safety issues.

In order to generate surrounding traffic in the virtual built environment Unity3D, a game engine comprising developed virtual environments is integrated with Vissim, a widely used microscopic simulation to analyze traffic situations. The two entities communicate with each other in every frame so that traffic flow is sent from Vissim to Unity3D, and the subject vehicle in Unity 3D can also interact with traffic flow in Vissim simultaneously. In addition, the VR with a Head-Mounted Display (HMD) and a Logitech game input device (steering wheel and pedals) are added as components of the driving simulator. The VR driving simulator is capable of providing a highly immersive driving sense for drivers, compared to the fixed-based driving simulator (7).

This research presents how Hi-VRiLS is developed, and driving experiments are conducted to investigate how non-experienced drivers respond to a completely new road environment. The experimental results will be compared with micro-simulation outcomes (here, Vissim only). The paper starts with a literature review for a better understanding of the HT, emerging technology in transport engineering and virtual reality. The methodology presents the Hi-VRiLS development procedure. The case study illustrates the difference between the driving behavior in Hi-VRiLS and that in micro simulation and also provides survey results about the VR experience. Finally, the results and limitations of this research are discussed and directions for future research are proposed.
LITERATURE REVIEW

Hook Turn

Although HT has been successfully implemented in Melbourne for more than 60 years, the little research that exists mainly focuses on the assessment and evaluation by comparison with other right-turning traffic management methods. Note that due to the word limitation in this paper, the layout and operation of HT can be referred to elsewhere (8).

O’Brien (9) utilized a macroscopic simulation to study the safety and operational impacts of HT to check its merit of operation in Melbourne. Comparison results from the study showed that the overall superiority of HT intersections depends on the volume and balance of turning flows. Also, drivers tended to switch to other roads to avoid HT, because of the increased conflict perception between right-turning vehicles and side-road traffic. In addition, Currie and Reynolds (10) proposed a comprehensive review of the HT and also explored its operations and safety impacts using performance data from two different intersections. The review demonstrated that the HT reduced more congestion than the conventional turn. In practice, the HT could increase the capacity of an intersection because 38% of drivers preferred to avoid HT.

Hounsell and Yap (11) used S-paramics to conduct microscopic simulations for intersections with and without HT. They conducted various scenarios by combining different traffic volumes and fixed signal controls. The result was that HT could reduce time delays in almost every scenario. Nevertheless, the overall performance of an HT intersection was also affected by additional delays for left-turning and road-side vehicles caused by right-turning traffic.

In a similar concept, Bie and Liu (12) also established two intersections and performed 24 microscopic simulation scenarios to assess the benefits of HT. The major difference with the research above was to adopt an actuated signal control to the intersection with and without HT. The comparison results indicated that the intersection with HT had a higher capacity than that with no HT; the reduction in average delay was mainly for through vehicles.

Human-In-The-Loop

The HITL approach has attracted great attention due to the inability of a computer system to accurately accomplish tasks that require human participation (13-15). HITL cooperates with the machine and produces human data as key elements. HITL is critical for improving the reliability of simulation results when considering human behavior directly.

Recently, Zanzotto (16) proposed a fairer Artificial Intelligent (AI) system, called Human-in-the-loop Artificial Intelligence (HitAI) that rewarded knowledge providers who were fed data. In the area of Cyber-Physical Systems (CPSs), the importance of HITL integration that brings humans, machines and software systems together has been demonstrated. Human-in-the-loop Cyber-Physical Systems (HitCPSs) were proposed based on a review of related HITL issues (17). Jirgl, Bradac (17) found that human-computer interaction has great ability to increase the strength of CPSs. Gil, Albert (18) provided a conceptual framework for a combination of humans and CPSs and techniques needed to realize this kind of HitCPSs.

Together with these, HITL has emerged in the last several years in the world of autonomous vehicles (AV) (19). Mirnig, Gärtnert (20) reviewed the application status of interaction solutions in autonomous vehicle control transitions and also concluded a categorization framework for this overview. Noah, Gable (21) helped a driver to take over the car quickly and safely when autonomous system failures occur by informing the driver of the system’s status. Beyond these points, Minaeian, Yuan (22) proposed a HITL agent-based simulation to establish an advanced
autonomous surveillance system using unmanned vehicles. Feng, Sequeira (23) introduced a HITL iterative process to improve generative models.

Additionally, a driving simulator is a critical application of HITL in the transportation area. Lei, Yalian (7) built a small driving simulator, using NI PXI hardware and related software, to conduct a fuel economy analysis on a hybrid electric vehicle in the HITL environment. Fitzpatrick, Samuel (24) studied driver aggression under limited travel time. They found that hurried drivers were inclined to choose the higher speed and generally more dangerous driving behavior. Xiong, Narayanaswamy (25) examined factors that influenced a driver’s performance in the indecision zone. The results showed that the driver’s age, distraction, the strength of pushing paddles and time to the stop line were related to decision making in the indecision zone.

Obeid, Abkarian (26) used a driving simulator to analyze driver-pedestrian interaction from the driver’s perspective and concluded that a driver’s aggression is affected by approach velocity, curbside parking, crosswalks, and the number of pedestrians crossing the street. Ābele, Haustein (27) compared young driver’s interaction behavior with child and adult pedestrians. They found that the most efficient safety measures that led to the most appropriate driving speed at pedestrian crossings were curb extension (28).

Similarly, the driver-cyclist interaction was researched using a driving simulator (29). In this experiment, the time point that a cyclist was seen and crossing design was demonstrated as the two most influential factors on the driver’s response.

Virtual Reality

Since VR has recently become affordable, any research team can easily access this unique visualization tool. It has been used in many areas, including the medical field, where it is regarded as an efficient and practical method of learning surgical skills in the 21st century (30). VR technology is usually used for surgical planning and surgical education by creating realistic multisensory imagery for observers (31). For example, Huang, Yang (32) investigated VR’s use in dentistry to increase the surgery success rate. Lee and Wong (33) reviewed the current application status of VR in the management of intracranial tumors and presented future development directions. In terms of healthcare, after the efficiency of virtual reality rehabilitation (VRR) programs was proven, important mechanisms that improved rehabilitation outcomes were identified to better use VRR (34). Rose, Nam (35) also stated that patients’ enjoyment in VR has great impact on their adherence to rehabilitation programs and rehabilitation results. In the economics field, VR overcame the limitation of the standard approach in economics and helped economists to investigate market efficiency and to study economic behavior in-depth (36). The development of VR technology has also led to the emergence of new forms of electronic retail, namely V-commerce. In this context, Martínez-Navarro, Bigné (37) found that consumers’ purchase intention depended on VR format and the device used. In the food industry, Crofton, Botinestean (38) identified the potential application of VR on sensory science. In addition to these, some researchers have recommended the use of VR techniques on some dangerous tasks that have the risk of compromising the participant’s health, such as nuclear issues (39).

The use of VR in transportation has also gained great interest in recent years. Some studies focused on pedestrian’s road crossing perceptions, behavior, and ability. For example, Simpson, Johnston (40) used VR to examine the pedestrian crossing behavior of children and young adults. The results showed that the decision on whether to cross the street was based on the distance between cars, not the cars’ speed. Sobhani, Farooq (41) analyzed pedestrians’ distracted behavior
when crossing using immersive VR, and concluded that the distracted pedestrian usually waits longer, but is faster to cross the street, compared to non-distracted participants.

Another commonly used study subject of VR is autonomous vehicles. Hartmann, Viehweger (6) studied the change of pedestrian behavior in this new environment. Sportillo, Paljic (42) compared the effectiveness of quick take-over training systems in three scenarios: VR, a user manual, and a fixed-base simulator. Comparison results showed the advantages of VR in training automated drivers to quickly take over autonomous vehicles.

In conclusion, the contributions of this paper are various. Firstly, the HITL is built using open source, the Unity3D game engine and the Vissim micro-simulation model. Secondly, advanced VR technology replaces the traditional fixed-based driving simulator as a driving system, which has advantages in price, setting time, space required, ease of use, and real experience. Thirdly, considering the insufficient studies on HT to date, this paper enriches the research on this scheme. Finally, to the best of our knowledge, this paper is the first one integrating the above which has great potential for other safety-related studies in the future.

**METHODOLOGY**

In this section, the development and evaluation processes of Hi-VRiLS are described as shown in Figure 1. The first step, microscopic simulation in Vissim, plays a role in traffic simulation according to the Wiedemann 74 car-following model. Second, the game engine Unity3D shows the virtual environment and connects to the VR devices. Since Unity3D is in charge of output, the input sources utilized comprises Vissim for traffic situation, VR devices for better reality environment, and a gaming steering wheel and pedals for a better driving experience. To import all input data into Unity3D, a script is needed to provide interaction between Unity3D and Vissim by spawning a pre-defined Vissim network. A driving experiment and a survey are performed for system evaluation. After that, the experimental results are used to analyze time-to-collision (TTC) using the Surrogate Safety Assessment Model (SSAM) and statistical t-test to compare the similarity.

![Figure 1 The development and evaluation processes of Hi-VRiLS](image-url)
Traffic Network Modeling in Vissim

Vissim is one of the microscopic simulations which allows reproduction of real traffic situations. The main reason for this ability is that verified driving behavior theories, such as Wiedemann 74 and Wiedemann 91, are embedded in Vissim (43). Among them, the Wiedemann 74 car-following model in Vissim is selected because it is suitable for urban traffic and merge areas. Thus, simulated cars can be driven just like driving a car in the real world, such as changing lanes and increasing or decreasing speed. Due to the practical output in the simulation, it is possible to analyze a particular driver’s driving skill as he or she travels along with the VR environment. Therefore, the Vissim network should be created to include a background traffic situation to ensure the human driving experience appears real. In order to be used as a background traffic simulation, basic traffic data that constitute Vissim is obligatory. Traffic volume, traffic signals, and public transportation schedule data are required. In addition, basic traffic rules that exist in a real traffic scheme need to be incorporated into the microscopic simulation.

Virtual Environment Modeling in Unity3D

The role of Unity3D in this research is to show a virtual scene to a driver since Unity3D is a powerful tool for creating a realistic virtual scenario with high-resolution models and various effects. 3D models are categorized into two types: static and dynamic models. A static model does not change during the simulation, while a dynamic model changes during every single simulation step based on conditions defined by the developers.

Static Model

A static model includes city components, such as road networks, buildings, parked cars, and traffic signs.

The road network in Unity3D should be modeled separately since the road segment models retrieved from Vissim do not look like the real roads, for example, there are no lane markings on the road and there are some unacceptable cracks on the curved road. A more realistic road network can be created with hook turn boxes, lane markings and other detailed markings and objects on the road (Figure 2-A) by utilizing RoadRunner, a road design software.

The building and traffic sign models are deployed according to Google’s satellite map and street view map. Since finding exactly the same building model is almost impossible, similar building models which make people feel it is a real environment are used (Figure 2-B). Also, a parked car is randomly placed in some of the road parking spaces but this can change depending on when the scenario is observed.

Dynamic Model

Dynamic models are created to make people feel the scenario is as real as possible: detailed cars, normal fixed traffic signals and in this case the hook turn are included.

The Polo, manufactured by Volkswagen, is applied as the driving simulator car for Hi-VRILS. This car has the basic physics in that it is driven by participants and is perceived as an obstacle for interacting with other cars in Vissim. In terms of the car interior, the movement of the steering wheel and the speedometer feel similar to actual driving. The side mirror and head-up-display (HUD) also are embedded for assisting with careful lane changes and checking current driving speed, respectively (Figure 2-D).
A traffic signal model is customized too. The reproduced traffic signal model without modification is just a simple block aligned with the location in Vissim. A typical and hook-turn traffic signal uses different 3D models. Two types of traffic signal models are additionally created (Figure 2-C). These 3D models are operated by a script at each simulation step according to Algorithm 1 (typical signal) and Algorithm 2 (hook-turn signal). To retrieve traffic signal information, the signal heads, links and lanes numbers in Vissim are assigned to the traffic signal 3D model in advance in each algorithm.

Algorithm 1
1. Postpone executing the code until Vissim runs.
2. Retrieve Vissim signal head data
   a. Find the ID number which is assigned to the traffic signal model
   b. Put the traffic signal model information into the traffic signal 3D model in Unity3D
3. Check the Vissim signal status every single frame
   a. Check the status of Vissim signal
   b. Change the color of the signal head in Unity3D accordingly

Algorithm 2
1. Same as algorithm 1 – steps 1 and 2
2. Check the Vissim signal status every single frame
   a. If the status of Vissim traffic signal is red or yellow, blink the signal every second
   b. If the status of Vissim traffic signal is green, turn it off

**Figure 2 Visualization in Hi-VRiILS**

**Integrated Platform**

C# programming software is used to integrate Vissim and Unity3D. The Vissim interface script plays a role in creating a Vissim network which contains signal information, as well as exchanging data in real-time, such as traffic flow and signal status. By accessing the Vissim XML file, Vissim interface script can perform the role. Since participants drive the car in the Unity3D
game engine, the script should be embedded in one of the Unity3D GameObjects, which opens a predefined Vissim network. This section explains how the script makes a connection.

**Main Script**

The main script that loads the Vissim network into Unity3D incorporates scripts that play different roles. Algorithm 3 describes the main script of this platform.

Algorithm 3

1. Mapping 3D Vehicle
2. Create VissimNetwork
3. Dispose Player Car
4. Import Signal Controller
5. Initialize Communicator
6. Perform Communication

**Mapping 3D Vehicle**

Since this script is only able to obtain numerical data from Vissim XML format, it is unable to map a 3D model automatically to the corresponding vehicle data. Mapping the 3D model to each vehicle data is necessary. Thus, the retrieved data from Vissim is mapped to the vehicle that has the same-named SketchUp file in the same directory.

**Create Vissim Network**

When loading Vissim, the script will load all network components in Vissim, such as the road network and signal head information. The process of the algorithm to create them is explained.

In order to create the Vissim network into Unity3D, each road segment should be enumerated with x and y coordinate information of all points, where a point indicates not only start and endpoints for the straight road but also the mid-point for a curved road. The Vissim XML file consists of all road network information, such as link numbers, the number of lanes, road or lane width, the x and y coordinates of the point. Therefore, the role of Algorithm 4 is to read that information from an XML file and to put those into the dictionary for creating the road network into Unity3D.

Algorithm 4

1. Create a Link_Dictionary
2. Access the XML file and find out link position information
3. Put data into the dictionary with enumerating data following the Vissim XML order of having the same link number.
4. Create a road segment based on the position information.

Similarly, all signal heads which represent traffic signal lights on each lane in the Vissim are recorded in the dictionary.

Since a traffic signal is updated every simulation second unlike the road network, the signal heads are controlled by an external signal controller, called Vissig. Each controlled signal head has a signal program and a signal group, where a signal controller consists of signal programs. Here, the signal program means that it can use a different time plan at the same intersection, such as a fixed time of day (TOD) plan. Further, the signal program consists of signal groups which
refer to a signal for each direction. Therefore, signal controller numbers, signal program numbers and signal group numbers should be imported together.

In addition, in order to distinguish the signal head object, road information such as link number and lane number are required. By doing so, a particular signal head can be found by searching link, lane, and signal head number in the dictionary.

Algorithm 5

1. Create a Signal_Dictionary
2. Access the XML file and find out if signal heads have all the necessary signal information.
3. Enumerate signal head data matching with the ID order from Vissim.

Dispose of Player Car

This method makes a car spawn in the Unity3D virtual environment. The car is able to start at the same point in every experiment. Plus, the x, y coordinates of the car are tracked and stored into the dictionary to be synchronized with Vissim.

Perform communication

The signal controller information containing signal groups, which are assigned to the signal heads in Vissim, is stored in a dictionary and is synchronized to operate traffic signal heads. Imported vehicle and traffic signal models are parallelized by interacting the two software.

The updated data in the dictionary keeps being parallelized by operating the Vissim and Unity3D simulation. In every single frame, the script retrieves data for Vissim vehicles and signal states and adjusts these states accordingly.

Algorithm 6

1. Create a Vissim_Vehicle_Dictionary and a Unity3D_Vehicle_Dictionary
2. Input the Vissim vehicle position information (x, y and z coordinates) and the player’s car information (x, y and z coordinates) into the dictionary
3. Retrieve the Vissim vehicle to Unity3D and the player’s vehicle to Vissim
4. Retrieve signal status by reading current signal status from the Signal_dictionary
5. Adjust the status of a vehicle, signal status to Unity3D and the status of player’s vehicle to Vissim

CASE STUDY

A part of the CBD in Melbourne is selected as a case study area. The frequency of TTC values is calculated based on the trajectory of the human-driven car in the virtual world and the computer-driven car using the Hi-VRiLS.

Experiment Design

Participants

Twenty volunteers (Mean age 22.88 years, SD = 2.28, 50% males, 50% females) participated in this experiment. They were postgraduate students at Southeast University-Monash University Joint Graduate School in Suzhou, China. They had held a driver’s license for at least 1 year.
Survey Results

All participants were asked about VR, driving ancillary equipment and their understanding and background of a hook turn. Table 1 shows that while 75% of participants had experienced VR before, none of them had left-handed driving experience or had experienced a hook turn before the experiment.

<table>
<thead>
<tr>
<th>TABLE 1 Survey Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Items</td>
</tr>
<tr>
<td>Participants Background Information (Yes or No)</td>
</tr>
<tr>
<td>Q1 Did you know what a Hook turn is?</td>
</tr>
<tr>
<td>Q2 Have you driven a vehicle in left-hand traffic?</td>
</tr>
<tr>
<td>Q3 Have you experienced VR before?</td>
</tr>
</tbody>
</table>

The reality of the simulator (Likert scale range: 1 = strongly disagree to 5 = strongly agree)

<table>
<thead>
<tr>
<th>Items</th>
<th>Mean Value (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q4 Do you think the simulation environment provides good visualization?</td>
<td>3.88 (2.28)</td>
</tr>
<tr>
<td>Q5 Do you find the driving simulator difficult?</td>
<td>1.88 (3.77)</td>
</tr>
<tr>
<td>Q6 Do you think the VR simulator can help beginner drivers?</td>
<td>3.50 (2.86)</td>
</tr>
</tbody>
</table>

Procedure

Prior to the actual experiment, a driving test was performed to discover unexpected problems and make sure the participants became familiar with driving in a virtual environment. The whole experiment consists of five steps: introduction, training, instruction, experiment and questionnaire. During the introduction, the participants listened to the purpose of the study and watched an HT instruction video clip produced by the Australian government (Figure 3-A). During the training step, participants were given time to get used to the Hi-VRiIS platform (Figure 3-B). Specifically, they were required to perform changing direction and to stop in front of a stop line and to check any discomfort while driving. If participants were uncomfortable, a 10-minute break was given. The participants were given several preconditions as follows to perform the experiment successfully:

- Drive as you do in the real world
- Follow the provided route and traffic rules (speed limit: 50km/h)
- Identify a hook turn intersection

The experiment continued as long as the participant did not break the traffic rules severely or drove the car the wrong way, such as out of the given route. After finishing the experiment, the participants were asked to complete a survey, which included relevant questions such as general information, and their experience of VR and the HT.
Figure 3 Training and Driving

Data analysis method
Statistical analysis was conducted. The trajectories were extracted from the Vissim simulation while the participant drove a car in the virtual world. Such data were processed using the SSAM for TTC (44). The threshold values of TTC were divided into three groups; under 0.5, under 1.0 and under 1.5. After that, the t-test was used to check the similarity of two different driving behaviors.

Target Area
A CBD area in Melbourne that has an HT maneuver was selected. This driving maneuver exists pervasively and is not familiar in other nations. Four intersections located in a rectangle were selected. One intersection has a 4-way hook-turn box, another has a 2-way hook-turn box, and the other two are normal intersections for making a circulated route during the driving experiment (Figure 4).

To create a reliable road network, Open Street Map and Google satellite map were utilized as a guideline to build a network. The detailed geometric information, such as lane width, was measured using street view function and the distance measuring tool from Google Maps.

Figure 4 Target Area
Traffic Volumes
Traffic volumes are assumed in this network. The vehicle inputs of each road are inputted depending on the hierarchy of the road. There are four roads according to the hierarchy shown as Figure 4, such as 1st level: road 1 and the road 2, 2nd level: the road 3 and 3rd level: road 4. The traffic volume of the road is 800veh/h, 500veh/h and 200veh/h, respectively. The rate of turning right, going straight and turning left are 0.05, 0.90 and 0.05, respectively.

Traffic Signal
Traffic signal data were obtained from Public Transport Victoria (PTV). Table 2 shows the signal plans of each intersection

<table>
<thead>
<tr>
<th>TABLE 2 Traffic Signals of Selected Intersections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intersection 1</td>
</tr>
<tr>
<td>Cycle time (s)</td>
</tr>
<tr>
<td>90</td>
</tr>
</tbody>
</table>

| Intersection 2 | Phase 1 | Phase 2 | Phase 3 |
| Cycle time (s) | Green/amber/red (s) | Green/amber/red (s) | Green/amber/red (s) |
| 90 | 27/3/0 | 7/3/3 | 41/3/3 |

| Intersection 3 | Phase 1 | Phase 2 | Phase 3 | Phase 4 |
| Cycle time (s) | Green/amber/red (s) | Green/amber/red (s) | Green/amber/red (s) | Green/amber/red (s) |
| 90 | 40/3/0 | 10/3/0 | 17/3/0 | 11/3/0 |

| Intersection 4 | Phase 1 | Phase 2 |
| Cycle time (s) | Green/amber/red (s) | Green/amber/red (s) |
| 90 | 38/3/3 | 40/3/3 |

Tram Timetable
The tram timetable was accessed from the database provided by PTV. All trams passing through the area from 8:00 am to 9:00 am were considered (45).

RESULTS
Trajectory Analysis Results
Trajectory data analysis is performed into two steps. The first step is to compare the likelihood of an accident from human-driven and computer-driven vehicles. The second step, the t-test is conducted in order to verify whether the two different datasets are statistically different.
Figure 5 presents the likelihood of accidents at each HT intersection based on the TTC threshold. Overall, a human-driven car has a higher likelihood of accidents compared to a computer-driven car at all intersections.

In the computer-driven case, the occurrence of TTC ≤ 0.5 and TTC ≤ 1.0 is recorded less than 10 times at both intersections. When the TTC threshold increases to less than 1.5, the average likelihood of an accident increases to 15.2 and 12.8 at intersections 1 and 2, respectively.

The human-driven case shows that the likelihood of an accident is significantly higher compared to the computer-driven case, especially at intersection 2 (Figure 5-D). The relative gap of the results from the two cases narrows as the range of TTC enlarges. The gap in TTC ≤ 1.5 at intersection 1 is smaller than at intersection 2 at 3.5 and 10.7, respectively.

As a second step, an independent-sample t-test is conducted to compare the similarity between the TTC < 0.5 and TTC < 1.5. There is a significant difference in driving trajectories. As Table 3 shows, the largest t-value is recorded at Intersection 1, TTC ≤ 0.5 case: t(38) = 8.701, p = 0.000 while, the smallest t-value is recorded at Intersection 2, TTC ≤ 1.5 case: t(38) = 2.823, p = 0.008. All results in this test meet the level of significance at 0.01 and suggest that the trajectories from these two cases are statistically different.

**TABLE 3 T-test Results**

<table>
<thead>
<tr>
<th></th>
<th>TTC ≤ 0.5</th>
<th></th>
<th>TTC ≤ 1</th>
<th></th>
<th>TTC ≤ 1.5</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intersection 1</td>
<td>Intersection 2</td>
<td>Intersection 1</td>
<td>Intersection 2</td>
<td>Intersection 1</td>
<td>Intersection 2</td>
</tr>
<tr>
<td>t-value</td>
<td>8.701</td>
<td>4.635</td>
<td>8.652</td>
<td>5.101</td>
<td>5.763</td>
<td>2.823</td>
</tr>
<tr>
<td>p-value</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.008</td>
</tr>
</tbody>
</table>

**DISCUSSION**
TTC values have been extracted from the trajectories in the micro-simulation as an index for determining the accident risk. However, the vehicles in the simulation do not take into account the driver's immaturity. Therefore, this paper develops Hi-VRiIS to consider human driving behavior when a person drives a simulated vehicle.

In this experiment, it is necessary to construct a good microsimulation model that includes background traffic environment. Data, such as traffic volume and traffic signals, are essential to building a traffic simulation network having the same conditions as in a real situation. Although the traffic volume is assumed, the main purpose of this study is to evaluate the influence of HITL in the simulation. Since having the same simulation condition to evaluation HITL effectiveness is necessary, the results are still meaningful.

Furthermore, since the number of accident risks varies depending on the person's gender, age, and other conditions, a wider range of participants should be encouraged in future studies.

CONCLUSIONS

This study presented a Hi-VRiIS, which mimicked a real-world traffic situation using VR technology. The Hi-VRiIS consisted of four-parts; traffic simulation (Vissim), 3D visualization engine (Unity3D), VR technology and gaming steering wheel and pedals. This research has shown how non-experienced drivers respond to a completely new road condition and how much they affect traffic safety. After the experiment, TTC values were derived from the trajectory of the human-driven and the computer-driven cars using the Hi-VRiIS and then their similarity was compared.

As a result, the frequency of TTC from the human-driven case is higher than from the computed one, and the similarity is statistically different (minimum t-value: 2.823 at Intersection 2 in TTC ≤1.5 case, p-value: 0.008).

The contribution of this paper to the research is as follows. First, an advanced driving simulator based on HITL was developed by integrating the VR technology of the Unity3D game engine and Vissim micro-simulation. Second, Hi-VRiIS has many benefits in terms of price, setting time, space required, ease of use, and user experience. Third, Hi-VRiIS can be used for training to reduce the likelihood of an accident caused by unfamiliar road conditions or rules. Fourth, insufficient studies on HT exist so this study adds to the literature. Finally, the developed Hi-VRiIS will be enhanced further and used for research in the future, such as conflicts with pedestrians and vehicles in traffic situations.

AUTHOR CONTRIBUTIONS

The authors confirm their contribution to the paper as follows. Study conception and design: Taeho Oh, Inhi Kim; data collection: Taeho Oh, Yanping Xu; analysis and interpretation of results: Taeho Oh; draft manuscript preparation: Taeho Oh, Yanping Xu, Inhi Kim, Zhibin Li. All authors reviewed the results and approved the final version of the manuscript.
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