Hindawi
Journal of Advanced Transportation
Volume 2022, Article ID 8929826, 12 pages
https://doi.org/10.1155/2022/8929826

*Research Article*

# Driving Risk Analysis Based on Driving Experience at Hook-Turn Intersection Using the Emerging Virtual Reality Technology

**Taheo Oh**[1,2] **Yanping Xu,**[1,3] **Zhibin Li**[1,3] **and Inhi Kim**[2,4]

[1]*School of Transportation, Southeast University, Nanjing, Jiangsu 210096, China*
[2]*Department of Civil Engineering, Monash University, Clayton, VIC 3800, Australia*
[3]*Jiangsu Key Laboratory of Urban ITS, Southeast University, Nanjing, Jiangsu 210096, China*
[4]*Department of Urban System Engineering, Kongju National University, Cheonan, Chungcheongnam-do 31080, Republic of Korea*

Correspondence should be addressed to Inhi Kim; inhi.kim@kongju.ac.kr

Received 7 April 2022; Revised 28 June 2022; Accepted 13 July 2022; Published 19 August 2022

Academic Editor: Luigi Dell'Olio



The hook turn, which is rarely seen outside of Melbourne, Australia, reduces congestion in narrow road spaces shared with trams. Australia allows people from 44 nations to convert their home country driver's license to an Australian driver's license without a driving test. Visitors who have never heard of the hook-turn experience difficulty driving following the new traffic rule. From this aspect, investigating how inexperienced drivers encounter the hook-turn intersection is valuable for safety reasons. A driving simulator including virtual reality technology is developed to evaluate the level of safety of human driving behavior. The simulator in this research was developed by integrating Vissim and Unity3D embedded head-mounted display and driving devices to ensure a better driving experience. This research presented the development of a robust virtual reality driving simulator. It investigated how nonexperienced drivers respond to a completely new road condition. The results were compared with microsimulation outcomes (here, Vissim). The results showed that a human-driven car had a higher collision risk than a computer-driven car. The trajectories of the driver type were statistically different ($t = 6.03$, $p$ 0.01, in the case of time-to collision ≤1.5 between experienced and computerized drivers). Participant responses to a postexperiment survey found that the simulator was realistic (4.31 out of 5.00), which could help beginner drivers (4.00 out of 5.00). Therefore, the simulator can be utilized for safety-related research as well as drivers' training.

## 1. Introduction

According to the Australian government statistics [1], the number of people coming to Australia has been raised for various reasons, such as education, business-related, and vacation. In addition, the ratio of visitors who have never been to Australia has been increasing for the last eight years. Travelers might need to drive themselves for trip purposes. While driving overseas, the traveler could not be familiar with different driving ways. For instance, Australia applies a left-hand drive rule, accounting for 31.5% (75 countries out of 240) of drivers worldwide. Drivers usually have their own driving habits in their home country. Therefore, driving in different road layouts could cause risky driving behavior.

Moreover, in Melbourne, Australia, road layouts include the longest tram network, over 200 km [2]. Tram tracks are located in the middle of the lane, sharing road space with vehicles in the central business district. Since different types of transport have to share the limited road space, there is a unique way to cross an intersection in Australia called hook turn (HT). Many people felt it challenging to drive with different driving directions and new ways of intersection crossing [3]. However, the Australian government allows driver's license holders from 28 countries to change to an Australian driver's license immediately. For drivers over 25 years old from 16 countries, converting their home country driver's license to an Australian driver's license is possible without any driving test [4]. Unverified driving in driving experience leads to consequences that are traffic congestion in the city center and accident risk exposure. Therefore, it is necessary to analyze the risk of driving in a new environment.

To evaluate the level of driving risk, including human factors, a human-in-the-loop VR embedded simulator (Hi-VRilS) is suggested. 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. Studies focused on the integrated operation of humans and machines have been tested and verified [5]. As further studies, researchers have recently started integrating HITL with virtual reality (VR) technology [6]. The research shows that HITL with VR becomes a significantly valuable tool for analyzing various conditions. The situation depends on analysis purpose; it is easily changeable, and it can test what is hard to be tested in the real world due to safety concerns.

In order to generate a realistic virtual traffic driving simulator in this research, two different software have to be integrated: (1) Unity 3D, a game engine for creating a virtual world, and (2) Vissim, microscopic traffic simulation for modeling and analysis traffic flow. The two simulations communicate with each other in every frame. In addition, a head-mounted display (HMD) and Logitech game input devices (steering wheel and pedals) are embedded as components of the driving simulator. The VR driving simulator can provide drivers with a highly immersive driving sense compared to the fixed-based driving simulator [7].

This research presents the components of Hi-VRilS as developed, and driving experiments are conducted to investigate how nonexperienced drivers respond to an entirely new road environment. The human- and computer-driven behaviors are recorded to trajectory data. The two driving behaviors are compared from a safety perspective using the surrogate safety assessment model (SSAM). The paper starts with a literature review to better understand HT, emerging technology in transport engineering, and virtual reality. The methodology presents the Hi-VRilS development procedure. The case study illustrates the safe experimental design. Finally, the results and limitations of this research are discussed.

## 2. Literature Review

*2.1. Hook Turn.* Although HT has been successfully implemented in Melbourne for more than 60 years, the reason for doing HT is to turn right at the intersection where the tram rail is located. The way of performing hook turn is waiting for the signal in the waiting box and driving following the red dashed arrow in Figure 1. The research about hook-turn maneuver is limited and focuses on the assessment and evaluation by comparison with other right-turning traffic management methods [8].

O'Brien [9] utilized a macroscopic simulation to study HT's safety and operational impacts to check its merit of operation in Melbourne. Comparison results from the study

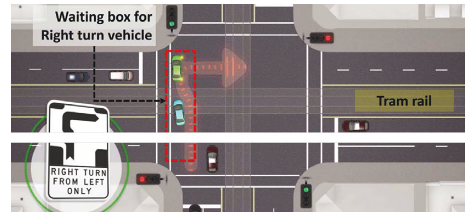


Figure 1: Typical traffic movements at the hook turn intersections (source: VicRoads: https://www.youtube.com/watch?v=Yh92LirlCf8).

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 between right-turning vehicles and side-road traffic. In addition, Currie and Reynolds [10] proposed a comprehensive review of the HT. Also, they explored its operations and safety impacts using performance data from two different intersections. The review demonstrated that HT reduced more congestion than the conventional turn. In practice, 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 roadside vehicles caused by right-turning traffic. Bie and Liu [12] also established two intersections in a similar concept. They performed 24 microscopic simulation scenarios to assess the benefits of HT. The major difference 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.

*2.2. Human-in-the-loop.* The HITL approach has attracted significant attention due to the inability of a computer system to accurately accomplish tasks that require human participation [12–14]. HITL cooperates with the machine and produces human data as crucial elements. HITL is critical for improving the reliability of simulation results when considering human behavior directly.

Recently, Zanzotto [15] proposed a fairer artificial intelligent (AI) system, called human-in-the-loop artificial intelligence (HitAI), that rewarded knowledge providers who were fed data. In 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 [16]. Jirgl and Bradac [16] found that human-computer interaction has a great ability to increase the strength of CPSs. Gil and Albert [17] 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 autonomous vehicles (AV) [18]. Mirnig and Gärtner [19] reviewed the application status of interaction solutions in autonomous vehicle control transitions and concluded a categorization framework for this overview. Noah and Gable [20] helped a driver 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 and Yuan [21] proposed a HITL agent-based simulation to establish an advanced autonomous surveillance system using uncrewed vehicles. Feng and Sequeira [22] introduced a HITL iterative process to improve generative models.

Additionally, a driving simulator is a critical application of HITL in the transportation area. Lei et al. [7] built a small driving simulator using NI PXI hardware and related software to conduct fuel economy analysis on a hybrid electric vehicle in the HITL environment. Fitzpatrick et al. [23] 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 et al. [24] 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 et al. [25] 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 et al. [26] compared young drivers' interaction behavior with child and adult pedestrians. They found that curb extension was the most efficient safety measure that led to the most appropriate driving speed at pedestrian crossings [27].

Similarly, the driver-cyclist interaction was researched using a driving simulator [28]. In this experiment, the time point that a cyclist was seen and the crossing design demonstrated the two most influential factors on the driver's response.

*2.3. 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. It is regarded as an efficient and practical method of learning surgical skills in the twenty-first century [29]. VR in transportation has also gained significant interest in recent years. Some studies focused on pedestrian road crossing perceptions, behavior, and ability. For example, Simpson et al. [30] used VR to examine the pedestrian crossing behavior of children and young adults. The results showed that whether to cross the street was based on the distance between cars and not the cars' speed. Sobhani et al. [31] analyzed pedestrians' distracted behavior when crossing using immersive VR. The distracted pedestrian usually waits longer but is faster to cross the street than nondistracted participants. VR technology is also commonly used in pedestrian and vehicles research. Hartmann et al. [6] studied the change of pedestrian behavior in this new environment. Sportillo et al. [32] compared the effectiveness of quick takeover 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.

*2.4. Surrogate Safety Assessment Model (SSAM).* The surrogate safety assessment model (SSAM) is a tool developed in the US for traffic safety analysis. This tool uses vehicle trajectory data to calculate collision risk between vehicles. Microscopic traffic simulation, such as Vissim, Aimsun, and Paramics, generates the trajectories of each vehicle in the simulation [33]. SSAM defines three types of collisions based on the vehicle's location: rear-end collisions, lane changes, and crossings. SSAM uses five indicators for safety analysis by crash type, which are TTC, PET, DR, MasS, and DeltaS. Among them, time-to-collision (TTC) is the standard indicator for evaluating traffic conflict [34, 35]. TTC is the time taken for two vehicles to collide if they maintain their current direction and speed. TTC is calculated using the following formula:

$$\mathrm{TTC} = \begin{cases} \dfrac{d_1}{v_1} \text{ if } \dfrac{d_2}{v_2} < \dfrac{d_2}{v_1} < \dfrac{d_2 + l_2 + w_1}{v_2} \text{ (side)}, \\[2ex] \dfrac{d_2}{v_2} if \dfrac{d_1}{v_1} < \dfrac{d_2}{v_2} < \dfrac{d_1 + l_1 + w_2}{v_1} \text{ (side)}, \\[2ex] \dfrac{X_1 - X_2 - l_1}{v_2 - v_1} \text{ if} v_2 > v_1 \text{ (rearend)}, \\[2ex] \dfrac{X_1 - X_2}{v_1 + v_2} \text{ (headon)}, \end{cases} \tag{1}$$

where $v, l, d, w$, and $X$ represent the speed, length, distance, width, and vehicle position, respectively. The conflict points, as a traffic safety evaluation index, were recorded when the TTC value was over the minimum threshold. A lower value of TTC means a higher collision probability, and a TTC value under 1.5 seconds is defined as a dangerous situation [33]. Therefore, in this research, TTC with surrounding vehicles is calculated based on the trajectory generated from human driving in a virtual environment.

The contributions of this paper are as follows. First, the HITL technology is used to build a driving simulator integrated with the Unity3D game engine and the Vissim microsimulation model. Second, advanced VR technology replaces the traditional fixed-based driving simulator as a driving system, with price advantages, time, space required, ease of use, and natural experience. Third, one thing that hook turning for the inexperienced driver could be dangerous can be analyzed based on the time-to-collision (TTC) value. Considering the insufficient studies on HT, this paper enriches the research on this scheme.

## 3. Methods

The development and evaluation processes of Hi-VRilS are described in Figure 2. The first step, microscopic simulation in Vissim, played a role in the traffic flow simulation according to the Wiedemann 74 car-following model. Second, the game engine Unity3D showed the virtual environment and connected to the external devices, such as HMD, Logitech gaming steering wheel, and pedals. Next, Unity and Vissim communicated by API scripting. A driving experiment and a survey were performed after developments. The experiment analyzed the risk value-driving in hook-turn intersection based on TTC and the driving behavior similarity between human- and computer-driven cars.

*3.1. Traffic Network Modeling in Vissim.* Vissim is one of the microscopic simulations which allows the reproduction of traffic situations. The verified car-following behavior, such as Wiedemann 74 and Wiedemann 91, are embedded in Vissim [36]. The Wiedemann 74 car-following model in Vissim was selected because it is suitable for urban traffic and merge areas. Therefore, the Vissim simulation was built to ensure surrounding vehicles similar to human driving in the simulator. Traffic volume, signals, and public transportation schedule data were collected to represent realistic traffic flow.

*3.2. Virtual Environment Modeling in Unity 3D.* The role of Unity3D in this research was 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 in the simulator were categorized into two types: static and dynamic models. A static model did not change during the simulation, while a dynamic model changed during every single simulation step.

*3.2.1. Static Model.* A static model included city components, such as road networks, buildings, parked cars, and traffic signs. The road network in Unity3D was modeled, since the road segment models retrieved from Vissim do not look like the actual roads. For example, there are no lane markings on the road, and there are some unacceptable cracks on the curved road. The realistic road networks were created with waiting boxes for hook turn, lane markings, and other detailed objects on the road (Figure 3(a)). The building and traffic sign models were deployed according to Google's satellite map and street-view map (Figure 3(b)). Also, a parked car was randomly placed in some of the road parking spaces.

*3.2.2. Dynamic Model.* Dynamic models were created to make people feel the scenario as real as possible: detailed cars, standard fixed traffic signals, and the hook turn are included.

Polo, manufactured by Volkswagen, was applied as a vehicle for Hi-VRilS. This car had fundamental physics that is driven by participants and is perceived as an obstacle for interacting with other cars in Vissim. The steering wheel and the speedometer moved according to the external controller in terms of the car interior. The side mirror and head-up-display (HUD) were also embedded to assist with careful lane changes and check current driving speed, respectively (Figure 3(d)).

Typical and hook-turn signal models identical to actual traffic signals were used (Figure 3(c)). These 3D models were controlled according to Algorithm 1 (typical signal) and Algorithm 2 (hook-turn signal) in every single step. 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.

*3.3. Integrated Platform.* This section explains how the script communicates traffic data between Unity and Vissim. In Algorithm 3, the integration procedure was processed.

*3.3.1. Mapping 3D Vehicle.* Since the script was only able to obtain numerical data from Vissim XML format, it could not automatically map a 3D model to the corresponding vehicle data. Thus, the retrieved numerical data from Vissim were mapped to the vehicle that has the same-named SketchUp file in the same directory.

*3.3.2. Create Vissim Network.* 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. The procedure of Algorithm 4 reads the link coordinate data from the XML file, includes it in the dictionary, and creates a road segment in the virtual environment.

Similarly, all signal heads representing traffic signal lights on each lane in Vissim were recorded in the dictionary. Since a traffic signal was updated every simulation second, unlike the road network, the signal heads were controlled by an external signal controller called Vissim. Each controlled signal head has a signal program and a signal group. Here, the signal program can use a different time plan at the same intersection, such as a fixed time of day (TOD) plan. Furthermore, the signal program consists of signal groups that refer to a signal for each direction. Therefore, signal controller numbers, program numbers, and group numbers should be imported together.

In addition, in order to distinguish the signal head object, location information, such as the link number and the lane number, was required (see Algorithm 5). A particular signal head can be found by searching link, lane, and signal head number in the dictionary.

*3.3.3. Dispose of a 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 car's $x$ and $y$ coordinates were tracked and stored in the dictionary to be synchronized with Vissim.

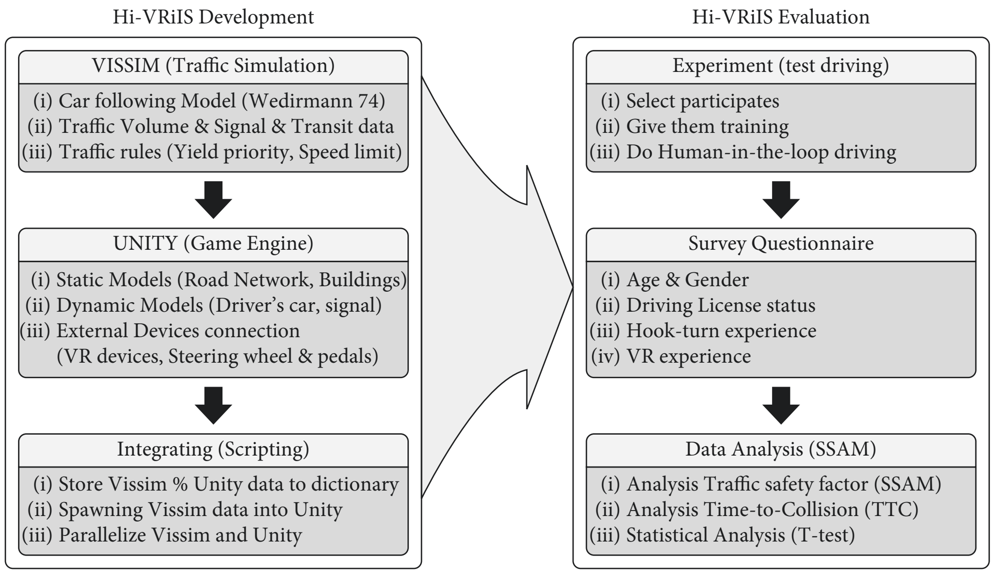


Figure 2: The development and the evaluation process of Hi-VRilS.

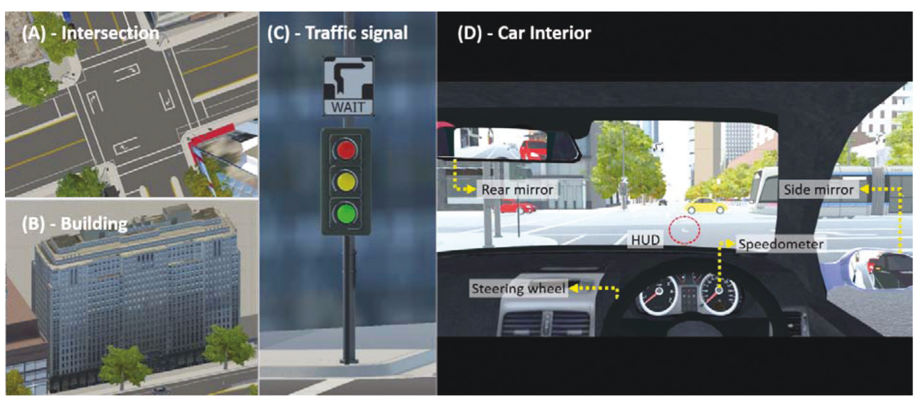


Figure 3: Objects in the simulator. (a) Intersection. (b) Building. (c) Traffic signal. (d) Car interior.

*3.3.4. Perform Communication.* The signal information containing signal groups, which are assigned to the signal heads in Vissim, was stored in a dictionary and was synchronized to operate traffic signal heads. Imported vehicle and traffic signal models were parallelized by interacting with the two software.

The updated data in the dictionary kept being parallelized by operating Vissim and Unity3D simulation. In every single frame, the script retrieved data for Vissim vehicles and signal states and adjusted these states accordingly (see Algorithm 6).

*3.4. Case Study.* In this section, based on the Hi-VRils simulator built in this research, we tried to analyze the risk of collision while driving in a new traffic environment that drivers have never experienced before. The TTC value was used for collision risk analysis. As a comparison group to observe the changed collision risk opportunity due to human driving, the trajectory of a computerized driven car created in the simulation was used.

## 4. Experiment Design

*4.1. Participants.* According to the 2016 Statistics in Melbourne, Australia, more than half of the drivers were involved in road accidents as drivers were under 40 years old. In addition, the statistics show that over 40 drivers in their early 20s died in crashes between 2014 and 2018 (VicRoads, 2019). Therefore, the average age of participants was intended to be in 20s. A total of 36 participants was recruited by advertising on the boards on the university campus. Of these 36 participants, 26 were students, and 10 were university employees. All of them had no experience in hook turn and left-hand drive. Participants were asked these conditions: valid driver's license holding at least a year, weekly driving frequency, and annual driving mileages in

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

Algorithm 1

(1) Same as algorithm 1 – steps 1 and 2
(2) Check the Vissim signal status every single frame
  (i) If the status of the Vissim traffic signal is red or yellow, blink the signal every second
  (ii) If the status of the Vissim traffic signal is green, turn it off

Algorithm 2

(1) Mapping 3DVehicle
(2) Create Vissim Network
(3) Dispose of Player Car
(4) Import Signal Controller
(5) Initialize Communicator
(6) Perform Communication

Algorithm 3

(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.

Algorithm 4

(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.

Algorithm 5

(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

Algorithm 6

Table 1: Participants' information.

| | Experienced drivers | Novice drivers |
|---|---|---|
| Age | 28.44 ± 4.73 | 22.94 ± 2.07 |
| Driving experience (year) | 8.22 ± 3.61 | 2.89 ± 1.84 |
| Annual driving mileages (km) | 11,826 ± 7,880 | Not answered |
| Level of education (high-school, under graduated, and graduated) | 1/13/4 | 1/17/0 |
| Accident history (yes/no) | 3/15 | 0/18 |
| VR experiences (yes/no) | 9/9 | 14/4 |
| Hook-turn knowledge (yes/no) | 0/18 | 0/18 |
| Experienced left-hand drive (yes/no) | 0/18 | 0/18 |

their home countries. These criteria were used to distinguish groups between experienced and novice drivers. The experienced driver had more than five years of driving experience and had driven more than 5,000 km in the past year [37]. Otherwise, the participants were grouped into novice drivers. As a result, each group had the same number of participants (Table 1).

*4.1.1. Experienced Drivers.* A total of 18 experienced drivers volunteered for this experiment. They were aged 28.44 on average with a 4.73 standard deviation. The period of holding a driver's license was more than five years (mean = 8.22 and SD = 3.61), and the average annual driving distance was more than 5,000 km (mean = 11,826 km and SD = 7,880). Three of them had the accident experience as a perpetrator, and one was a victim of the accident. For the VR experiences, half of the participants had experienced VR equipment before the experiments.

*4.1.2. Novice Drivers.* A total of 18 novice drivers participated (mean = 22.94 years old and standard deviation = 2.07). The average period of holding a driver's license was 2.89 years with 1.84 standard deviations. Most novice drivers had no driving experience on the real road after acquiring driving licenses. Therefore, they did not respond to the average annual driving distance on the survey. In addition, none of them have been involved in car accidents due to the short driving mileage. The minority of novice drivers (22%) have not tried VR devices before the experiment.

*4.2. Procedure.* Before 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. They watched an HT instruction video clip produced by the Australian government (Figure 4(a)). During the training step, participants were given time to get used to the Hi-VRilS platform (Figure 4(b)). Specifically, they were required to perform changing direction, stop in front of a stop line, and check any discomfort while driving. If participants were uncomfortable, 10 minutes break was given. The participants were given several preconditions as follows to experiment successfully:

(i) To drive as you do in the real world

(ii) To follow the provided route and traffic rules (speed limit: 50 km/h)

(iii) To identify a hook turn intersection

The experiment continued as long as the participant do not break the traffic rules or drive the car in the wrong 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 HT (see Table 1).

## 5. 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 SSAM for TTC [33]. 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.

*5.1. 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 (see Figure 5).

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 the street view function and the distance measuring tool from Google Maps.

*5.2. Traffic Information.* Traffic volumes were assumed in this network. The vehicle inputs of each road are inputted depending on the hierarchy of the road. According to the hierarchy shown in Figure 5, such as 1st level: road 1 and road 2, 2nd level: 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.

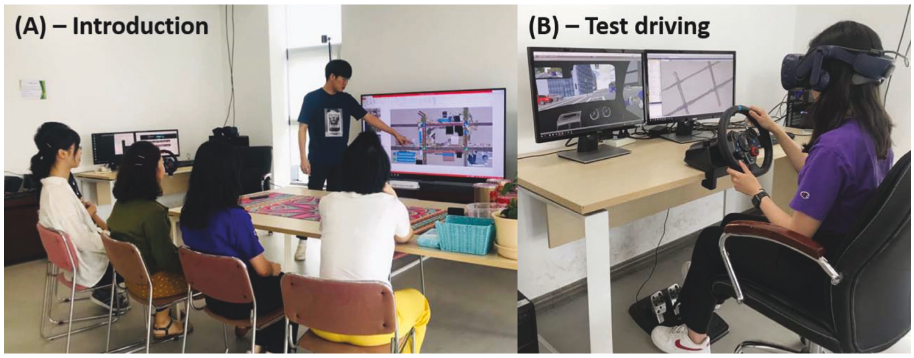


Figure 4: Training and test-driving session. (a) Introduction. (b) Test driving.

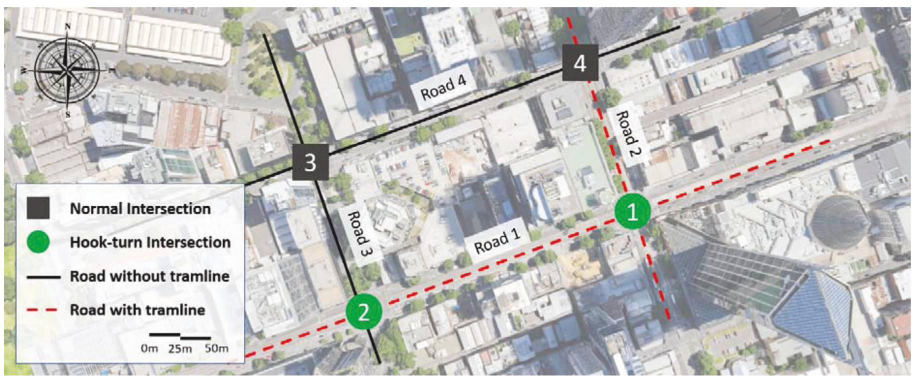


Figure 5: Case-study area.

Traffic signal information and public transport timetable from 8:00 am to 9:00 am were obtained from Public Transport Victoria (PTV) [38].

## 6. Result

Trajectory data analysis is performed in two steps. The first step is comparing the collision risk value between experienced- and novice- and computer-driven vehicles. The ANOVA test was conducted to verify whether the three datasets are statistically different. After the results of a significant difference were obtained from the ANOVA test, a Bonferroni correction post-hoc analysis was performed to verify the mean difference level.

Figure 6 presents the likelihood of collision at each HT intersection based on TTC thresholds. Overall, a human-driven car has a higher risk of accidents than a computer-driven car at all intersections. In the computer-driven case, TTC ≤0.5 and TTC ≤1.0 were recorded less than ten times at both intersections. When the TTC threshold increased to less than 1.5s, the average collision risk value increased to 12.19 and 15.13 at intersections 1 and 2, respectively. The human-driven case shows the likelihood of the accident was significantly higher than the computer-driven case, especially at intersection 2 (Figure 6(d)). The relative gap between the results from the two cases narrows as the range of TTC enlarges.

As a second step, a one-way ANOVA test was conducted. Table 2 shows that there were significant differences in the three driver types.

Therefore, a post-hoc test was performed to find the significance of driving safety indicators for experienced, novice, and computer drivers. The comparison group was divided into three groups, such as group 1 (experienced vs. novice), group 2 (experienced vs. computerized), and group3 (novice vs. computerized). As shown in Table 3, most cases had significant differences based on the driver types. However, there was no statistically significant difference in the number of collisions in group 1. From this result, it is judged that the risk figure is similar to the first intersection because it is an intersection where both experienced and newbies are unfamiliar with the traffic method.

## 7. Discussion

*7.1. Hi-VRils Driving Simulator Platform.* In order to analyze how human driving affects the result of traffic safety, Hi-VRilS was proposed by integrated with microsimulation. The trajectory dataset was significantly different in all intersections, according to statistical analysis. Therefore, with the driving simulator, a meaningful result considering the human factor was available.

Moreover, Hi-VRilS provided a realistic driving experience to drivers according to a questionnaire that recorded a mean of 4.31 out of 5 points. Regarding the experience of the new driving position and rules, participants answered that the simulator is easy to operate (4.00 points). It is helpful to drive in a new environment for inexperienced drivers (3.92 points). Therefore, the simulator developed in this research

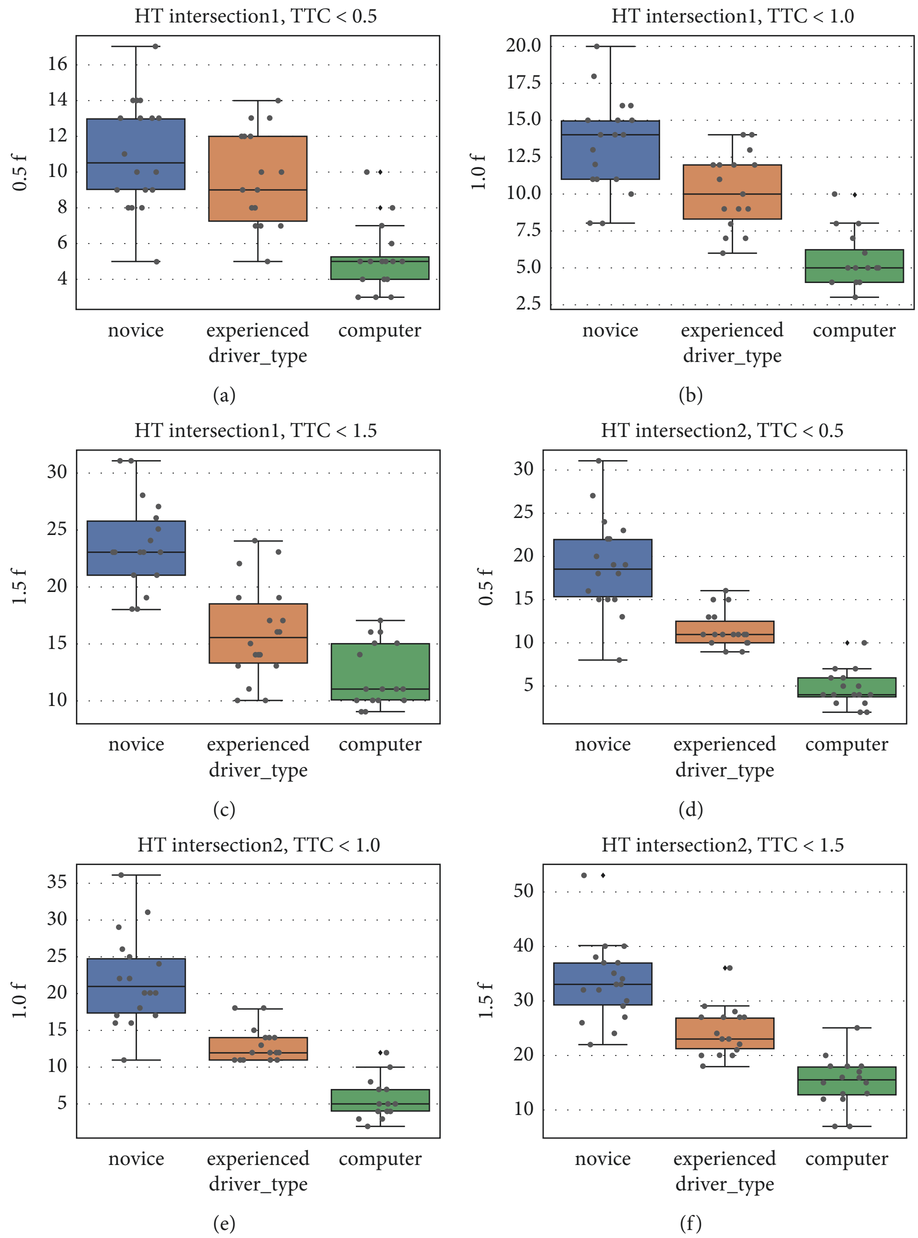


FIGURE 6: The number of risky driving behavior at the intersections depending on a different TTC value.

TABLE 2: One-way ANOVA-test result.

| Intersection 1 | | | Intersection 2 | | |
|---|---|---|---|---|---|
| TTC≤ 0.5 | TTC≤ 1.0 | TTC≤ 1.5 | TTC≤ 0.5 | TTC≤ 1.0 | TTC≤ 1.5 |
| 23.37*** | 39.20*** | 42.83*** | 66.59*** | 66.56*** | 46.41*** |

* $p$ value < 0.05, ** $p$ value < 0.01, and *** $p$ value < 0.001.

TABLE 3: Post-hoc test result.

| | Intersection 1 | | | Intersection 2 | | |
|---|---|---|---|---|---|---|
| | TTC≤ 0.5 | TTC≤ 1.0 | TTC≤ 1.5 | TTC≤ 0.5 | TTC≤ 1.0 | TTC≤ 1.5 |
| Group 1 (experienced-novice) | −1.59# | −3.40*** | −5.71*** | −5.48*** | −5.83*** | −4.62*** |
| Group 2 (experienced-computerized) | 5.52*** | 6.06*** | 3.04** | 9.48*** | 8.55*** | 6.03*** |
| Group 3 (novice-computerized) | 6.68*** | 8.62*** | 9.77*** | 9.89*** | 9.81*** | 8.77*** |

* $p$ value < 0.05, ** $p$ value < 0.01, *** $p$ value < 0.001, and # $p$ value > 0.05.

is enough for a participant to give a more realistic driving experience with VR technology.

Additionally, the use of a driving simulator is to give opportunities to test the driving behavior as well as the state-of-art technique, regrading autonomous driving. For instance, one of the open-source driving simulators called Carla was developed. Carla has unique characteristics for learning to drive autonomous vehicles [39]. In contrast, Hi-VRliS focuses on extension with microscopic traffic simulation and unlimited scenario design. Therefore, it is possible to freely configure the environment in which the realistic vehicle is driving according to the research purpose.

*7.2. Selecting Experimental Group.* According to the case study experiment's aim, experimental and comparison groups were carefully selected. For the experimental group, every participant has no driving experience in hook-turn intersections. Instead of people experiencing a hook turn, a computer-driven car from the microsimulation was utilized for the comparison group. The computer-driven car in simulation is modeled based on the psycho-physical model, such as Wiedemann 74. The trajectories from the simulated car represent generalized human driving behavior without considering the driver's immaturity. Therefore, accident risk analysis based on the human-driven car from a simulator and computer-driving from the microsimulation is affordable to safety comparative analysis.

## 8. Conclusion

Due to globalization, the number of traveling to other countries has increased. When people visit other countries, they might need to drive themselves. However, driving in an unfamiliar area can be more dangerous than driving in an area driving every day. Therefore, the level of collision risk of driving in unfamiliar areas needs to be analyzed.

In order to consider the human factor in the simulation, the HITL technology was adapted in the driving simulator. For a better immersive virtual driving experience, HMD, gaming steering wheel, and pedals, were utilized. The driving simulator developed in this research was integrated with microsimulation, such as VISSIM, so that realistic surrounding vehicles based on the car-following model were performed.

Driving in Australia is required for a new way for the right turn and left-hand drive, which is used in 31.5% of all over the world. Therefore, to analyze the risk of driving in unfamiliar areas, intersections in Melbourne, Australia, required hook turn for the right turn. A total of thirty-six people who have never experienced left-hand drive and hook-turn participated in the experiments. For comparison, computer-driven cars from VISSIM were replaced with local driver roles.

The results show that TTC frequency from the human-driven case, including experienced and novice drivers, is higher than from the computed one. The similarity was statistically different between human and computerized cases. One thing to note is that comparisons between novice and experienced drivers were interesting. There was no statistically significant difference in the collision risk values of experienced and novice drivers recorded at the HT intersection after the start of the experiment. However, it was analyzed that, as time went by, the collision risks decreased as experienced drivers quickly adapted to crossing intersections compared to novice drivers. It can be interpreted that the skilled person adapts to the road driving environment faster due to the driving experience, despite being unfamiliar with the hook-turn method.

For the limitation, the vehicle in microsimulation was used as a comparison baseline instead of the local human drivers. Computerized driving could not perfectly reflect local human driving. However, Wiedemann 74 in Vissim was considered the general driving behavior, since it is based on human socio-demographic characteristics behavior [40]. The risk level comparison according to driving experiences, thus, is still worth investigating.

By combining the advantages of a driving simulator and microsimulation, it was possible to analyze the safety of intersections without going to the site. In the future, conducting driving simulator tests can be used to reduce accidents by experiencing local traffic characteristics in advance when overseas entrants drive. In addition, to driving alone for safety analysis, since crossing the intersection needs cooperation with other vehicles, it might be necessary to evaluate the safety of a new transportation system with a multiagent driving environment. Since the number of accident risks varies depending on the person's gender, age, and other conditions, a more comprehensive range of participants should be encouraged in future studies.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Disclosure

A part of this research was presented at 99th Annual meeting of transportation research board. The structure was reconstructed, the experiment was redesigned, and the analysis was conducted again. The majority of the manuscript was amended.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## Acknowledgments

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (no. 2021R1C1C1006405) and the research grant of the Kongju National University in 2022.

## References

[1] A. G. Austrade, *Lateset international visitor survey results*, 2019, https://www.tra.gov.au/data-and-research.

[2] G. Currie and P. Smith, "Innovative design for safe and accessible light rail or tram stops suitable for streetcar-style conditions," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 1955, no. 1, pp. 37–46, 2006.

[3] S. Saito, Y. Murata, T. Takayama, and N. Sato, "An international driving simulator: recognizing the sense of a car body by the simulator," in *Proceedings of the 2012 26th International Conference on Advanced Information Networking and Applications Workshops*, March 2012.

[4] Austroads, "Applying for a licence in Australia or New Zealand," 2019, https://austroads.com.au/drivers-and-vehicles/overseas-drivers/applying-for-a-license.

[5] M. Inoue and V. Gupta, ""Weak" control for human-in-the-loop systems," *IEEE Control Systems Letters*, vol. 3, no. 2, pp. 440–445, 2019.

[6] M. Hartmann, M. Viehweger, W. Desmet, M. Stolz, and D. Watzenig, "Pedestrian in the Loop": An approach using virtual reality," in *Proceedings of the 2017 26th International Conference on Information, Communication and Automation Technologies (ICAT)*, pp. 1–8, IEEE, Sarajevo, Bosnia and Herzegovina, October 2017.

[7] W. Lei, Y. Yang, Z. Peng, G. Yang, and H. Xiaosong, "Research on hybrid electrical vehicle based on human-in-the-loop simulation," in *Proceedings of the 2014 IEEE Conference and Expo Transportation Electrification Asia-Pacific (ITEC Asia-Pacific)*, pp. 1–5, IEEE, Beijing, China, August 2014.

[8] Z. Liu and Y. Bie, "Comparison of hook-turn scheme with U-turn scheme based on actuated traffic control algorithm," *Transportmetrica: Transport Science*, vol. 11, no. 6, pp. 484–501, 2015.

[9] A. O'Brien, "Review of Hook Turns (Right Turn from Left)," *Research and development project*, vol. 729, 2000.

[10] G. Currie and J. Reynolds, "Managing trams and traffic at intersections with hook turns," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2219, no. 1, pp. 10–19, 2011.

[11] N. B. Hounsell and Y. H. Yap, "Hook turns as a solution to the right-turning traffic problem," *Transportation Science*, vol. 49, no. 1, pp. 1–12, 2015.

[12] D. Perez and Y. Shen, "A-PED Augmented Reality Enabled Pedestrian-In-The-Loop Simulation.Pdf," in *Proceedings of the 2019 Transportation Research Board's 98th Annual Meeting*, Washington, DC, USA, January 2019.

[13] P. Hasan and S. Yang, "Distributed Microscopic Traffic Simulation witheHuman-In-The-LoopeEnabled by Virtual Reality Technologies," *Advances in Engineering Software*, vol. 154, no. 3, 2021.

[14] A. Sebok and C. Wickens, "Simulator-based investigations of human error potential with railroad automation in the locomotive cab," *Proceedings of the Human Factors and Ergonomics Society - Annual Meeting*, vol. 61, no. 1, pp. 1964–1968, 2017.

[15] F. M. Zanzotto, "Viewpoint: human-in-the-loop artificial intelligence," *Journal of Artificial Intelligence Research*, vol. 64, pp. 243–252, 2019.

[16] M. Jirgl, Z. Bradac, and P. Fiedler, "Human-in-the-Loop issue in context of the cyber-physical systems," *IFAC-PapersOnLine*, vol. 51, no. 6, pp. 225–230, 2018.

[17] M. Gil, M. Albert, J. Fons, and V. Pelechano, "Designing human-in-the-loop autonomous cyber-physical systems," *International Journal of Human-Computer Studies*, vol. 130, pp. 21–39, 2019.

[18] Z. Ma, M. Huang, and Z. James, "Hardware-in-the-loop Testing of Connected and Automated Vehicle Applications a Use Case for Queue-Aware Signalized Intersection Approach and Departure," in *Proceedings of the Transportation Research Board's 98th Annual Meeting*, vol. 2672, no. 22, Washington, DC, USA, January 2019.

[19] A. G. Mirnig, M. Gaertner, A. Laminger et al., "Control transition interfaces in semiautonomous vehicles: a categorization framework and literature analysis," in *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, pp. 209–220, ACM, Oldenburg Germany, September 2017.

[20] B. E. Noah, M. G. Thomas, C. Shao-Yu, S. Shruti, and B. N. Walker, "Development and preliminary evaluation of reliability displays for automated lane keeping," in *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, pp. 202–208, ACM, Oldenburg Germany, September 2017.

[21] S. Minaeian, Y. Yuan, J. Liu, and Y. -J. Son, "Human-in-the-loop agent-based simulation for improved autonomous surveillance using unmanned vehicles," in *Proceedings of the 2015 Winter Simulation Conference (WSC)*, pp. 3126-3127, IEEE, Huntington Beach, CA, USA, December 2015.

[22] D. Feng, P. Sequeira, E. Carstensdottir, M. Seif El-Nasr, and S. Marsella, "Learning generative models of social interactions with humans-in-the-loop," in *Proceedings of the 2018 17th IEEE International Conference on Machine Learning and Applications (ICMLA)*, pp. 509–516, IEEE, Orlando, FL, USA, December 2018.

[23] C. D. Fitzpatrick, S. Samuel, and M. A. Knodler Jr., "The use of a driving simulator to determine how time pressures impact driver aggressiveness," *Accident Analysis & Prevention*, vol. 108, pp. 131–138, 2017.

[24] H. Xiong, P. Narayanaswamy, S. Bao, C. Flannagan, and J. Sayer, "How do drivers behave during indecision zone maneuvers?" *Accident Analysis & Prevention*, vol. 96, pp. 274–279, 2016.

[25] H. Obeid, H. Abkarian, M. Abou-Zeid, and I. Kaysi, "Analyzing driver-pedestrian interaction in a mixed-street environment using a driving simulator," *Accident Analysis & Prevention*, vol. 108, pp. 56–65, 2017.

[26] L. Ābele, S. Haustein, and M. Møller, "Young drivers' perception of adult and child pedestrians in potential street-crossing situations," *Accident Analysis & Prevention*, vol. 118, pp. 263–268, 2018.

[27] F. Bella and M. Silvestri, "Effects of safety measures on driver's speed behavior at pedestrian crossings," *Accident Analysis & Prevention*, vol. 83, pp. 111–124, 2015.

[28] C. N. Boda, M. Dozza, K. Bohman, P. Thalya, A. Larsson, and N. Lubbe, "Modeling how drivers respond to a bicyclist crossing their path at an intersection: how do test track and driving simulator compare?" *Accident Analysis & Prevention*, vol. 111, pp. 238–250, 2018.

[29] I. G. Papanikolaou, D. Haidopoulos, M. Paschopoulos, I. Chatzipapas, D. Loutradis, and N. Vlahos, "Changing the way we train surgeons in the 21th century: a narrative comparative review focused on box trainers and virtual reality simulators," *European Journal of Obstetrics & Gynecology and Reproductive Biology*, vol. 235, pp. 13–18, 2019.

[30] G. Simpson, L. Johnston, and M. Richardson, "An investigation of road crossing in a virtual environment," *Accident Analysis & Prevention*, vol. 35, no. 5, pp. 787–796, 2003.

[31] A. Sobhani, B. Farooq, and Z. Zhong, "Distracted pedestrians crossing behaviour: application of immersive head mounted

virtual reality," in *Proceedings of the IEEE 20th International Conference on Intelligent Transportation Systems (ITSC)*, pp. 1–6, IEEE, Yokohama, Japan, October 2017.

[32] D. Sportillo, A. Paljic, and L. Ojeda, "Get ready for automated driving using Virtual Reality," *Accident Analysis & Prevention*, vol. 118, pp. 102–113, 2018.

[33] R. Fan, H. Yu, P. Liu, and W. Wang, "Using VISSIM simulation model and Surrogate Safety Assessment Model for estimating field measured traffic conflicts at freeway merge areas," *IET Intelligent Transport Systems*, vol. 7, no. 1, pp. 68–77, 2013.

[34] D. N. Lee, "A theory of visual control of braking based on information about time-to-collision," *Perception*, vol. 5, no. 4, pp. 437–459, 1976.

[35] M. M. Morando, Q. Tian, L. T. Truong, and H. L. Vu, "Studying the safety impact of autonomous vehicles using simulation-based surrogate safety measures," *Journal of Advanced Transportation*, vol. 2018, Article ID 6135183, 11 pages, 2018.

[36] P. Ag, *PTV Vissim 10 User Manual*, PTV Group, Karlsruhe, Germany, 2018.

[37] G. Yang, B. Jaeger, and R. R. Mourant, "Driving performance of novice and experienced drivers in lane-change scenarios," in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, October 2006.

[38] P. T. Victoria, *Tram Timetable in Victoria*, Victoria, Australia, 2019.

[39] A. Dosovitskiy, G. Ros, F. Codevilla, A. López, and V. Koltun, "CARLA: an open urban driving simulator," in *Proceedings of the 2017 Conference on Robot Learning*, PMLR, Mountain View, CA, USA, November 2017.

[40] B. Higgs, M. Abbas, and A. Medina, "Analysis of the Wiedemann car following model over different speeds using naturalistic data," in *Proceedings of the 2011 3rd International Conference on Road Safety and Simulation*, Indianapolis, IN, USA, September 2011.