EFFECTS OF READING TEXT WHILE DRIVING

ANALYSIS OF 200 HONOLULU TAXI DRIVERS ON A VS500M SIMULATOR

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAI‘I IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING

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SUMMARY

Although 47 US states make the use of a mobile phone while driving illegal, many people still use their phone for texting and other tasks while driving. The first purpose of this research is to summarize the large literature on distracted driving and compare major outcomes with those of our study. In this study, I have focused only on distraction due to reading text because this activity is most common. For this research project**,** we collected simulator observations and survey of 203 professional taxi drivers (175 male, and 28 female) working at the same Honolulu taxi company, using the mid-range driving simulator VS500M by Virage. After a familiarization period, drivers were asked to read realistic text content relating to passenger pick up displayed on a 7-inch tablet affixed to the dashboard.

The large sample size (N=203) of our study provides a strong statistical sample base for driving distraction investigation on a driving simulator compared to all but one of the previous studies. The comparison between regular and text-reading conditions revealed that the drivers significantly increased their headway (20.7%), lane deviations (353.9%), total time of driving blind (351.8%), maximum duration of driving blind (87.6% per glance), driving blind incidents (169.7%), driving blind distance (337.5%) and significantly decreased lane change frequency (35.1%). There was no significant effect on braking aggressiveness while reading the text. The outcomes indicate that driving performance degrades significantly by reading text while driving.

Texting is a distraction to driving a vehicle. The second purpose of this study is to provide additional insights on the association of demographic characteristics (age, gender, race, education, and driving experience) with driving performance while texting. The dependent variables generated by the simulator were: Average following interval (headway), line encroachment-incidents, lane change frequency, hard braking, and total time, maximum time, incidents, and travel distance of driving distracted. Correlation, analysis of variance and regression analyses were conducted. We considered three conditions: Control (No Texting), Texting and Change due to Texting. Our sample includes a large number of Asian and Asian-American drivers including Chinese, Japanese, Korean, Filipino and Vietnamese drivers, so ethnicity was modeled with dummy variables. Gender and some ethnicity variables have significant associations with driving performance outcomes, but driver age has the most significant associations with worsened driving performance under texting conditions. Drivers with higher levels of education seem to have a driving performance that is less affected by texting conditions. There are indications that drivers of Korean dissent may be somewhat more aggressive (shorter headways) and drivers of Vietnamese dissent may be somewhat more distracted than average (longer distance driving blind.)

Keywords: Headway, Lane deviation, Braking Aggressiveness, Lane Change, Driving Blind, Age, Gender, Race, Education, Experience, Simulator, Driving Performance

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CHAPTER 1- INTRODUCTION

1.1 GENERAL BACKGROUND

Distracted driving is seen as one of the major factors contributing to the rise in a number of injuries and deaths in the US. According to National Highway Traffic Safety Administration (NHTSA 2013b), more than 3,285 people died and more than 386,900 were injured per year due to distracted driving *(1).* In 2015, 3,477 people died and 391,000 were injured in motor vehicle crashes due to distraction *(2)*. NHTSA (2006) reported that 78% of crashes and 65% of near crashes occurred due to the most common distraction which is mobile phone use *(3).* Also, 87.7% drivers use a cell phone, but this is not evenly distributed: beginner drivers (50%) use more cell phones than experienced drivers (6%) while getting involved in accidents) *(4).* In terms of gender, 54% male and 46% female use cell phones in the USA while driving (*4*). According to Pew Research Center, 75% of U.S. teens have cell phones and they text while driving *(5).*

Drivers can be distracted by different uses of a mobile phone such reading text, writing text, dialing and conversing in handheld or hand free mode, listening to music, playing games, navigating, etc. In this paper, I have focused only on distraction due to reading text, because this activity is most common and necessary for taxi and delivery drivers. Text messages to taxi drivers are necessary for (1) giving detailed information, (2) can read it when it is safer to do so, (3) maintain privacy compared to audio, and (4) overcome the language barrier. At the same time the service of the taxi drivers is crucial (1) Who do not know how to drive, (2) Who do not want to drive, (3) Who are physically mutilated, (4) who do not have the personal car and do not want to take ride in public buses, (5) When people are planning to travel, (6) New arrival persons. So, wide range training and awareness about distraction among those valuable service providers is necessary for safe driving. Study on driving behavior of taxi drivers was not found in USA before our study. So, considering all these things, the author was inspired to conduct the scientific study on Honolulu taxi drivers using mid-range driving simulator Virage VS500M in Traffic and Transportation Laboratory (TTL) of University of Hawaii at Manoa, USA. The large sample size (N=203) of our study provides a strong statistical sample base for driving distraction investigation on a driving simulator compared to the driver sample size all but one of the previous studies.

1.2 GOALS AND OBJECTIVES

The goals of this research were to:

1. Study the distracted driving behavior while reading text for professional taxi drivers
2. Study the association of professional taxi driver demographics with driving performance

To achieve these goals the following objectives are carried out:

- Collection of demographic information of the drivers.
- Confirmation of standard driving simulator experimental setup, expert instructors, and professional taxi drivers.
- Determine what data can be collected from the simulator to measure the actual driving performance.
- Selection of data based on simulator maximum high-quality output that will be useful for finding effects and co-relation with driving performance.
- Identify which driving performance variable interacts more during distracted driving.
- Evaluate the overall driving performance based on analysis and compare with major findings from the comprehensive literature review.

1.3 THESIS OUTLINE

The thesis is grouped into six chapters. Chapter 1 has an introduction with goals and objectives of research. Chapter 2 contains detailed literature review, simulator features, history of simulator, uses, classification of simulator, advantages, limitations, effectiveness and popular driving simulator.

Chapter 3 describes on Virage VS500M simulator which has been used for this research project. In this chapter, working principle, features, advantages, barriers, and learning from major scenarios have been described in detail.

Chapter 4 presents the experimental procedure, research methodology, data collection and results obtained from VS500M simulator experiment using SPSS analysis. This chapter also has an important graphical representation of different driving performance parameters.

Chapter 5 covers the overall summary on results with past literature review and discussion. Chapter 6 demonstrates conclusions with limitations and future scope of research.

CHAPTER 2- LITERATURE

2.1 LITERATURE REVIEW

The main literature review section is divided into three parts: human factors, operations factors and Demographic association. Under human factors, ten driving performance indicators are discussed: Mean speed, speed fluctuation, reaction time, headway, lane deviations, lane change frequency, driving performance, looking away from road, control on vehicle, and braking aggressiveness. Under operations factors, three performance indicators are discussed: Vehicle collision, safety, and traffic flow. In total, 13 performance indicators have been measured under seven different types of distraction brought about by portable or in-vehicle communication devices: Handheld mobile conversation, hand-free mobile conversation, handheld mobile phone dialing, hand-free mobile phone dialing, text writing and text reading. In addition, literature on conversation with passenger is included. Summary tables show the variation of these indicators in past research, with respect to baseline conditions.

2.1.1 Human Factors

Drivers can be distracted by different uses of a mobile phone such as reading text, writing text, dialing and conversing in handheld or hand-free mode, listening to music, playing games, navigating, etc. Emily et al. showed that 60% of the respondents use their cell phones for reading and writing texts while driving; among them, 48% read texts, 33% wrote texts, and 43% people viewed a navigation map *(6)*. 91% of U.S. college students sent texts while driving *(7)*. Paul et al. reported that 98% young drivers send texts while driving *(8)*. Regan et al. found that 59.2% and 71.5% of young people wrote and read text message while driving *(9)*. Hosking et al. concluded that people aged between 18 and 21 kept their eyes off from the road while texting four times more compared with undistracted driving *(10)*. Also people aged under 30 and above 65 have a higher risk for secondary task related distractions than middle-aged drivers *(11)*. Lee et al. found that distracted driving affected 31 to 44-year-old people to a lesser extent compared to 60 to 70-year-old people *(12)*. Struckman-Johnson et al. found that males sent 1 to 5 sentence long texts while females wrote less than a sentence *(13)*.

The following summary focuses on specific driving performance parameters found in the literature: Mean speed, speed fluctuation, reaction time, headways, lane deviation, lane change frequency, looking away from road, control on vehicle, braking aggressiveness, vehicle collisions, and safety.

Speed control reflects the fact that drivers drive their vehicles above or below the speed limit or prevailing speed due to distraction. According to Schattler et al., handheld conversation resulted in significantly lower average speed and poor driving performance; it also yielded significantly higher improper lateral placement and twofold crashes compared to control conditions *(14)*. Along curves, distracted drivers choose a lower speed but on straight segments, distractions have negligible effects on the choice of speed *(15,16)*. When distracted drivers encounter a pedestrian at a marked crossing, they reduce their speed by braking aggressively *(17)*. Most of the reviewed articles found that handheld mobile phone users decrease their speed from baseline values during a conversation *(14-27)*. Stavrinos et al. showed that the fluctuation in speed during handheld conversation is very high *(28)*.

Hands-free conversation tends to decrease speed *(15,17,21-27,29)* but Patten et al. (*20*) and Rosenbloom *(30)* reported an increase in speed. Patten showed that the mean speed was bigger than baseline condition for both simple and complex conversation which was not statistically significant. According to Rosenbloom's on-road study, speed didn't change during short conversation but exceeded the baseline value when the driver had long conversations (more than 16 minutes). Kircher et al. (*23*) and Rosenbloom et al. *(30)* found that drivers perceived hand free phone conversation to be free of risk and that explains why they didn't reduce their speed. Decrease in speed has been reported during handheld phone dialing *(19,23,31)* and hand free dialing *(19,23,31)*. Text writing also results in a decrease in speed *(18,32,33)* and introduces more variation in speed *(28,34,35)*. Text reading results in a decrease in speed *(32,33,36)* and introduces more variation in speed *(34,35)*.

Reaction time represents how quickly a driver can respond to control the vehicle in a particular situation. All reviewed research came to the same conclusion about reaction time: it declined due to mobile phone related distraction during driving. Reaction time increased due to handheld conversation(*15,19,20,23,24,27,37–40*),hands-free conversation (*19,20,23,24,27,29,38,39,41,42*), handheld dialing (*19,23,27*), hands-free dialing (*19,23*), conversation with a passenger (*27,38,42*), text writing (*27,33,34,37,43,44*) and text reading *(32,33,34,44)*.

Headway is the time spacing between successive vehicles on the same lane. Kircher (*23*), Saifuzzaman (*25*), and Yannis et al. (*45*) demonstrated that for handheld conversation, there is an increase in headway. Kircher (*23*), Saifuzzaman (*25*), Caird (*27*) and Strayer et al. (*29*) found that headway increased due to hands-free conversation but Alm et al. (*41*) found that it was unaffected. Several authors found an increase in headway due to text writing *(10,43,44,46)* but Papadakaki et al. (*47*) reported a contrary outcome. Therefore, there is some disagreement on headway change due to distraction.

Lane Deviation refers to the deviation of a vehicle's centering along a lane. For handheld conversation, Schattler et al. (*14*) and Stavrinos et al. (*28*) reported a rise in lane deviations while

Törnros et al. (*19*) and Kircher et al. (*23*) reported the opposite. Haigney et al. (*22*) and Choudhary et al. (*48*) didn't find any effect of handheld phone conversation on lane deviations. Haigney et al. (*22*) and Alm et al. (*41*) found similar results for hands-free conversation whereas, Törnros (*19*), Kircher (*23*), and Papadakaki et al. (*47*) showed a decline in lane deviation. Lane deviation increased due to handheld dialing *(19)*, hands-free dialing *(19,23)*, text writing *(10,33-35,43,47-50)*, and text reading *(10,33-35)* but these outcomes are not consistent: Stavrinos *(28)*, and Boets et al. *(32)* did not observe any change in lane deviations for text writing, and for text reading, Papadakaki et al. found a reduction *(47).*

Lane Change Frequency refers to the number of instances where drivers relocate from their current lane to an adjacent lane. Fitch et al. *(51)* concluded that handheld conversation will stimulate the drivers to change the lane more significantly than the baseline condition (10% versus 4%). Choudhary et al. *(48)* found handheld conversation to have no impact on lane changing action. On the other hand, Stavrinos et al. *(28)* found a decrease in lane change frequency during handheld conversation. Beede et al. *(52)* found that lane change frequency decreased during hands-free conversation. Choudhary et al. (*48*) reported an increase in lane change frequency while writing texts but Stavrinos et al. (*28*) didn't find any change in lane change frequency while drivers were writing text. For text reading, all reviewed literature showed a common finding of increasing lane change frequency *(10).*

Driving Performance has been measured based on one or more of these variables like speed profiles, reaction time, vehicular lateral placements within travel lanes, spacing between surrounding cars, stimulus detection and response, number of crashes, and overall performance score. After evaluating multiple different behavioral parameters, all reviewed articles

(14,15,19,22,26,28,29,35-37,39,42-44,46,48,49,52-55) came to the common conclusion that driving performance deteriorates for all the distracting activities discussed so far.

Looking Away from Road refers to a driver's engagement in secondary tasks which reduce their visual and cognitive attention from the road traffic. Fitch et al. *(51)* found handheld conversation, and Hosking (*10*), Boets (*33*), Rudin-Brown (*35*) and Young et al. *(36)* identified text writing and reading as sources of distraction that lead to a decline in attention on the road.

Control on a Vehicle means keeping the vehicle within a lane with respect to other vehicles, situational awareness, and overall control. Schattler (*14*), Rudin-Brown (*35*), Peng (*46*), Choudhary (*48*), Ranney (*56*), Muttart (*57*), and Hagiwara et al. (*58*) showed that vehicle control worsens when drivers use mobile phones. For hand free conversation, Beede et al. *(52)* did not find any change in control on the vehicle.

Breaking aggressiveness refers to impulsive or harder braking by drivers. Aggressive braking occurs when the drivers are engaged in secondary tasks and they respond to a situation by a delayed and more acute response. Braking aggressiveness has been found to increase both for handheld conversation (*17*) and hands-free conversation (*17,57*).

2.1.2 Operational Factors

Vehicle collision is the ultimate risk of distracted driving which results in damages, injuries and loss of life. Distraction-related motor vehicle crash is found to be greater among novice drivers than experienced drivers *(59).* Many researchers found an increase in collision for handheld conversation *(14,18,60,72),* hands-free conversation *(29,41,52,54,57,60),* conversation with a passenger *(54),* text writing *(10,18,28,35,44,49),* and text reading *(10,33).*

Safety was found to decrease *(17,22-24,28,50,60)* for all kinds of distracting activities like handheld conversation, hands-free conversation, hands-free dialing, text writing and text reading. A summary of the literature review is given in Table 1.

The number of participants in mid to high level driving simulator studies reported in the literature is as follows:

- up to 20 *(10,21,53,54)*
- 21 to 40 *(14-17,20,22,24,25,29-32,34-36,38,41,43,44,46,50,52,56)*
- 41 to 60 *(19,26,39,42,47,49)*
- 61 to 80 *(23,28,33)*
- 100 to 120 *(18,37,48,54)* and,
- 559 *(27)*.

The large sample size (N=203) of our study provides a strong statistical sample for the investigation of distractions to driving on a driving simulator compared to all but one of the previous studies.

Table 1. Effects of Communication Devices and Other Distractions on Driving Tasks

	Performance Indicator	Handheld Mobile Conversation [I]	Hand-free Mobile Conversation [II]	Phone Dialing [I]	Phone Dialing [II]	Conversa-tion with Passenger	Text Writing	Text Reading
Human Factors	Mean Speed	↓14,15,16,17,18,19,20, 21,22,23,24,25,26,27	↑20; —23; ↓15,17,21,22,23,24,25, 26,27,29	↓19,23, 31	↓19,23, 31		↑36; ↓18,32,33	↓32,33,36
	Speed fluctuation	↑28					↑28,34,35	↑34,35
	Reaction Time	↑15,19,20,23,24,27,37, 38,39,40	↑19,20,23,24,27,29,38,39,41,42	↑19,23, 27	↑19,23	↑27,38,42	↑27,33,34,37,43,44	↑32,33,34,44
	Headway	↑23,25,45	↑23,25,27, 29; —41; ↓47				↑10,43,44,46; ↓47	↑10,46; ↓47
	Lane deviation	↑14, 28; —22, 48; ↓19,23	—22, 41; ↓19,23,47	↑19	↑19,23		↑10,33,34,35, 43, 47,48,49,50; —28,32	↑10,33,34, 35; —32; ↓47
	Lane Change Frequency	—48; ↓28	↓52				↑48; —28; ↓10,28	↓10
	Driving Performance	↓14,15,19,22,28,37,39,48	↓19,22,26,29,39,42, 52,53,54,55	↓19	↓19	↓26,42,54,55	↓35,36,37,43,44,46,48,49	↓35,46
	Looking away from road						↑10,33,35,36	↑10,33,35,36
	Control on Vehicle	↓14,48	↓57; —52				↓35,46,48	↓35,46
	Braking Aggressiveness	↑17	↑17,57					
Operational Factors	Vehicle Collisions	↑14,18,60; —22, 28	↑29,41,52,54,57,60; —22			↑54	↑10,18,28,35,44,49	↑10,33; —32
	Safety	↓17,22,23,24,60	↓17,22,23,24,60		↓23		↓28,50	
	Traffic Flow						↓28	

Key: ↑= An increase; ↓= A decrease; —= No Effect; 1, 2, 3 ………….60= Reference

2.1.3 Demographic Association

Distracted drivers are associated with 10% of all fatal crashes and 15% of all injury crashes. Drivers 15 to 19 years of age were involved in 9% of fatal crashes due to distraction. Indeed, teenage drivers and their passengers have more severe injuries while being distracted by a cell phone (*61*).

Many researchers have looked into the effects of sociodemographic descriptors; most of the attention has been focused on age. Relatively recent findings related to our investigation on texting are summarized below; we limited our backward search to about year 2005 when the first fully featured smartphones with email and texting started selling in large numbers. Ayalon et al. (*62*) found that speed selection was influenced by both age and gender. Yannis et al. (*45*) reported that young drivers have been reduced speed significantly under all traffic condition while using a mobile phone. Horberry et al. (*63*) found that both male and female tend to reduce speed when engaged in a distracting activity; younger drivers traveled at a faster mean speed than older drivers. Bao et al. (*64*) reported that older drivers (60 to 70) have a larger lateral control variation than age groups 20 to 30 and 40 to 50 during visual-manual tasks. Rumschlag et al. (*49*) reported that lane deviation was significantly correlated with age but there was no significant correlation with gender while texting. The effects of texting on driving performance are worse for the older drivers (*49*). Choudhary et al. (*65*) found that age and gender influenced a number of lane excursions while texting. Guo et al. (*11*) noted that drivers aged 30 to 64 years are less affected by a secondary task than teenagers, young adults, and senior drivers. Jean et al. (*66*) reported that older drivers were more cautious in using advanced traveler information system (ATIS) (e.g., navigation assistance) whereas younger drivers were less careful about ATIS use and driving performance. Ikeda (*67*) noted that older drivers (60+) have a longer detection time than younger drivers (15 to 25) and middle-aged drivers (35 to 45), but the older drivers exhibit a shorter judgment and operation time when an accident is imminent. Jonas et al. (*68*) reported that older adults (averaging 64 years of age) have a greater divided-attention effect on reaction times compared with younger adults (averaging 23 years of age). The same research found that older adults were 27% slower in a choice reaction time, 46% slower in a simple reaction time task with increased visual complexity than that of the younger adult group (35 to 45 years of age).

Sun et al. (*4*) deployed field survey interviews and reported that driving safety was influenced by gender, age, driving experience and cell phone use intensity. According to Mustapha et al. (*69*), older drivers have more degraded dividing and selective attention, leading to a greater crash risk compared with younger drivers. Armeli and Tennen (*70*) reported that novice drivers are engaged more in high-risk secondary tasks over time than experienced drivers; as a result, novice drivers have a significant crash risk or near-crash risk while distracted by cell phone use or any other activities during driving. Liu and Ou (*71*) reported that the performance (i.e., acceleration, lane deviation, reaction time and accuracy) is affected significantly for older drivers than for younger drivers while using a hands-free mobile phone; also, young drivers are accurate 96.3% while older 66.3% during divided attention activities. Strayer et al. (*29*) reported that the driving performance of both younger and older adults was affected by cell phone conversation.

Hosking et al. (*10*) found that driving performance while texting worsened as follows: Time of not looking on the road 400%, lane position variability 50%, missed lane change 140%, and following distance variability 150%. These dimensions of performance are similar to those in our tests. Overall, the recent literature on driving distractions and association with sociodemographic characteristics has focused on effects of age, with occasional results about gender. The effects of race and ethnicity, education status of drivers and their driving experience are unknown. Our relatively large sample and detailed sociodemographic characteristics of 203 taxi drivers tested on a driving allow us to look into more potential associations, some of which turned out to be statistically significant.

2.2 DRIVING SIMULATORS

Driving simulator is a device that have the original car set up and driving scenario to test and develop a whole car setup, to optimize driving skills and to learn new tracks.

Before the WW-II, history of driving Simulator had been started. Flight simulator appeared as the first simulator for training purposes to reduce the operational cost than actual equipment. Flight simulator with high fidelity was designed for effective training purposes and "as phony as it can be” flight simulator was designed without considering training effectiveness *(73).* In late 1950’s highway simulators were developed and in the early 1960’s, it was operated for the first time *(74).*In mid-1960’s highway driving simulator usage was decreased due to lack of visual display and computer technology but it was overcome in late 1960 *(75).*NASA developed a lot of new technologies to conduct their space program which also accelerated highway simulation technics in USA by 1975. At that time 16 driving simulators were using different technologies to create a visual scenario. Only two driving simulators were functional in Europe by that time. One from SAAB and another from VW using electric image *(74).*

In last 40 years, a lot of improvements have been happened in the innovation of modern driving simulator to reduce the training cost, understand driving behavior at different road environment, make it environment-friendly, make more effective, attractive for training and research purposes. In driving simulator, now researcher can control the environment with a high degree of realism of driving environment compare to past.

Driving simulator has four key elements- i) Modified car ii) Visual system iii) Motion system iv) Audition

i) **Modified Car:** Most of driving simulator car is modified by removing motor, drivetrain and running to make it simple and cost saving. Rear or front or top of the car can be also removed like TNO, VTI and MAZDA driving simulator *(75).* Others all instrumentations (steering wheel, brakes, gas pedal, transmission, and speedometer) should feel real. Secondary options like radio, hazard, flash, air-condition and an extra fan to make open window environment etc. are only instrumented if the training company or research teams feel necessary.

ii) Visual System: To point light source, cathode-ray tubes are using and computer graphics imagery (CGI) is forming using film techniques. The combination of these two systems is producing advanced visual system. Southern California Research Institute used first visual generation system in driving simulator *(76).*

Currently graphics or animation model and projection system are widely using to create a visual system in a driving simulator. High regulation visual system is crucial to conduct traffic-related research as it widely depends on visual information. Kemeny and Reymond *(77)* reported that 1000 X 1000 pixels resolution per channel is necessary to produce traffic and road network details correctly.

iii) Motion System: The motion system basically depends on the cost of device. High-cost motion system has a dome with a car cab which is mounted on hydraulic actuators. The motion system may be effective for whole car or part of the car with three to six degree of freedom, for instance, Daimler-Benz, and Iowa driving simulators. On the other hand, low-cost driving simulator comprises with hydraulic rams that are fitted into four wheels of the car cab. This type of simulator usually has roll, pitch, and heave, for example, TRL, Autosim driving simulators. The response time should be limited in each direction 20-40 ms to avoid overall transport delay *(75).* Nordmark *(78)* reported that to avoid interference between human perceptions about lateral acceleration and roll, roll motions should be less than or equal to 3 degrees per second.

iv) Audition: It is the idea of people that simulated car having speed and others traffic related sounds will make it more real. But Devis and Green *(79)* reported that there is a small improvement in driving performance while providing sound effects. It was also found that providing more sound effects degraded the driving performance than only speed-related sounds. So, simulation of sound in driving simulator has a lesser effect on overall driving performance.

2.3 CLASSIFICATION OF DRIVING SIMULATOR

Driving simulator can be classified into two categories based on use-

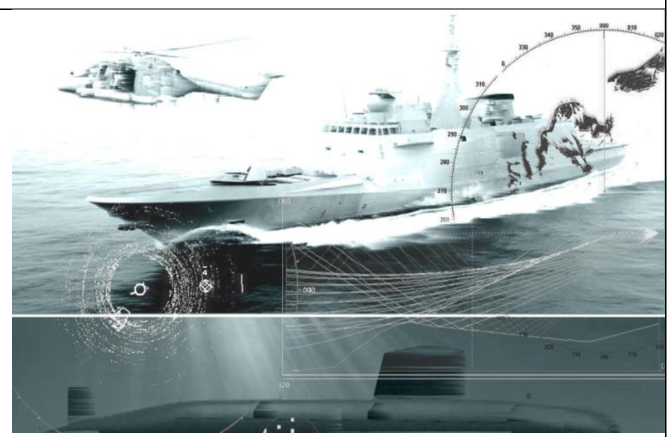
i) Training Driving Simulators
ii) Research Driving Simulators

i) Training Driving Simulators: This type of simulator started its journey after WW-II *(80)***.** It was used for military training to teach how to operate a tank, a ship, and an aeroplane. The reason for using simulator was the cost-effective technology as well as safety. It can also be used for training drivers and make them perfect before going to an on-road test. However, before using any kind of driving simulator, validation is required to compare the results with real-world conditions. Figure 1 shows the image of some training simulators.

Training Simulation

Merchant Maritime Training

Aviation Simulation



Naval Forces Training

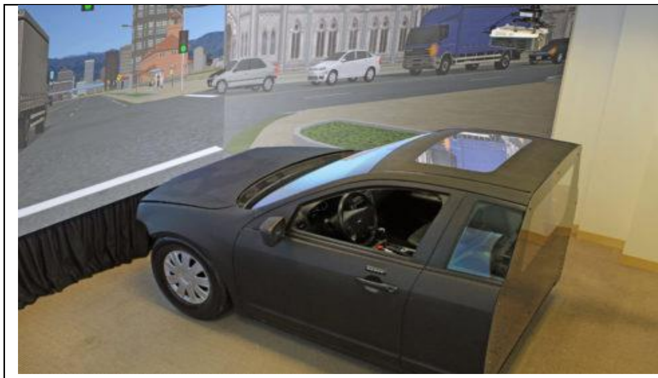
Training for Fire Fighting

Military and Law Enforcement Simulation

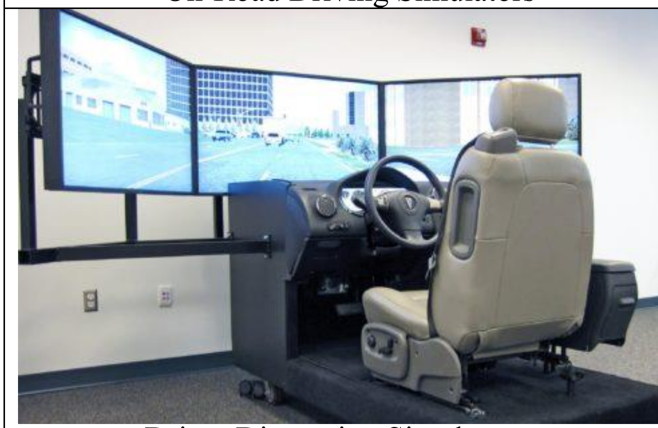
Figure 1: Different Type of Training Simulator *(72, Google)*

ii) Research Driving Simulators: Digital computer-generated image processing system with a fixed base or moving base research simulator are using widely in USA and Europe nowadays. See figure 2 for some research simulators. Research simulators can be used for the following purposes:

a) To investigate effects of existing or non-existing road-infrastructures on design.
b) To study the behavior of drivers in the interaction of different road and traffic environments.
c) To study the effectiveness of signal controlling systems before implement of real project.
d) To obtain the knowledge before passed the laws related to driver and vehicle and consider research results as the assessment criteria.
e) The simulator research is cost and time-saving. So, it can be used effectively for the trial of highly innovative research projects where there is some doubt about the successful realization and large cost.


On-Road Driving Simulators


Off-Road Driving Simulators


Driver Distraction Simulator


Modular Driving Simulators


Desktop Driving Simulator


Entry Level Driving Simulator


Research Bike Simulator

Figure 2: Different Types of Research Simulators ***(72, Google)***

Driving simulators can be classified into three categories based on cost, as follows.

i) Low-cost Driving Simulators: This type of simulator has inexpensive graphics display. It is normally used for students and dissertation-related projects, vehicle manufacturers and part suppliers who are finding to support research with limited budgets. The following are the detail features of low-cost driving simulators- 1) Color Projection System; 2) Buck with passenger car seat; 3) Steering wheel, brake and accelerator control; 4) Scene display; 5) Fixed-base, cabs and torque motor; 6) Two degrees of freedom motion system (roll and pitch); 7) Supervisor Computer/Model: power PC processor 601, Onyx; 8) Driver training, safety aspects; 9) Manufacturer: Apple Macintosh and SGI; 10) Resolution 640x480 front, 8-bit color depth; 11) Screen Radius Shape 2.5m x 3.7m;.

The PC based Systems Technology Inc. driving simulator

The desk-top Systems Technology Inc. simulator within-vehicle navigation

The Autosim driving simulator

Figure 3: Low-cost Driving Simulators *(75, Google)*

ii) Medium-cost Driving Simulators:

This type of simulators creates real type of animation scene in front of drivers on a large projection screen. The system should also include full-size complete vehicles with all normal controls. The features of medium cost driving simulators are: 1) Maximum Six degree of freedom, SGI power 4D/420; 2) Screen radius shape flat, curved, cylindrical and compound curve; 3) Maximum screen size 3m x 4m; 4) Maximum screen distance from driver head 3m; 5) Maximum Resolution 1280 x 1024 pixels; 6) Maximum angular field of view (AOV): H210, V40; 7) Maximum number of channels 4; 8) Maximum frame rate variability 20-60 HZ; 9) Maximum throughout delay variability 10-50 ms.

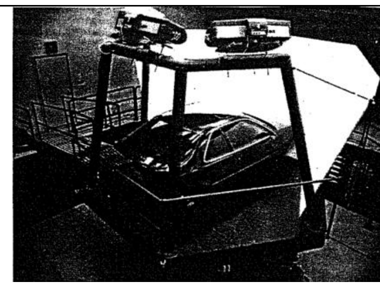
The FORD driving simulator


The FIAT driving simulator


The BMW driving simulator


The Leeds Advanced Driving Simulator


The Transport Research Laboratory (TRL) driving simulator


The DRI driving simulator

The RENAULT driving simulator


The TNO driving simulator

Figure 4: Medium-cost Driving Simulators *(75, Google)*

iii) High-cost Driving Simulators

In terms of cost, this type of simulator is costlier than the previous two types of simulators, but it has a lot of advanced level of features. The characteristics of high-cost simulators are as follows: 1) 360 degrees field of view; 2) An extensive moving base; 3) It is built using the aircraft flight simulators technology; 4) The translational motion capability can be greater than 2m; 5) Degree of freedom from 12-37 degree; 6) Frame rate variability 30-60 HZ; 7) Throughout delay

The National Advanced Driving Simulator

The Daimler-Benz driving simulator

The VTI driving simulator

The FHWA (HYSWI) driving simulator

The General Motors (GM) Driving simulator

The MAZDA driving simulator

The JARI driving simulator

The IOWA driving simulator

Figure 5: High-cost driving simulators *(75, Google)*

Variability 40-124 ms; 8) Minimum Resolution 1024 x 875; 9) Minimum angular FOV: H35, V20; 10) Maximum angular FOV: H190, V60: 11) Screen Radius shape: continuous sphere, curve, dome, flat screen and widescreen; 12) Maximum screen distance 4 m; 13) Nonlinear kinematics and elasto-kinematics of axles and steering system; 14) A wide-angle visual system, a vibration generator system, a sound system and a temperature regulating system; 15) The road is defined by algorithms and random numbers where the control parameters define the type of the road, instead of specific road data.

2.4 USERS OF DRIVING SIMULATORS

Driving simulators are widely being used for research as well as for training purposes. The following are the specific organizations that are using driving simulators- 1) Taxi Company/Private Business; 2) Individual; 3) University/Educational Institute; 4) Private Research group 5) Medical College/Hospital; 6) Military; 7) Rehabilitation Centers; 8) Driving Schools; 9) Police for high school driver safety programs; 10) Youth Detention Centre for traffic offender programs; 11) Others organization for specialized training (snow plow, refuse truck etc.)

2.5 ADVANTAGES OF DRIVING SIMULATORS

Driving simulator has plenty of advantages in terms of safety, fuel consumption, maintenance, and repair, crashes, training quality, cost and time saving. De Winter *(81)* et al. reported that driving simulator have benefits such as controllability, reproducibility, standardization, easy data collection, novel opportunity for feedback and instruction. They have also mentioned that without any kind of physical risk, dangerous driving conditions can be overcome easily in driving simulator. According to the requirements of research and training, traffic, weather and road layout can be designed in the simulator which is costly, time consuming and sometimes impossible in reality. In driving simulator, trainee has the opportunity to practice wide number of dedicated maneuvers per unit time as the scenarios can be developed based on purpose. The different participants are also able to practice the same scenarios under same traffic, road-infrastructure and weather conditions. Wassink et al. presents software technology that can produce dynamic scenarios in driving simulator *(82)*. In real road, data collection for research is costly, time consuming, risky and laborious, but this work can be done accurately and effectively using driving simulator. Hoeschen et al. reported that simulator is perfect for handling uncertainty or safety-critical tasks which is not appropriate in the real road, for instance collision avoidance or risky driving *(83)*. Flach et al. stated that simulators "offer an opportunity to learn from mistakes in a forgiving environment" *(84)*. Allen *(85)* et al. presented that "Motor vehicle crashes are significantly higher among young drivers during the first year of license, and crash risks decline with increased experience". To overcome this dilemma driving simulator is the best option to give training and make expert drivers without any crash. Vlakveld *(86)* et al. reported that simulator is the easy way to provide feedback and instructions that is not easily achieved in real vehicle. As in simulator, it is possible to freeze, reset and replay a scenario based on requirement. All these feedbacks and instructions even can be presented in visual overlays along with speech to highlight the critical features.

2.6 LIMITATIONS OF DRIVING SIMULATORS

De Winter *(81)* et al. summarized that driving simulator have limited physical, perceptual, and behavioral fidelity. Käppler *(87)* stated that original risk and consequence of actions never happen in driving simulator. It only gives rise of a false sense of safety, responsibility or competence. Lee *(88)* and Reed *(89)* et al. found that although in some cases subjects are deviating from its target, driving simulator is producing valid results. Evans *(90)* has raised a question that what experiment can be performed to improve our knowledge level about make-believe equipment. He has described driving simulator as the make-believe because only reset button instantly can erase all damages to people and equipment. De Winter (*81*) et al. reported that validation of simulator sometimes is easy due to lack of on road research outputs. Simulator may make people sick, undermine training effectiveness, and adversely affect the usability of simulators *(91).*

2.7 EFFECTIVENESS OF DRIVING SIMULATORS

After reviewing numerous driving simulator validity studies, Mullen *(92)* et al. stated that driving simulator are valid for measuring relative driving performance under speeding, road position, divided attention as well as traffic violations and crashes. Lang *(93)* et al. reported that all used simulators were appropriate 95% for novice, 85% for experts, 35% for instructors, and 30% for elderly or disable drivers. They had also found that simulators were appropriate 95% for vehicle control, 90% for maneuvering in traffic, 40% for goals for driving and 20% for goals for life.

2.8 MAJOR DRIVING SIMULATOR SUPPLIER COMPANIES

The following companies *(94,95)* are active in manufacturing Driver Simulators:

1. Simworx, Australia
2. RSEAT Ltd., Bulgaria
3. Virage Simulation, Canada
4. Beijing Sunheart Simulation Technology L, China
5. Foshan World Safety Technology Co., Ltd., China
6. Great Gold East Network Technology Co., Ltd., China
7. Sun heart Simulation Technology Co., Ltd., China
8. World Safety Technology Co., Ltd. in China
9. ECA Group, France
10. Speedmaster, Germany

11. ADH Labs Pvt. Ltd, India
12. Car Driving Simulator, India
13. Faros Simulation System, India
14. Tecknotrove in India
15. Global Pronet, Japan
16. Neo Information Systems Co., Ltd., Korea
17. JAYONIK MSC SDN. BHD, Malaysia
18. Lasting Power Trading Co., Taiwan
19. XPI Simulation in UK

2.9 POPULAR DRIVING SIMULATOR FOR RESEARCH

Some research organizations use their self-manufactured driving simulators. But a few simulators have become popular for research purposes. These are listed below alphabetically.

1. AMOS II (14)
2. Aston Driving Simulator (ADS) (22)
3. BRSI STISIM3 (33)
4. CRISS *(15)*
5. CARRS-Q *(16,17,24,25)*
6. EACPHS (49)
7. MUARC (35,36)
8. NADS MiniSim (46)
9. PatrolSim (29,44)
10. STISIM (28,32,52,55)

11. TRL (21)

12. VTI *(19,20,23,26,41)*

13. VS500M (47)

14. XPDS 300, Version1.6 *(34)*

CHAPTER 3- THE VIRAGE VS500M SIMULATOR

3.1 WORKING PRINCIPLES

The VS500M driving simulator consists of an open cabin cockpit with center console of a car with braking, acceleration, steering control and other instrumentation as a mid-2000 model year GM passenger car. The visual optical system consists of a five-channel PC-based high-quality graphics (1920x1080 pixels per front display) generator with three 55-inch LCD displays that provide 180-degree front view with 3D sound. It was equipped with a high fidelity 5.1 surround sound which provides realistic directional sound cues associated with road traffic conditions, engine RPM and speed of vehicle. Sounds coming from other vehicles have been simulated based on Doppler Effect to create additional reality. A compact three-axis platform with electric actuators, high fidelity vibration system with motion cues at frequency up to 100 Hz provides acceleration cues, engine vibration and road texture feedback as a function of the car speed and road surface. The system has a suite of sophisticated diagnostics and it requires self-inspection and calibration at the beginning of its booting, to ensure that the operation of and the outputs from every session are reliable. Moreover, rear view and side view mirrors are simulated through a window inset within the main screen. The simulator stores the records of driving performance indicators on a computer hard drive. The Virage VS500M Simulator is a medium cost driving simulator which can be used for training as well as research purposes. Driving schools, Universities and other organizations can use this device for their designated purposes. Different types of scenario are already available based on the requirement of training for beginner to expert drivers. For research purposes, scenarios can be developed based on requirement of research.

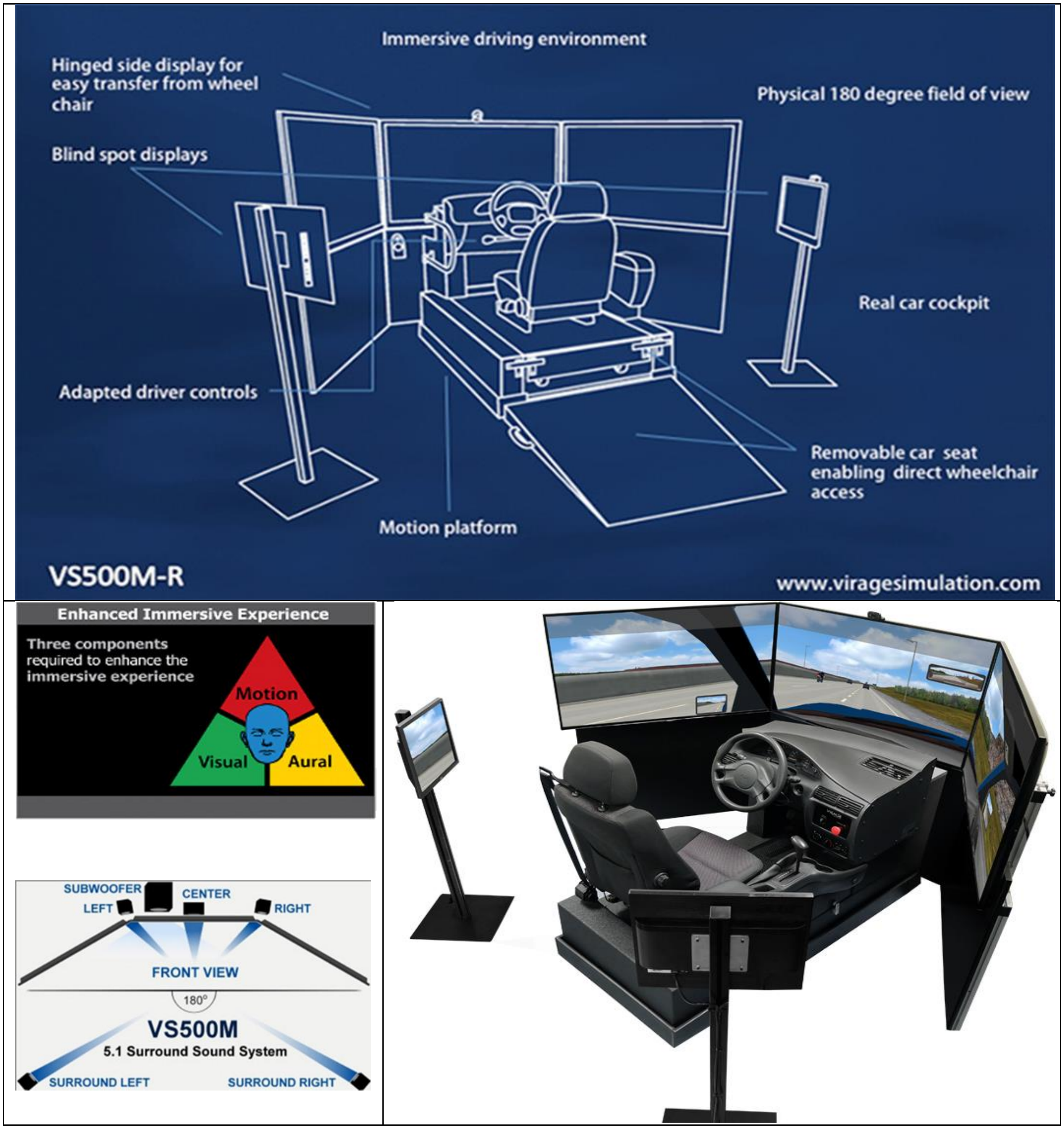


Figure 6: Car Driving Simulator – VS500M

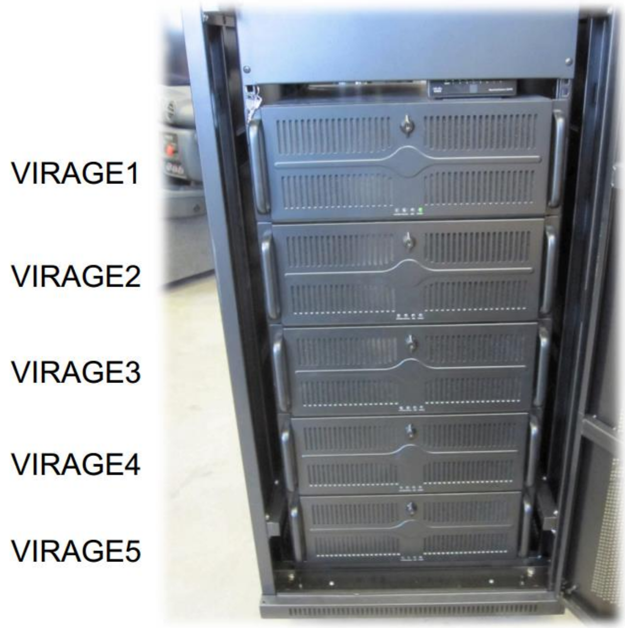


Figure 7: Virage Five Server Computers

The process of starting of simulator begins with calibration when car ignition should be kept in "RUN" position. Then VIRAGE 1 computer should be started, and the Virage logo will be displayed at the middle of VIRAGE2, VIRAGE3, VIRAGE4, and VIRAGE5 computer screens. After auto calibration, steering should be rotated completely right and left. Then, the instructor should select student and instructor name from "Log On' screen option. The default language of the simulator is English but other languages can be also selected. After that, instructor should click on "Start" button to see the available scenarios in the display on operating monitor. At the very starting of the experiment, Morning readiness scenario 0.1 should run to ensures that all categories pass with a green check. At this stage, Simulator is ready to run any scenario for conducting training or research. After finishing the training, simulator should be shut down by clicking "Log Off" followed by "Operator Station" and "Stop".

3.2 ADVANTAGES

Following are the advantages of the VS500M simulator-

- It has pre-established scenarios for each learning task.
- Its wide variety of scenarios has been designed for all groups of learners i.e. novice, experienced, confident and nervous learners.
- It prepares learner for practical driving lessons.
- It has the option i.e. driving practice with or without a teacher and evaluation process.
- It provides reliable and objective feedbacks for both students and teachers.
- Environment, traffic, and coefficient of friction can be controlled.
- Record and replay features are available.
- Green technology i.e. zero greenhouse gas emission.
- 180^0 field of view, 3D sound, and 6 degrees of freedom.
- Simulator provides almost virtual reality for effective learning with its high fidelity technology.

3.3 LIMITATIONS

The limitations of VS500M Simulators are listed below.

- The brake and steering are slightly different from real road cars.
- In some cases, ending of scenarios after first crashing i.e. "Don't Text and Drive" Scenario
- Ghost crashing in some scenarios i.e. "Distraction and Crash Risk" scenario.
- Open cab car which does not have a full setup of vehicle.
- Ignition system (instead of a switch) which is very uncommon nowadays.
- Lack of high traffic density scenarios.

- Creation of custom scenario is costly and time-consuming.
- Unstandardized programming of some output data which is not usable for research purposes.
- VS500M simulator is not designed for wide research purposes.
- It does not have 360^0 field of view with 12 degrees of freedom.

3.4 LESSIONS FROM MAJOR SCENARIOS

The two major scenarios were used for adaptation and experimental purposes. The observed learnings from these two scenarios are described below:

Distraction and Crash Risk (Time: 5 mins or more, Context: Urban Highway)

- How to merge onto a busy highway with a speed limit of 60 mph
- How to change lane safely and keep up with traffic
- How to apply the brakes at the appropriate time to avoid a collision
- The driving experience in sunny, rain, fog, windy, day and night time.
- Getting an idea about crash cost
- How to pull over the vehicle on the shoulder safely
- Understanding about applying hard brake will increase the possibility of a rear-end collision

Distracted Driving – Texting (Time: 10mins or more, Context: Expressway)

- Understanding the danger of divided attention.

- A better understanding of the reduction of speed, increasing of surrounding space of driving vehicle compared with other traffics, controlling of steering movement while distracted by any means.
- Understanding the interaction between road configurations and the geometric elements.
- Understanding the importance of longer headway for safety while doing a secondary task.
- How to reduce lane deviation while distracted by an additional task.
- A better understanding of the danger of changing a lane while distracted.
- How to avoid unexpected and urgent braking action while drivers are distracted by mobile texting.
- Good head position while driving and where should they focus on driving.
- How to control the vehicle when driver's head position glances away from the road ahead.
- How to improve the driver's ability to observe the road environment complexity ahead of his vehicle.
- How to keep up with traffic.
- Driving on an empty stomach may make them sick.
- How and when they need to check the side and rear view mirrors.
- Reading text is dangerous while driving.
- How they should deal with mobile phones in vehicle while driving.
- To read or write text, they should pull over on the shoulder or do it while stopped at an intersection.

- How to bring the vehicle under control when it is out of control.
- Improve awareness about using a seat belt.

CHAPTER 4- ANALYSIS AND RESULTS

4.1 RESEARCH METHODOLOGY

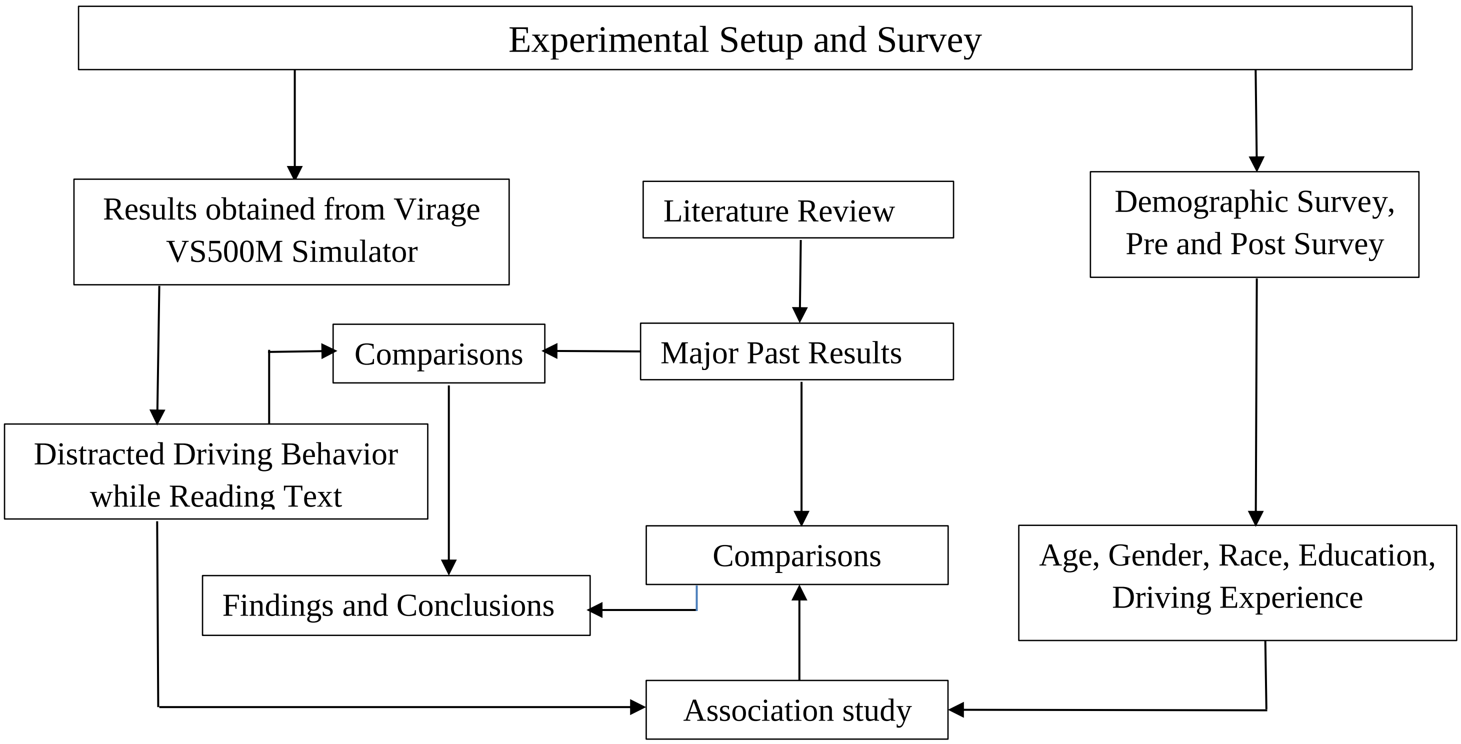


Figure 8: Flowchart of the Methodology of Research

4.2 OBJECTIVES

The main objectives of this study were to know the unknown truth about distracted driving behavior of professional taxi drivers. To uncover the unknow driving behavior of subjects, driving simulator experiments were conducted on professional taxi drivers while driving and reading text. There were two main goals as mentioned in chapter one, (1) Study the distracted driving behavior while reading text for professional taxi drivers and, (2) Study the association of professional taxi driver demographics with driving performance. To fulfill the research objectives, experimental setup, skilled instructors, delicate filtering of data and standard survey were ensured.

4.3 EXPERIMENTAL SETUP

The typical process for each driver progresses along these steps: First, the drivers were greeted by the UH team and the human resources representative of Charley's Taxi who verified their basic data. Then each driver participated in an online traffic survey before the simulator experiment took place; this survey also collected their demographic characteristics. Both survey and simulation results were linked with each driver's Charley's Taxi four-digit unique code. Driver names were not recorded by the research team. Once the survey was finished, they were given information about simulation sickness and adaptation to the video. Then, each driver drove for 10 to 12 minutes to adjust to the feeling of the steering, accelerator and braking of the simulator, and overall driving feel on the simulator.

Figure 9: Driving Simulator Used for Text Reading and Driving Study.

Once the adaptation was complete, the next scenario which involved distracted driving was explained to each driver. Then, they were asked to start for a driving and reading texts scenario which lasted up to 9 minutes. Approximately past the half point of this scenario, a roadside billboard displayed "TEXTING ZONE BEGINS" and soon after this point the driver needed to read the first text message. The trainer reminded them to read two more texts prior to completing the scenario. At the end, they had to fill out another form about their driving experience with the driving simulator.

A 7-inch tablet was used for text reading. The tablet was placed on the right-hand side the driver at the center stack of the dashboard. In this study, three texts, related to traffic and passenger information, were selected to be read while driving. The texts were delivered to the driver in approximately one-minute intervals. During each reading, their eyes and head movements were monitored using the webcam placed at the top of the simulator screen. The three text messages were as follows:

1. “Nobu Honolulu, Traditional Home-Style Restaurant, located at 1118 Ala Moana Blvd”
2. “Time: 14.30, Name: John Niles, Phone: 808-330-7619, Pick up: 3473 Waialae Ave, Passengers: 5”
3. “Heavy traffic in Makiki, much slower than usual, delays of up to 30 min. Congestion on the H201 west”

These texts were selected based on real-life text messages received by Honolulu taxi drivers. At the end of the third segment, an instruction appeared on the screen and asked the driver to move to the side of the road and stop the engine which was the conclusion of the driver’s testing and training. During the distraction scenario, feedback or other conversation by the trainer was kept to a minimum, which was the reminders to read text messages 1, 2 and 3

4.4 DATA COLLECTIONS

All the data collection was conducted at the Traffic and Transportation Laboratory (TTL) at the Department of Civil and Environmental Engineering of the University of Hawaii. A new VS500M driving simulator manufactured by Virage Simulation Inc., Canada and owned by Charley's Taxi and Limousine, the oldest taxi company of Honolulu Hawaii, was used. It was installed in the TTL in March 2018 by a manufacturer's representative, and tested Virage's chief scientist who also provided several train-the-trainer sessions on the proper use of the simulator and its scenarios. The system has a suite of sophisticated diagnostics and it requires self-inspection and calibration at the beginning of its booting, to ensure that the operation of and the outputs from every session are reliable.

4.5 PARTICIPANTS

All 203 participants were professional taxi drivers from Charley's Taxi and had a valid driving license. The drivers volunteered their participation for training and research purposes as well as continuing education insurance credits, and most were tested on Sundays to minimize the impact on their income. All subjects were capable of speaking and reading English; for over one half of the subjects, their mother tongue is other than English. Among the total of 232 drivers, 29 drivers or 12.5% of the sample were sensitive to simulation sickness; they quit the experiment without completion of the familiarization and distraction scenarios. For this research, five different demographic characteristics (Age, Gender, Race, Education, and Driving Experience) were considered that was obtained from the above-mentioned systematic survey. The 203 participants were categorized into seven age groups. There was 28 female (13.8%) and 175 male (86.2%) participants. The race of participants included Asian Indian, Bangladeshi, Black or African American, Chinese, Chinese-Korean, Eritrean, Filipino, Japanese, Japanese-Korean, Korean, Native Hawaiian or part Hawaiian, Other Asian, Other Asian-Nepalese, Other Pacific Islanders, Samoan, Vietnamese, and White. Five races had a relatively large number of participants, (Chinese (N=24), Filipino (N=20), Japanese (N=27), Korean (N=79) and Vietnamese (N=19). The participants reported their education level into six categories. The driving experience of all subjects was also collected to check the association with driving performance.

Table 2: Demographic Characteristics of Participants

Factors	Value Level	Mean	St. Dev.	Number of Participants (N)	Percentage (%)
Age	15-25	53.30	11.58	4	2.0
	26-35			13	6.4
	36-45			22	10.8
	46-55			64	31.5
	56-65			74	36.5
	66-75			25	12.3
	76 or older			1	1.0
Gender	Female	0.86	0.35	28	13.8
	Male			175	86.2
Race	Japanese	0.13	0.34	27	13.3
	Korean	0.39	0.49	79	38.9
	Chinese	0.12	0.32	24	11.8
	Vietnamese	0.09	0.29	19	9.4
	Filipino	0.10	0.30	20	9.9
Education	Less than high school degree	2.12	1.37	10	4.9
	High school degree or equivalent			80	39.4
	Some college but no degree			47	23.2
	Associate degree			16	7.9
	Bachelor degree			41	20.2
	Graduate degree			9	4.4
Experience	Less than 5 years	32.71	12.44	4	2.0
	5-9			8	3.9
	10-19			27	13.3
	20-29			46	22.7
	30-55			118	58.1

4.6 SIMULATED ROAD ENVIRONMENT

Two-lane rural highway (lanes separated by white dashed lines) with a solid shoulder on the right and steel barrier on the left was simulated for the experimental scenario. A cloud-free sunny weather condition was made to ensure good visibility. The road surface was made to appear dry. Medium traffic was assigned in the front, left and back of the subject's car to simulate real traffic flow in a highway. The speed limit was 60 miles per hour but, the subjects were suggested to keep up with the traffic flow.

4.7 STATISTICAL ANALYSIS AND RESULTS ON DRIVING BEHABIOUR CHANGE OF PROFESSIONAL TAXI DRIVERS

The statistical analyses relied on a two-tailed α-level of 5% to determine statistical significance of the difference in performance indicators between the base or Control condition of driving with no distractions and the test condition of Text Reading which involved the mandatory reading out loud of texts. IBM SPSS 22.0 software was used to compute the statistics.

Table 3 clearly shows that the drivers increased headway, lane deviation, driving blind-total time, driving blind-maximum duration, driving blind-incidents, driving blind-travel distance, and decreased their lane change frequency. Since most of the performance indices examined are not normally distributed, the T-test in Table 3, between and the Control and Texting means is not strictly valid, but the non-parametric Wilcoxon test provides assurance that all, but one differences are significant at the 95% level, and in fact all but two are significant at the 99% level of statistical confidence. Incidents of hard braking is the only variable that did not change significantly between control and texting conditions, largely because professional taxi drivers have developed skills for smoother driving to avoid passenger displeasure. The detailed distributions of each performance index are shown in Figure 10.

Table 3: Main Test Results for Base and Text Reading Conditions

Simulator Measurements	Base Mean, Std.Dev.	Text Reading Mean, Std.Dev.	Diff.	N	T-stat. test	Sig.	Wilcoxon Z	Sig.
Avg. Following Interval (s)	4.86, 2.79	5.87, 2.53	1.01	203	5.262	0.000	-6.157	0.000
Line Encroachment-Incidents	0.90, 1.42	4.07, 3.92	3.17	203	11.094	0.000	-9.857	0.000
Lane Change Frequency	0.46, 0.97	0.30, 0.70	- 0.16	203	2.263	0.025	-2.136	0.033
Hard Braking-Incidents	0.43, 1.35	0.31, 0.84	- 0.12	203	1.292	0.198	-0.823	0.410
Driving Blind-Total time (s)	7.16, 11.09	32.37, 22.56	25.21	203	17.527	0.000	-12.032	0.000
Driving Blind-Max. Duration (s)	1.20, 1.56	2.25, 1.96	1.05	203	6.368	0.000	-8.364	0.000
Driving Blind-Incidents	18.77, 27.69	50.63, 27.75	31.86	203	21.752	0.000	-11.768	0.000
Driving Blind-Distance (m)	100.93, 157.11	441.52, 272.53	340.59	203	20.310	0.000	-12.025	0.000

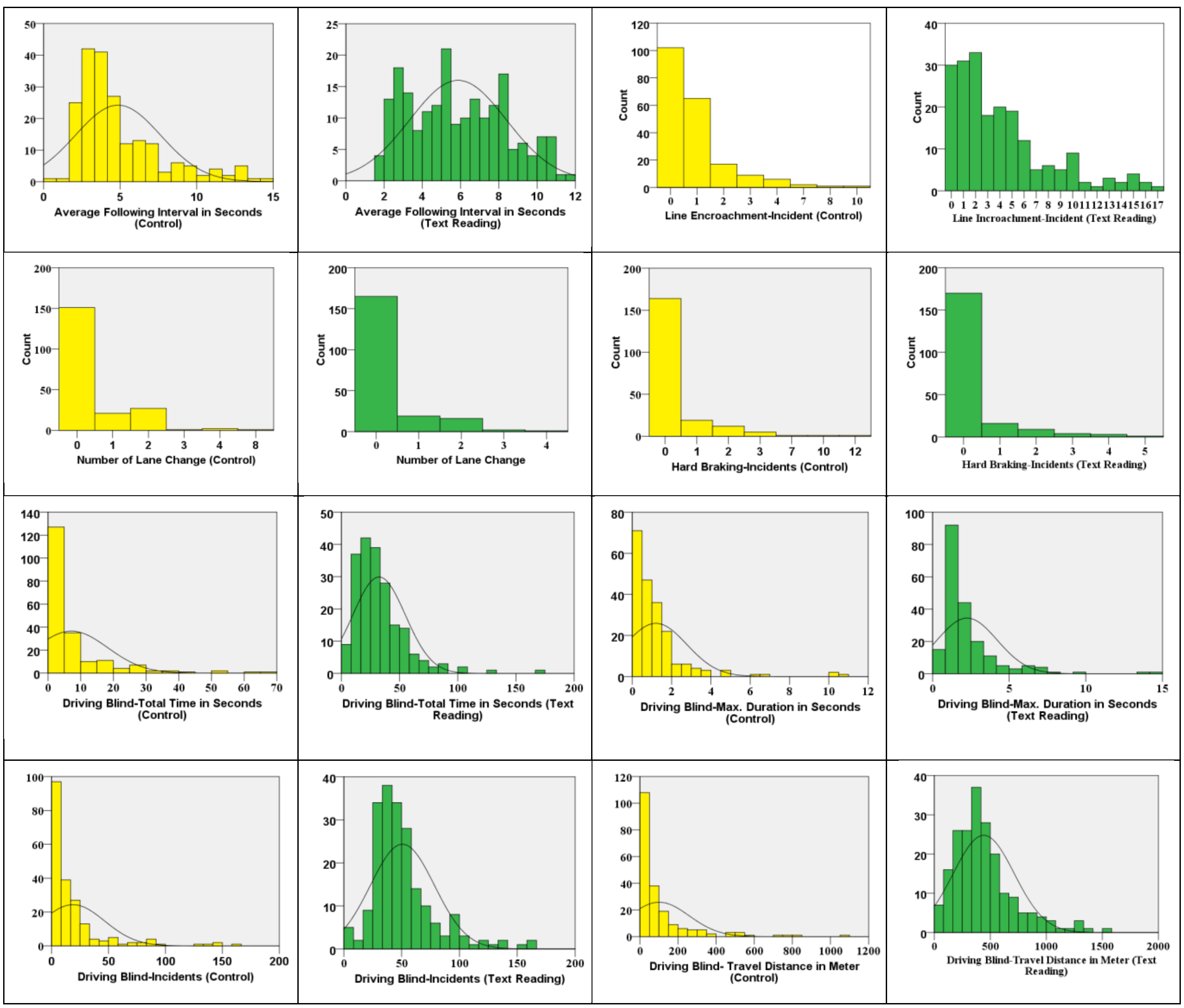


Figure 10: Frequency Distribution of Different Driving Performance Indicators

Figure 11 depicts the large changes which correspond to a significant degradation in driving performance. Reading text certainly decreases driving performance. One interesting observation that is indirectly reflected in the line encroachment and lane change outputs is that as the drivers tilted their head to the right to read the text on the tab, their vehicle tended to veer to the right as well, slightly for most, but eight drivers totally lost control of the vehicle, went off the road, and had a simulated crash (which always ends the scenario.) These eight drivers had a total of 13 crashes; two of the eight were among those who could not finish the distraction scenario.

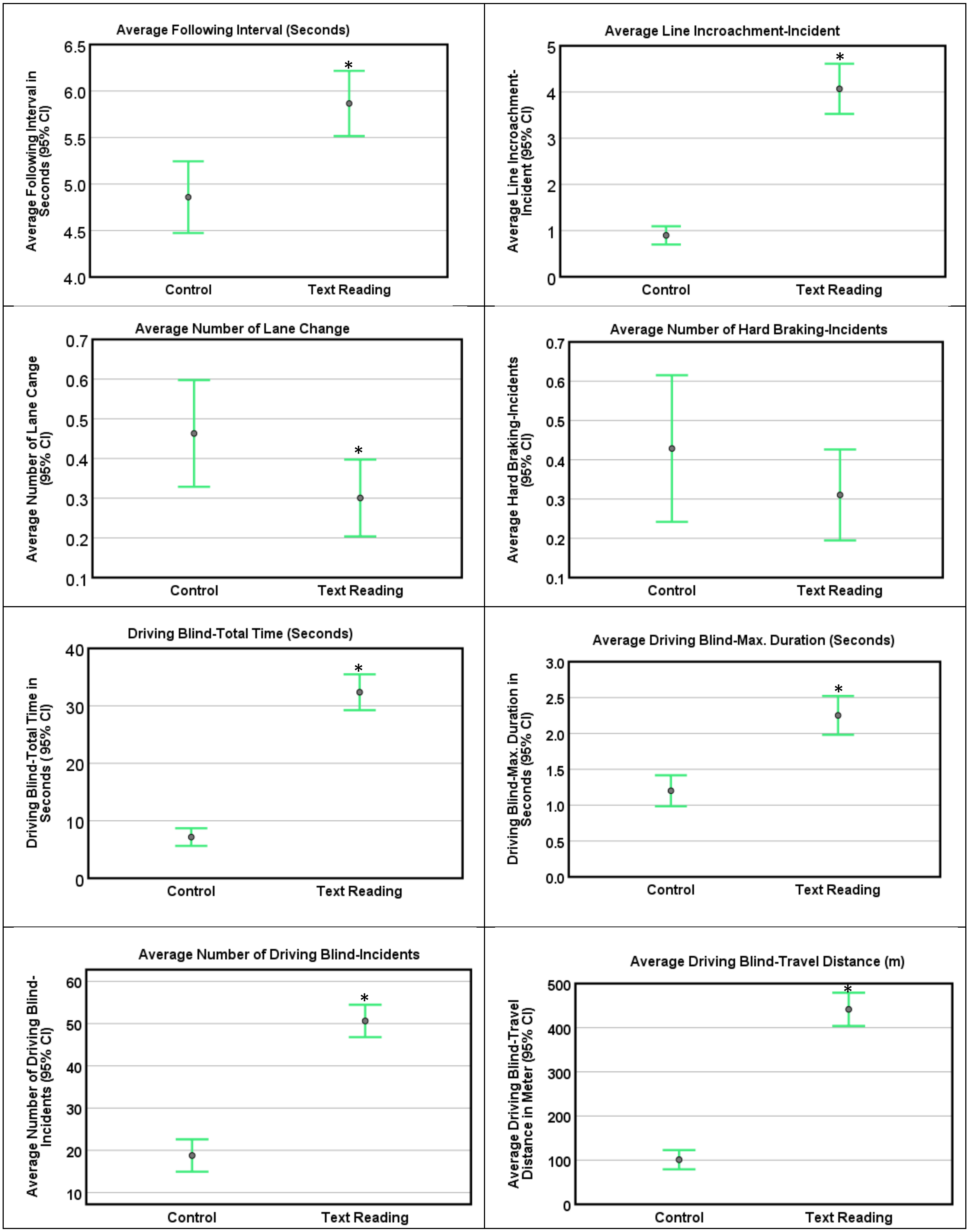


Figure 11: Effects of text reading on different driving performance indicators

4.8 STATISTICAL ANALYSIS AND RESULTS FOR DEMOGRAPHIC CHARACTERISTICS ASSOCIATION WITH DRIVING PERFORMANCE

Statistics of the demographic characteristics of our taxi driver sample are presented in Table 4. Race and gender were modeled using (0,1) dummy variables. The age and experience were collected as a range value which is coded as an average integer between the lowest and the highest value. The education level is coded from 0 to 5 with 5 representing that the driver has a graduate degree. The variables are classified as discrete and continuous as shown on Table 4 along with the range of values for each variable.

Table 4. Summary of Variables and their Values

Variables	Type	Values
Average Following Interval	Continuous	Seconds
Line Encroachment-Incidents	Discrete	Number
Lane Change Frequency	Discrete	Number
Hard-Braking	Discrete	Number
Driving Blind-Total Duration	Continuous	Seconds
Driving Blind-Maximum Duration	Continuous	Seconds
Driving Blind-Incidents	Discrete	Number
Driving Blind-Travel Distance	Continuous	Meter(m)
Age	Discrete	20:15-25y / 30:26-35y / 40:36-45y / 50:46-55y / 60:56-65y / 70:66-75y / 80:76y or older
Gender	Discrete	0: Female / 1: Male
Race (Japanese)	Discrete	1: Japanese / 0: Other
Race (Korean)	Discrete	1: Korean / 0: Other
Race (Chinese)	Discrete	1: Chinese / 0: Other
Race (Vietnamese)	Discrete	1: Vietnamese / 0: Other
Race (Filipino)	Discrete	1: Filipino / 0: Other
Education	Discrete	0: Less than high school degree / 1: High school degree or equivalent / 2: Some college but no degree / 3: Associate degree / 4: Bachelor degree / 5:Graduate degree
Experience	Continuous	2.5: Less than 5y / 7:5-9y / 15:10-19y / 25:20-29y / 42.5: 30-55y

The IBM SPSS 22.0 software was used to compute statistics. Two-tailed α-level of 0.01, 0.05 and 0.15 were used to determine statistical significance of the association between demographic characteristics and performance indicators of driving with no distractions (control), text reading and the difference between control and text reading conditions. (**see Table 6 for details**).

A series of correlation tests and estimations of linear regression models were carried out to reveal possible associations between demographics of subjects such as age, gender, race, education and driving experience on the independent side of the equation, and driving performance indicators such as average following headway, line encroachment-incidents, lane change frequency, hard braking, driving blind-total duration, etc. on the dependent side of the equation. A total of 120 models were estimated, that is, 40 models for each condition: control, texting, and difference.

The survey included 17 activities relating to the question "How often do you do the following while driving?" The responses of the taxi drivers are summarized in Table 5. This table includes all 236 participating taxi drivers, that is, it includes drivers who did not complete the simulator session. Activities such as listening to the radio, thinking about work and errands, drink, talk to passengers, make phone calls and use the GPS are done sometimes, often and always 50% of the time or more. On the other hand, only 12% of the drivers claimed that they read texts sometimes, often and always 50% of the time. This may seem surprising as reading addresses to pick up or deliver passengers is a routine part of a taxi driver's job. However, by taking to them, we clarified their response given the "while driving" condition in the question: The taxi drivers in our sample read texts when stopped at an intersection at red signal, or they stop at a safe place in order to read the text; text reading is infrequent during driving, as reflected in Table 5

Table 5. Frequency of Involvement of Tested Taxi Drivers with Activities during Driving

Questions/Response	Always	Often	Sometimes	Rarely	Never	N
Listen to the radio	20.1%	14.5%	32.9%	10.7%	21.8%	234
Listen to CD, iPod, or Podcasts	3.0%	5.2%	17.4%	10.0%	64.4%	230
Change CDs, DVDs, or Tapes	0.0%	1.4%	2.3%	8.6%	87.7%	220
Think about work and things you need to do	14.2%	20.6%	41.2%	8.6%	15.5%	233
Talk or interact with children in the back seat	3.9%	4.7%	29.5%	13.7%	48.3%	234
Talk to other passengers in the vehicle	8.9%	21.7%	52.3%	10.6%	6.4%	235
Travel with an animal companion	0.4%	1.3%	14.1%	15.0%	69.2%	234
Eat	0.4%	2.1%	22.2%	16.7%	58.6%	234
Drink	4.3%	15.0%	55.4%	11.2%	14.2%	233
Make or take phone calls	1.3%	6.1%	46.8%	17.8%	28.1%	231
Read e-mails or text messages	0.4%	0.4%	11.2%	12.45%.	75.5%	233
Send e-mails or text messages	0.4%	0.9%	3.9%	8.6%	86.2%	232
Surf the net or social media	0.4%	0.0%	0.9%	5.6%	93.1%	233
Put on make-up in traffic or at stop lights	0.9%	0.4%	1.7%	1.7%	95.3%	232
Read a book, newspaper, iPad, or Kindle	0.0%	0.4%	0.4%	0.9%	98.3%	232
Use GPS or map service	10.7%	16.2%	49.2%	10.7%	13.3%	234
Multitask two or more activities	1.8%	2.2%	24.0%	18.8%	53.3%	229

Figure 12 presents the mean and standard deviation for one of the driving performance variables, the car following interval or headway, for the difference between control (B) and texting (A) conditions vis-à-vis demographic characteristics. Sample size plays a substantial role: Large samples (e.g., male or all other races) have a much smaller variance than small samples (e.g., female, one specific race, etc.) The mean values suggest that gender, and Korean and Vietnamese ethnicity may affect the difference in car following headway between control and texting conditions. Females did not change their headway much, but males elongated their headway during texting. All ethnic groups elongated their headway under texting conditions, but Koreans elongated it less than the rest (possibly suggesting more aggressive traits in driving), and Vietnamese elongated more than the rest (possibly suggesting less aggressive traits in driving).

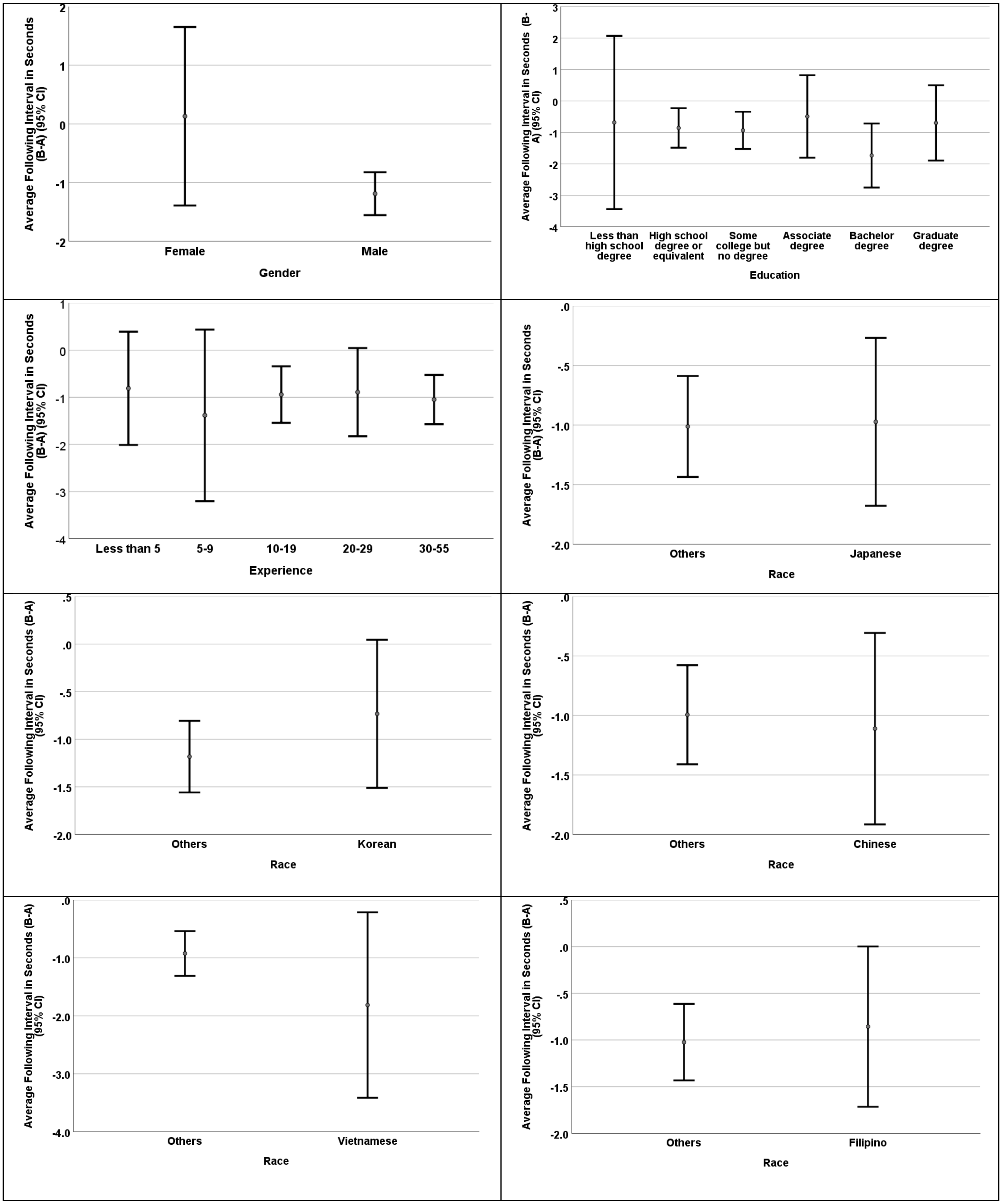


Figure 12: Variation of the Change in the Following Interval between Control (B) and Texting (A) Conditions by Demographic Characteristics.

Correlation analysis revealed only one substantial collinearity among independent variables, between age (years) and driving experience (years), which is not surprising. Age had a higher correlation with the dependent variables, which are the simulator driving performance outputs or their difference between control and texting conditions. As a result in most models presented in Table 6, age is the independent variable that is included in the model specification. The 22 models in Table 6 are those with statistically significant parameters (based on a t-test), however, their explanatory power is low, as manifest by the R^2, which suggests that sociodemographic characteristics do not explain a large portion of the variance observed in the various driving performance measures.

Table 6: Selected Linear Regression Models of Driving Performance

Test Condition	Simulator Output Variables	Constant	Age	Gender	Education	Experience	Japanese	Vietnamese	Chinese	Korean	R^2
CONTROL	Average Following Interval	7.6E-23***		0.001***	0.045**						0.06
		2.7E-12***		0.001***	0.034**	0.043**					0.08
		5.9E-17***		0.011**	0.042**					0.006***	0.10
TEXTING	Average Following Interval	3.3E-18***				0.015**					0.03
	Line Encroachment-Incidents	0.057*	2.1E-7***								0.13
	Driving Blind-Total Time	0.419 NS	7.8E-8***								0.13
		0.708 NS	5.4E-8***		0.144*						0.14
		0.387 NS	9.8E-8***					0.070*			0.15
	Driving Blind-Travel Distance	0.561 NS	8.3E-9***								0.15
		0.180 NS	5.9E-9***	0.086*							0.17
		0.898 NS	5.4E-9***		0.119*						0.16
		0.005***		0.146*	0.099*	2.6E-4***	0.031**				0.12
DIFFERENCE (CONTROL-TEXTING)	Average Following Interval	0.261 NS		0.009***	0.120*						0.04
	Line Encroachment-Incidents	0.028 **	3.0E-6***								0.10
		0.012**			0.051*	0.009***			0.052*		0.07
	Driving Blind-Total Time	0.396 NS	4.0E-6***					0.030**			0.12
	Driving Blind-Travel Distance	0.510 NS	2.2E-7***								0.13
		0.146 *	1.6E-7***	0.070*							0.14
		0.881 NS	1.3E-7***		0.080*						0.14
		0.359 NS	1.1E-7***	0.116*	0.133*						0.15
		0.123*		0.056*		1.3E-4***					0.08
		2.5E-4***				2.0E-4***		0.141*			0.08

Note: ***=99%, **=95%, *=85%, NS=not statistically significant

The top block of models represents successful attempts to correlate sociodemographic variables with basic driving performance. Not surprising, only a small portion of the variance in driving performance measure is explained by sociodemographic variables, but gender, education, driving experience and race having statistically significant effects. Specifically, males, more educated, more experienced, and Korean or Korean-dissent drivers produced slightly more aggressive driving behaviors.

The middle block of models represents successful attempts to correlate sociodemographic variables with driving performance that involves reading three text messages. Age has a dominant and very significant (alpha=0.01) effect indicating the relative unfamiliarity and perhaps uneasiness of older drivers to interact with digital equipment, which, in turn, produces significantly longer headways. Some of the rest of the sociodemographic variables have marginally significant contributions with education being a positive contributor (at alpha=0.15) suggesting that higher education represents higher familiarity and ability to interface with digital equipment, which produces relatively smaller effects on driving performance.

The bottom block of models represents successful attempts to correlate sociodemographic variables with the difference in driving performance between texting and control conditions. Age or experience in alternate specifications, since they are largely collinear, have strong effects, but models with age in their specification yield higher R^2 values. Education and Vietnamese ethnicity have marginally significant effects.

CHAPTER 5- SUMMARY

The first goal of this research was to study the effect of text reading on the driving performance of professional taxi drivers. Collectively, the outcomes from the experiment suggest that text reading has impaired driving performance significantly. Our results are in good accord with past literature, as summarized in Table 7.

Table 7: Comparison between Past Research and our Research Results

Performance Indicator	Our Results	Results of Past Research		
Headway	↑	↑ 10,46	↓ 47	
Lane Deviation	↑	↑ 10,33,34,35	— 32	↓ 47
Lane Change Frequency	↓	↓ 10		
Driving Performance	↓	↓ 35,46		
Looking Away from Road	↑	↑ 10,33,35,36		
Speed Fluctuation	↑	↑ 34, 35		
Braking Aggressiveness	—	…..		
Driving Blind-Incidents	↑	…..		
Driving Blind-Travel Distance	↑	…..		

Key: ↑ = An increase; ↓= A decrease; — = No Effect; 1, 2, 3 …… 57 = Reference Numbers

Text messages to taxi drivers are necessary for (1) giving detailed information, (2) can read it when it is safer to do so, (3) maintain privacy compared to audio, and (4) overcome the language barrier. Brief exit interviews summarized in Table 8 indicate that the drivers tend to enjoy the simulated lessons and found utility in this harmless way of experimenting with important distraction tasks that they must deal with constantly as part of their job.

Table 8: Exit Interview Responses of 144 Drivers

Exit Question	No	A little	A lot
Did you get dizzy?	37%	52%	12%
Was it fun?	19%	47%	34%
Was it useful?	15%	35%	50%

The findings of this research are statistically significant and important. It has focused on professional taxi drivers, who provide valuable transportation services and the findings readily extend to transportation network companies such as Didi, Lyft and Uber, and all drivers in the urban logistics chain that deal frequently with digital interfaces as part of their driving task. This work will continue by testing truck and bus drivers and expand to other scenarios.

This study also reveals the comprehensive research outcomes about the association of driver's demographic with driving performance under Control, Texting, and Change due to Texting conditions. All previous studies focused on only age and gender. But in this study, race, education and driving experience have been considered along with age and gender.

This study provided additional insights on the association of demographic characteristics (age, gender, race, education, and driving experience) with driving performance while texting. A total of 203 (175 male and 28 female) professional taxi drivers participated in the survey and simulator driving sessions. The dependent variables generated by the simulator were: Average following interval (headway), line encroachment-incidents, lane change frequency, hard braking, and total time, maximum time, incidents, and travel distance of driving distracted. Correlation, analysis of variance and regression analyses were conducted. We considered three conditions: Control (No Texting), Texting and Change due to Texting. Our sample includes a large number of Asian and Asian-American drivers including Chinese, Japanese, Korean, Filipino and Vietnamese drivers, so ethnicity was modeled explicitly. Gender and some ethnicity variables have significant associations with driving performance outcomes, but driver age has the most significant associations with worsened driving performance under texting conditions. Drivers with higher levels of education seem to have a driving performance that is less affected by texting conditions. There are indications that drivers of Korean dissent may be somewhat more aggressive (shorter headways) and drivers of Vietnamese dissent may be somewhat more distracted than average (longer distance driving blind.)

In general, our more generic results are in agreement with findings reported in recent past literature, as depicted in Table 9. More specifically, the results of our study indicate that line encroachment or lane deviation are significantly influenced by age and driver experience. In contrast, level of education, race, and gender do not have any impact on it while texting. This outcome is consistent with past results of Rumschlag et al. (*49*) who reported that driver age was significantly correlated with lane deviation and did not have any relation with gender. We did not find any past literature that considered race, education and driving experience with lane deviation.

We found that older people (55+) have more Lane Deviation, Driving Blind-total Time, Incidents and Travel Distance while texting. Older taxi driver driving performance is more affected compared with middle-aged (36 to 55) and younger drivers (15 to 35). These results are supported by the research of Bao et al. (*64*) who reported that drivers of age 20 to 30, and 40 to 50, have less lane deviation than drivers of age 60 to 70 while doing visual-manual tasks. Guo et al. (*96*) also found drivers aged less than 30 years and greater than 64 are more affected by secondary tasks. Rumschlag et al. (*49*) also described that older drivers were worse while texting. All these findings strongly support our negative outcomes of age to driving performance.

Basacik et al. (*97*) reported that females had a larger headway variation than males while texting; we found that males changed their headway more from control to texting conditions which is largely due to the shorter headways of males in control conditions. Lane change frequency, hard-braking, driving blind-maximum duration and driving blind-incidents do not seem to be affected or explained by differences in demographic characteristics.

Table 9: Summary of important observed effects based on Linear Regression Models results.

Performance Measures	**Influencing Factors While Text Reading**	**Supporting Literature**
Average Following Interval	Experience, Gender	Gender *(97)*
Line Encroachment-Incidents	Age, Experience	Age *(49,64,71)*, Gender* *(49)*
Lane Change Frequency	*	-
Hard-Braking	*	-
Driving Blind-Total Time	Age, Race (Vietnamese)	-
Driving Blind-Maximum Duration	*	-
Driving Blind-Travel Distance	Age, Experience, Race (Japanese)	-
Driving Safety	Age, Gender, Experience, Race	Age, Gender, Experience *(4)*

*No Association; 1, 2, 3 …97 = Reference Number

CHAPTER 6- CONCLUSION

6.1 CONCLUDING REMARKS

The study can be concluded with the following research outcomes:

- Taxi drivers significantly increased their headway (20.7%), lane deviations (353.9%), total time of driving blind (351.8%), maximum duration of driving blind (87.6% per glance), driving blind incidents (169.7%), driving blind distance (337.5%) and significantly decreased lane change frequency (35.1%).
- There was no significant effect on braking aggressiveness while reading the text.
- The outcomes indicate that driving performance degrades significantly by reading text while driving
- Gender and some ethnicity variables have significant associations with driving performance outcomes.
- Driver age has the most significant associations with worsened driving performance under texting conditions.
- Drivers with higher levels of education seem to have a driving performance that is less affected by texting conditions.
- There are indications that drivers of Korean dissent may be somewhat more aggressive (shorter headways).
- Drivers of Vietnamese dissent may be somewhat more distracted than average (longer distance driving blind.)

6.2 LIMITATIONS OF THE STUDY

Only simulator recorded dependent variables are considered for this study. Other important variables like reaction time, average speed, and acceleration are not considered. The female (28) sample size compared to male (175) was small. In the case of race, we did not find good sample except for five races to consider a wide variety of samples. This study did not consider a combination of typing and reading the text which might be also a common distraction. The simulated road layout used in this experiment was two lane rural highway without any traffic signals. So, different road environments with traffic signals may have some partial influences on the driving behavior.

6.3 FUTURE RESEARCH

This study has focused only text reading distraction for taxi drivers on the simulator. This work will continue by testing truck and bus drivers and expand to other scenarios. The future research will focus on-road study on reading text while driving to validate VS500M simulator. A forthcoming study will conduct focusing on large sample number with a wide variety of samples and different traffic environments for both simulator and real road to develop real-time traffic distraction algorithm to detect driving behavior. The research will also focus on other sources of distraction such as hand-held and hand-free conversation and dialing, conversation with a passenger, navigation impact and text writing. New scenarios will be developed based on Honolulu present and future conditions to assess the driving performance.

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APPENDIX A

AVAILABLE SCENARIOS OF VIRAGE SIMULATOR *(98)*

The Virage scenarios are designed to increase the traffic mobility with a lower risk of injuries and harmful consequence of drivers, society, and environment. The driving simulator allows them to take decisions and actions while driving in a wide range of roads, weather and traffic conditions without facing any extreme real-world penalties. The Virage have scenarios from basic maneuvers to advanced techniques and emergency situations. The scenarios have arranged according to the order of complexity and difficulty. It is designed considering the capability of beginner, novice, and experienced drivers. To complete a comprehensive training program, scenarios can be followed according to sequence. They also can be selected and integrated into existing theory and practical training. The available scenarios of VS500M simulators are listed below-

- Lesson: 0.1 - Morning Readiness
- Lesson: 1.0 - Simulator Adaptation
- Lesson: 1.1 - Urban Driving – Introduction
- Lesson: 1.2 - Simulator Adaptation
- Lesson: 1.3 - Basic Controls, Instruments & Warnings
- Lesson: 1.3.1 - Manual Transmission - Practice I
- Lesson 1.3.2 Manual Transmission – Practice II
- Lesson: 1.3.5 - Lights and signals
- Lesson: 1.3.6 - Basic vehicle control – PbP
- Lesson: 1.4 - Aiming & Steering – Basic Turns
- Lesson: 1.4.1 - Aiming & Steering – Expressways
- Lesson: 1.4.2 - Aiming & Steering – Rural Highways
- Lesson: 1.4.8 - Stop and Go Traffic
- Lesson: 1.5.1a - Blind Spots & Mirrors
- Lesson: 1.5.1b - Lane Change Preparation – Relative Distance
- Lesson: 1.5.2 - Lane Change Preparation – Relative Speed
- Lesson: 1.5.3 - Mirrors and Lane Changes – Review
- Lesson: 1.6 - Entering Traffic from a Parked Position
- Lesson: 2.0 - Turns – Preparation
- Lesson: 2.1 - Right Turn – Basic
- Lesson: 2.5 - Right turns – PbP
- Lesson: 3.0 - Left Turns – Basics I
- Lesson: 3.1 - Left Turns – Basics II
- Lesson: 3.2 - Left Turns – Practice
- Lesson: 3.3 - Intersections – Advanced Practice
- Lesson: 3.3b - Intersections – Advanced Practice
- Lesson: 4.0 - Lane Changes – Introduction
- Lesson: 4.1 - Lane Changes – Practice – Expressway
- Lesson: 4.2 - Lane Changes – Practice in the City

- Lesson 4.3 Lane Changes Followed by a Turn
- Lesson: 4.4 - Lane Changes – Night Practice
- Lesson: 4.4.1 - Lane Changes – Rain
- Lesson: 5.1 - Passing – Expressways
- Lesson: 5.2 - Passing – Rural Highways
- Lesson: 6.0 - City Driving – Practice 1
- Lesson: 6.1 - City driving – Practice 2
- Lesson: 7.0 - Rural Highways – Introduction
- Lesson: 7.1 - Rural Highways – Practice
- Lesson: 8.1 - Merging on Expressways – Basics
- Lesson: 8.1.1 - Merging on Expressways – Practice I
- Lesson: 8.1.2 - Merging on Expressways – Practice II
- Lesson: 8.2 - Expressway – Approaching Merges
- Lesson: 8.3.1 - Space Ahead – Following Intervals
- Lesson: 8.4.1 - Speed Adjustment – Reduced Visibility
- Lesson: 8.4.2 - Speed Adjustment – Reduced Traction
- Lesson: 8.4.3 - Speed Adjustment – Reduced Traction
- Lesson: 10.1 - Intersections - Controlled & Uncontrolled
- Lesson: 10.2 - Right-of-Way Rules at Stop Signs
- Lesson: 10.4 - Anticipation of Yellow Light
- Lesson 12.1 Eco-driving – The Reality of Physics
- Lesson 12.2 Eco-driving – The Effect of Acceleration
- Lesson 12.3 Managing Accelerations – Competition
- Lesson 12.4 Eco-driving on the Expressway
- Lesson 12.5 Eco-driving in the City
- Lesson 12.6 Eco-driving – Evaluation
- Lesson 12.7 Eco-drive – Stop and Go
- Lesson: 13.5.1 - Head-on Collisions
- Lesson: 13.5.2 - Head-on Collisions
- Lesson: 13.6.1 - Rear-End Collision Risk – 1
- Lesson: 13.6.2 - Imminent Rear-End Collision – 2
- Lesson: 13.6.3 - Imminent Rear-End Collision – 3
- Lesson: 15.0 - Hazard Perception – Pedestrians
- Lesson: 15.1 - Hazard Perception – Pedestrians
- Lesson: 15.2 - Hazard Perception – City Intersections
- **Lesson 15.8 Distraction and Crash Risk**
- Lesson: 15.3.1 - Unprotected Road Users – Practice
- Lesson: 16.1 - Keep Eyes Moving – Observation Challenge I
- Lesson: 16.2 - Look Wide & Aim Far - Observation Challenge II
- Lesson: 16.3.1 - Lane Changes –Vigilance PbP 1
- Lesson: 16.3.2 - Lane Changes – PbP 2
- Lesson: 16.3.3 - Mastering Lane Changes – PbP
- Lesson: 16.3.4 - Lane Change Practice – PbP
- Lesson: 17.1 - Speed and Braking Distances – Demonstration
- Lesson: 17.2 - Road Conditions and Braking Distances
- Lesson: 17.3 - Speed, Total Stopping Distance and Visibility

- Lesson: 17.4 - Speed, Total Stopping Distance & Kinetic Energy
- Lesson: 20.2 - Parallel Parking –Right Side – PbP
- Lesson: 20.3 - Parallel Parking – Left Side – PbP
- Lesson: 25.1 - Free drive – City
- Lesson: 25.1 - Free Drives - City (Series ID – 25)
- Lesson: 25.2 - Free Drives - Expressway (Series ID – 25)
- Lesson: 25.3 - Free Drives - Rural (Series ID – 25)
- Lesson: 25.4 - Free Drives - Mountain (Series ID – 25)
- Lesson: 25.5 - Free Drives - Mountain Spring (Series ID – 25)
- Lesson: 25.6 - Free Drives - Mountain Winter (Series ID – 25)
- **Lesson: 27.2 - Distracted Driving – Texting**
- Lesson: 27.3 - Driver Fatigue
- Lesson: 28.1 - Evaluation Rural highway
- Lesson: 28.2 - Evaluation – Expressway
- Lesson: 30.0 - Precision Maneuvers - Extra Practice
- Lesson: 33.0.5 - Precision_Driving_Half_Closed_Circuit_Practice
- Lesson: 33.1 - Closed Circuit – Practice
- Lesson: 33.2 - Forward Slalom – PbP
- Lesson: 33.2b - Forward Slalom – Group Challenge
- Lesson: 33.3 - Reverse Slalom – PbP
- Lesson: 33.3b - Reverse Slalom – Group Challenge
- Lesson: 33.4 - Precision Stopping PbP
- Lesson: 33.5 - Precision Steering (Tennis Ball) – PbP
- Lesson: 33.5b - Precision Steering (Tennis Ball) –Group Challenge
- Lesson: 33.6 - Narrow Passages – PbP
- Lesson: 33.7 - Closed Circuit – Practice – Winter
- Lesson: 33.8a - Precision Driving – The Alley – Practice
- Lesson: 33.8b - Precision Driving – The Alley – Practice
- Lesson: 33.8c - Precision Driving –The Alley – Practice
- Lesson: 33.9 - 90-degrees turns – PbP
- Lesson: 33.10 - Precision Driving – The Alley – Evaluation
- Lesson: 33.11 - Closed Circuit – Evaluation