EFFECTS OF READING TEXT WHILE DRIVING: A DRIVING SIMULATOR STUDY

FINAL PROJECT REPORT

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16. Abstract

Although 47 US states make the use of a mobile phone while driving illegal, many people use their phone for texting and other tasks while driving. This research project summarized the large literature on distracted driving and compared major outcomes with those of our study. We focused on distraction due to reading text because this activity is most common. For this research project, we collected simulator observations 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 experimental scenario was simulated on a two-lane rural highway having a speed limit of 60 mph and medium traffic. Drivers needed to follow the lead vehicle under regular and text-reading conditions. The large sample size of this study provided a strong statistical base for driving distraction investigation on a driving simulator. The comparison between regular and text-reading conditions revealed that the drivers significantly increased their headway (20.7%), lane deviations (354%), total time of driving blind (352%), maximum duration of driving blind (87.6% per glance), driving blind incidents (170%), driving blind distance (337%) and significantly decreased lane change frequency (35.1%). There was no significant effect on braking aggressiveness while reading text. The outcomes indicate that driving performance degrades significantly by reading text while driving. Additional analysis revealed that important predictors for maximum driving blind time changes are sociodemographic characteristics, such as age and race, and past behavior attributes.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	milimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square milimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milimeters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	milimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square milimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yard	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milimeters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

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

(Revised March 2003)

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EXECUTIVE SUMMARY

Although 47 US states make the use of a mobile phone while driving illegal, many people use their phone for texting and other tasks while driving. This research project summarized the large literature on distracted driving and compared major outcomes with those of our study. We focused only on distraction due to reading text because this activity is most common.

For this research project, we collected simulator observations 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 experimental scenario was simulated on a two lane rural highway having a speed limit of 60 mph and medium traffic. Drivers needed to follow the lead vehicle under regular and text-reading conditions. The large sample size of this study provided a strong statistical base for driving distraction investigation on a driving simulator.

The comparison between regular and text-reading conditions revealed that the drivers significantly increased their headway (20.7%), lane deviations (354%), total time of driving blind (352%), maximum duration of driving blind (87.6% per glance), driving blind incidents (170%), driving blind distance (337%) and significantly decreased lane change frequency (35.1%). There was no significant effect on braking aggressiveness while reading text.

Age, experience and race are the most important influencers in distraction prediction, under no text reading and text reading scenarios. Older drivers, although more experienced, in most cases become more distracted when involved into parallel tasks while driving. Race has significant contributions. For example, drivers of Filipino dissent may be somewhat more aggressive (shorter car following intervals with or without text reading) and drivers of Vietnamese dissent may be somewhat more distracted than average (longer duration of driving blind). Drivers with higher levels of education seem to have a driving performance that is less affected by texting conditions. Gender also influences drivers' inattention. For example, women drivers followed traffic at longer intervals than men. Also, lane encroachment incidents in the no text reading scenario were more for women than for men, but this inverted while reading text which suggests that women are more conservative than men in their lane position.

Distraction caused by text reading has negative effects on driving performance and safety. Our findings suggest that all taxi drivers should be discouraged from engaging in reading text while driving. Our results are in good accord with past literature. The findings of this research are statistically significant and important. They apply to all drivers and particularly to the drivers of 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.

Decision tree analysis revealed that driving performance is not only affected by the several demographic attributes, which are widely covered in the literature, but also the behavioral profile of each driver which should be collected and incorporated in the estimation of the impact of distractive tasks while driving. The behavioral profile includes driving preferences, control beliefs, behavioral beliefs, descriptive norms, risk appreciation and traffic record.

Keywords: Headway, Lane deviation, Driving Blind, Safety, Text Reading, Driving Simulator.

CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW

Distracted driving is seen as one of the major factors contributing to the rise in number of injuries and deaths in the US. According to National Highway Traffic Safety Administration (NHTSA), in 2011, 3,331 people died and 387,000 were injured in motor vehicle crashes due to distracted driving [1]. NHTSA also reported that 78% of crashes and 65% of near crashes occurred due to multiple types of driving inattention like secondary task, driving-related inattention, and driver drowsiness etc. [2]. 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) [3]. In terms of gender, 54% of males and 46% of females in the USA use cell phones while driving [3]. According to Pew Research Center, 75% of U.S. teens have cell phones and they text while driving [4]. In this research, we have focused only on distraction due to reading text, because this activity is necessary for taxi and delivery drivers; and practiced by many other drivers. Text messages to taxi drivers are necessary for giving detailed information, can be read when it is safe to do so, can maintain privacy compared to audio, and help to overcome the language barrier.

The literature review section is divided into two parts: human factors and operations factors. 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 observed by various researchers 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.

1.1 Human Factors

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. Gliklich 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 [5]. Atchley et al. reported that 98% young drivers send texts while driving [6]. Bergmark et al. found that 59.2% and 71.5% of young people wrote and read text message while driving [7]. 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 [8]. Also, people aged under 30 and above 65 have higher risk for secondary task related distractions than middle-aged drivers [9]. 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 [10]. Struckman-Johnson et al. found that males sent 1 to 5 sentence long texts while females wrote less than a sentence [11].

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 [12]. Along curves, distracted drivers choose a lower speed but on straight segments, distractions have negligible effects on the choice of speed

[13]. When distracted drivers encounter a pedestrian at a marked crossing, they reduce their speed by braking aggressively [14]. Most of the reviewed articles found that handheld mobile phone users decrease their speed from baseline values during a conversation [12-24]. Stavrinos et al. showed that the fluctuation in speed during handheld conversation is very high [25].

Hands-free conversation tends to decrease speed [14,18-24,26] but Patten et al. [17] and Rosenbloom [27] 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 did not change during short conversation but exceeded the baseline value when the driver had long conversations [more than 16 minutes]. Kircher et al. [20] and Rosenbloom et al. [27] found that drivers perceived hand free phone conversation to be free of risk and that explains why they did not reduce their speed. Decrease in speed has been reported during handheld phone dialing [16,20,28] and hand free dialing [16,20,28]. Text writing also results in a decrease in speed [15,29,30] and introduces more variation in speed [25,31,32]. Text reading results in a decrease in speed [29,30,33] and introduces more variation in speed [31,32].

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 [16,17,20,21,24,34–37], hands-free conversation [16,17,20,21,24,26,35,36,38,39], handheld dialing [16,20,24], hands-free dialing [16,20], conversation with a passenger [24,35,39], text writing [24,30,31,34,40,41] and text reading [29,30,31,41].

Headway is the time spacing between successive vehicles on the same lane. Kircher [20], Saifuzzaman [22], and Yannis et al. [42] demonstrated that for handheld conversation, there is an increase in headway. Kircher [20], Saifuzzaman [22], Caird [24] and Strayer et al. [26] found that headway increased due to hands-free conversation but Alm et al. [38] found that it was unaffected. Several authors found an increase in headway due to text writing [8,40,41,43] but Papadakaki et al. [44] 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. [12] and Stavrinos et al. [25] reported a rise in lane deviations while Törnros et al. [16] and Kircher et al. [20] reported the opposite. Haigney et al. [19] and Choudhary et al. [45] didn't find any effect of handheld phone conversation on lane deviations. Haigney et al. [19] and Alm et al. [38] found similar results for hands-free conversation whereas, Törnros [16], Kircher [20], and Papadakaki et al. [44] showed a decline in lane deviation. Lane deviation increased due to handheld dialing [16], hands-free dialing [16,20], text writing [8,30-32,40,44-47], and text reading [8,30-32] but these outcomes are not consistent: Stavrinos [25], and Boets et al. [29] did not observe any change in lane deviations for text writing, and for text reading, Papadakaki et al. found a reduction [44].

Lane Change Frequency refers to the number of instances where drivers relocate from their current lane to an adjacent lane. Fitch et al. [48] concluded that handheld conversation will stimulate the drivers to change the lane more significantly than the baseline condition (10% versus 4%). Choudhary and Velaga [45] found that handheld conversation had no impact on lane changing action. On the other hand, Stavrinos et al. [25] found a decrease in lane change frequency during handheld conversation. Beedeand Kass [49] found that lane change frequency decreased during hands-free conversation. Choudhary and Velaga [45] reported an increase in lane change frequency while writing texts but Stavrinos et al. [25] didn't find any change in lane change frequency while drivers were writing text. Lane change frequency increased while driving and reading text [8].

Driving Performance has been measured based on one or more of variables such as 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, some of the reviewed articles [12,16,19,23,25,26,32-34,36,39-41,43,45,46,49-52] concluded that driving performance deteriorates for some of 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. [48] found handheld conversation, and Hosking [8], Boets et al. [30], Rudin-Brown et al. [32] and Young et al. [33] identified text writing and reading as sources of distraction that lead to a decline in attention on the road.

Control of a Vehicle means keeping the vehicle within a lane with respect to other vehicles, situational awareness, and overall control. Schattler et al. [12], Rudin-Brown et al. [32], Peng et al. [43], Choudhary and Velaga [45], Ranney et al. [53], Muttart et al. [54], and Hagiwara et al. [55] showed that vehicle control worsens when drivers use mobile phones. For hand free conversation, Beede and Kass [49] did not find any change in controlling the vehicle.

Braking 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 with a delayed and more acute response. Braking aggressiveness has been found to increase both for handheld conversation [14] and hands-free conversation [14,54].

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 crashes are found to be greater among novice drivers than experienced drivers [56]. Many researchers found an increase in risk for collisions for handheld conversation [12,15,57,58], hands-free conversation [26,38,49,51,54,57], conversation with a passenger [51], text writing [8,15,25,32,41,46], and text reading [8,30].

Safety was found to decrease [14,19-21,25,47,57] for several types of distracting activities like handheld conversation, hands-free conversation, hands-free dialing, text writing and text reading. A summary of the literature review on distracted driving using driving simulators is given in Table 1.

The focus of this study was to conduct a simulator-based study with professional taxi drivers to measure the effects of reading text while driving. According to literature review which is summarized in Table 1, major findings of distraction while reading text include that drivers increased speed fluctuation [31,32], reaction time [29,30,31,41], headway [8,43], lane deviation [8,30,31,32], looking away from road [8,30,32,33] and vehicle collision [8,30] while reading text and driving. Drivers also decreased mean speed [29,30,33], lane change frequency [8], control on vehicles [32,43] and driving performance [32,43].

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	↓12,13,14,15,16,17, 18,19,20,21,22,23,24	↑21; —20; ↓14,18,19,20,21,22,23,24,26	↓16,20, 28	↓16,20, 28		↑33; ↓15,29,30,	↓29,30,33
	Speed fluctuation	↑25					↑25,31,32	↑31,32
	Reaction Time	↑16,17,20,21,24,34, 35,36,37	↑16,17,20,21,24,26,35,36,38,39	↑16,20, 24	↑16,20	↑24,35,39	↑24,30,31,34,40,41	↑29,30,31,41
	Headway	↑20,22,42	↑20,22,24, 26; —38; ↓44				↑8,40,41,43; ↓44	↑8,43; ↓44
	Lane deviation	↑12, 25; —19, 45; ↓16,20	—19, 38; ↓16,20,44	↑16	↑16,20		↑8,30,31,32, 40, 44,45,46,47; —25,29	↑8,30,31, 32; —29; ↓44
	Lane Change Frequency	—45; ↓25	↓49				↑45; —25; ↓8,25	↓8
	Driving Performance	↓12,16,19,25,34,36,45	↓16,19,23,26,36,39, 49,50,51,52	↓16	↓16	↓23,39,51,52	↓32,33,34,40,41,43,45,46	↓32,43
	Looking away from road						↑8,30,32,33	↑8,30,32,33
	Control on Vehicle	↓12,45	↓54; —49				↓32,43,45	↓32,43
	Braking Aggressiveness	↑14	↑14,54					
Operational Factors	Vehicle Collisions	↑12,15,57; —19, 25	↑26,38,49,51,54,57; —19			↑51	↑8,15,25,32,41,46	↑8,30; —29
	Safety	↓14,19,20,21,57	↓14,19,20,21,57		↓20		↓25,47	
	Traffic Flow						↓25	

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

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

- up to 20 [8,18,50,52]
- 21 to 40 [12-14,17,19,21,22,26-29,31-33,35,38,40,41,43,47,49,53]
- 41 to 60 [16,23,36,39,44,46]
- 61 to 80 [20,25,30]
- 100 to 120 [15,34,45,51] and,
- 559 [24].

The large sample size [N=203] of our study provides a large sample for the investigation of distractions to driving on a driving simulator compared to all but one of the previous studies. As result, comparative findings are expected to have a stronger statistical significance.

CHAPTER 2. DRIVING SIMULATOR EXPERIMENT

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 (CTL), 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 by Virage's chief scientist, who 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.

As shown in Figure 1, the 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. A three-axis high fidelity vibration system with motion cues at frequency up to 100 Hz makes the driving environment similar to driving on the road. 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.

Figure 1. Driving simulator used for text reading and driving study

All 203 participants were professional taxi drivers from CTL with a valid driver 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. Participants were categorized in seven age groups (≤25 (N=4), 26-35 (N=13), 36-45 (N=22), 46-55 (N=64), 56-65 (N=74), 66-75 (N=25) and ≥76 (N=1)). All drivers were capable of speaking and reading English; the native language for over one half of them 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.

The experimental scenario was a combination of three continuous segments; the first was normal driving without text reading (the demarcation of the segment was defined by a roadside billboard). In the second segment, the traffic slowed down through a construction zone which was a cue to prepare for the texting phase of the experiment. The start of the third segment was marked by a roadside billboard that displayed, "TEXTING ZONE BEGINS".

Two-lane rural highway (lanes separated by white dashed line) 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 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 drivers were advised to keep up with the speed of the traffic flow.

The typical process for each driver progressed along these steps, first the drivers were greeted by the UH team and the human resources representative of CTL 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 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 of the simulator. Once the adaptation was complete, the next scenario which involved distracted driving was explained to each driver. Then, they were asked to start the 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 out loud 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 a short feedback 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 of 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 marked 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; typically limited to the reminders to read text messages 1, 2 and 3.

CHAPTER 3. BASIC ANALYSIS

The basic statistical analyses relied on two-tailed tests to determine statistical significance of the difference in performance indicators between the base condition and text reading condition. The base condition (control condition) included no distractions while driving; the text reading condition involved mandatory reading out loud of three text messages. The SPSS 22 software was used to compute the statistics.

Table 2 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 2, between and the control and texting estimates of 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 2.

Table 2. 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

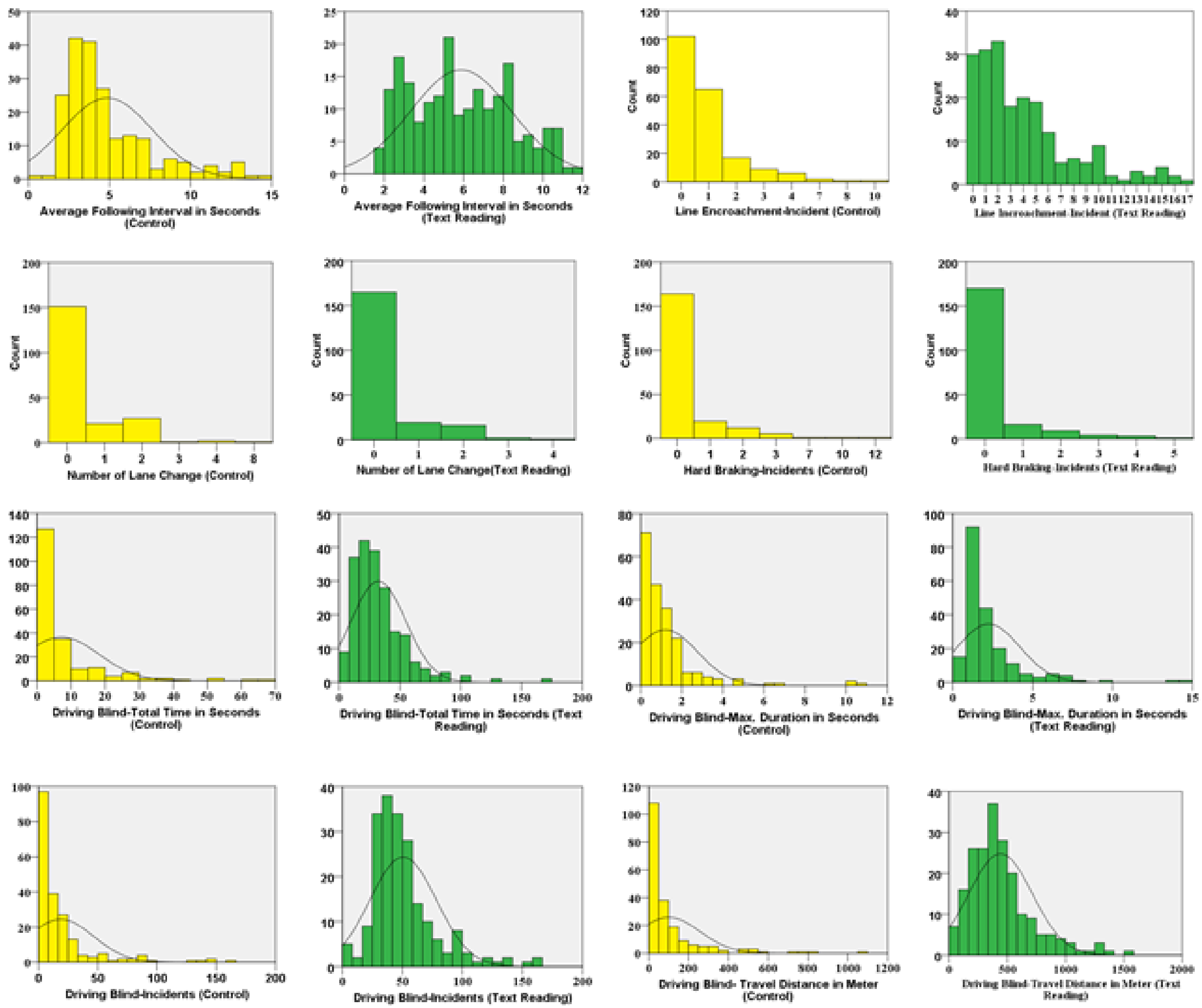

Figure 2. Frequency distribution of different driving performance indicators

Figure 3 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 lost control of the vehicle, went off the road, and had a simulated crash (which ended 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.

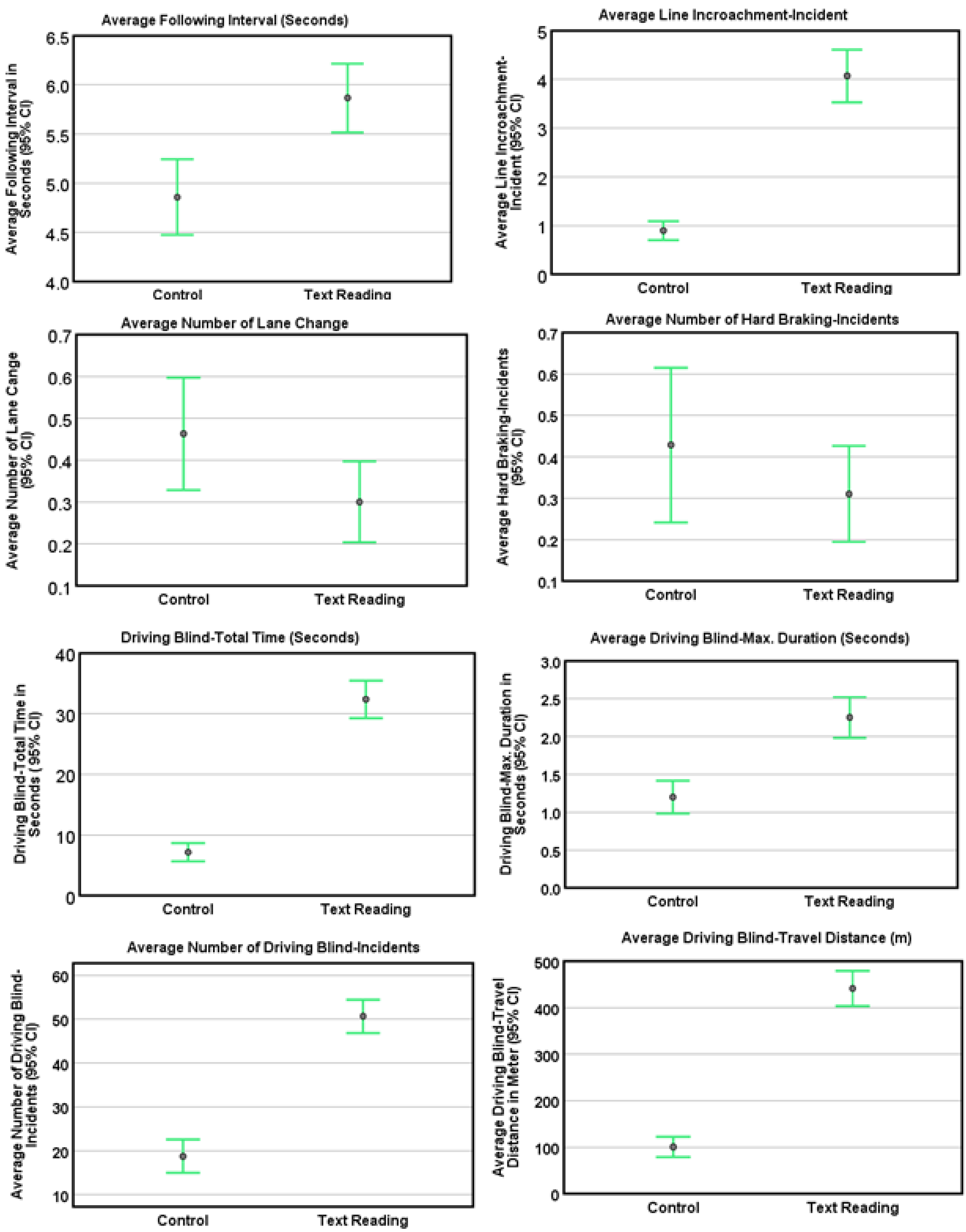

Figure 3. Effects of text reading on different driving performance indicators

CHAPTER 4. ENHANCED ANALYSIS: PREDICTING BEHAVIOR USING CLUSTER MODELING

Hypothesis testing was used to define clusters, based on gender, age, experience, educational level and race. The interrelation between the driving behavior and the driving performance indicators was also investigated. The Kruskal-Wallis and Mann Whitney two sample U-test were performed to assess differences among and between the samples. The three driving performance indicators were examined under the "no text reading" and "text reading" scenarios for different groups of gender (male, female), age (15-25, 26-35, 36-45, 46-55, 56-65, 66-75, >75), race (Korean, Japanese, Chinese, Filipino, Vietnamese, other), education level (less than high school, high school, some college with no degree, associate degree, bachelor degree, graduate degree), and experience (<5 years, 5-9, 10-19, 20-29, >30).

Two-way ANOVA and Scheirer Ray Hare tests were performed to examine interactions between the two scenarios and the demographic characteristics. Two behavioral indicators were also used as factors affecting driving performance. Subjects had stated the frequency of text reading and text writing while driving, in a scale from 1 to 5, with 1 meaning rarely and 5 very often. The distribution of the answers is shown in Figure 4. Testing also considered the interaction between the two driving scenarios and the behavioral indicators.

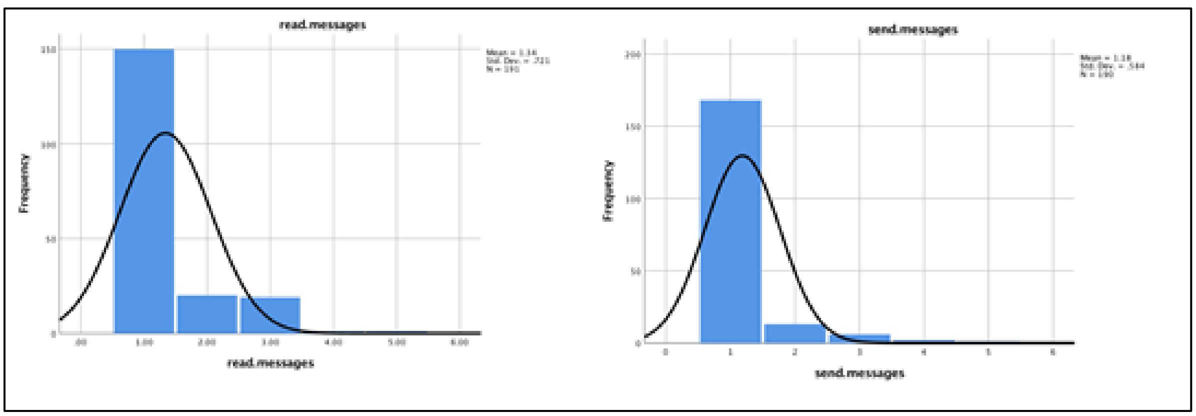

Figure 4. Frequency distribution of responses on frequency of reading messages while driving

The three driving performance indicators, average following interval, line encroachment incidents and driving blind total time were clustered based on the demographic characteristics of the drivers. The average values were compared among and between and clusters and the differences were assessed. Comparisons were made on the measurements under no text reading, under text reading and their differences as shown in Table 3.

Women drivers followed at longer intervals than men, in both scenarios, with the result in no text reading being significant at a confidence level 97%. The interval increased in text reading as compared to no text reading for women but increased for men under the text reading scenario. A possible explanation is that men's interval was very short in the no text reading scenario, but the discomfort appeared when they had to accomplish more demanding tasks such as text reading.

Line encroachment incidents in the no text reading scenario were more for women than for men, but this inverted in the text reading scenario. This suggests that women are more conservative than men in their lane position. Inattention in terms of driving blind time was higher in men in both scenarios, than in women. No statistical differences were recorded between the two genders for these two driving performance indicators.

Age significantly affects all three indicators. Older ages kept longer intervals in the traffic flow, and both young drivers (up to 25) and older drivers were involved in more line encroachment incidents than the remaining age groups, as they also drove blind for a longer time, especially under text reading.

Race affected mainly the following interval with higher values shown for Korean and Vietnamese drivers. Filipino drivers tend to follow closest to the leading vehicle under both base and text reading scenarios. The duration of driving blind was the highest for Japanese drivers in the no text reading scenario, and one of the highest in the text reading scenario, which was similar for Vietnamese drivers. No significant differences among races were recorded for line encroachment incidents.

Education seemed to affect line encroachment incidents under text reading conditions. Drivers who received less education showed more inattention than the rest of the drivers under each scenario.

Following interval increased with increasing driving experience in both scenarios. It is interesting to note that duration of driving blind also increased with experience, owing to the possible collinearity of experience with age. Line encroachment incidents differ among years of experience groups, in the text reading scenario. Fewer incidents were recorded in the 10-19 years of experience as compared to the other groups (except for novice drivers), owing to the collinearity of this attribute with the age, which assumes a balanced combination between experience and reflections.

When studying average following intervals, as affected by the scenarios of no text reading and text reading, (while controlling for gender, age, race, education, and driving experience,) we observed that the impact of gender ($F_{(1,201)}$=5.984, p-value=0.015), and the interaction between the effects of the scenarios and gender ($F_{(2,199)}$=7.008, p-value 0.009) on this variable was significant. Significant differences were observed in the mean values of the intervals in the text reading scenario (z=-2.478, sig=0.013).

Furthermore, results showed that intervals are significantly affected by age ($F_{(1,197)}$=3.182, p-value=0.005), but the interaction between the effects of the scenarios and age on intervals was not significant ($F_{(1,191)}$=0.457, p-value=0.839). The mean values of the no text reading scenario (Chi-Square=19.801, sig=0.003) presented significant differences.

In addition, it was indicated that intervals were affected by race ($F_{(1,197)}$=5.221, p-value=0.000), but the interaction between the effects of the scenarios and race on this variable ($F_{(2,191)}$=0.896, p-value 0.485) was not significant. Both in scenario of no text reading (Chi-Square=13.706, sig=0.018) and scenario of text reading (Chi-Square=19.183, sig=0.002), the mean values of intervals were significantly different among races.

Table 3. Effect of Demographic Characteristics on Driving Performance

Performance Indicators	GENDER		Mann-Whitney	
	G E N D E R	Male	z	sig
Avg.FollowingIntervalB	6.478	4.592	-2.478	0.013
Avg.FollowingIntervalA	6.259	5.859	-0.791	0.429
ChangeofAvg.FollowingIntervalBA	0.219	-1.266	-1.753	0.080
LineEncroachmentIncidentB	1.04	0.86	-1.165	0.244
LineEncroachmentIncidentA	3.85	4.23	-0.238	0.812
ChangeofLineencroachmentIncidentsBA	-2.81	-3.37	-0.381	0.703
TotalDurationDrivingBlindB	6.77	7.296	-0.251	0.802
TotalDurationDrivingBlindA	27.048	33.807	-1.012	0.311
ChangeofTotalDurationDrivingBlindBA	-20.281	-26.508	-1.219	0.223

Performance Indicators	A G E						Kruskal-Wallis	
	16-25	26-35	36-45	46-55	56-65	65-75	Chi-Square	Sig
Avg.FollowingIntervalB	3.575	4.255	3.886	4.638	5.396	5.07	6.419	0.378
Avg.FollowingIntervalA	3.95	4.991	4.541	5.538	6.623	6.565	19.801	0.003
ChangeofAvg.FollowingIntervalBA	-0.4	-0.727	-0.65	-0.907	-2.045	-1.478	4.636	0.591
LineEncroachmentIncidentB	0.25	1.36	1.09	0.63	0.79	1.26	6.519	0.368
LineEncroachmentIncidentA	3	1.91	2.55	3.17	4.97	7.04	27.439	0.000
ChangeofLineencroachmentIncidentsBA	-2.75	-0.55	-1.45	-2.53	-4.18	-5.78	22.742	0.001
TotalDurationDrivingBlindB	1.625	9.7	8.623	4.828	5.447	14.974	13.395	0.037
TotalDurationDrivingBlindA	19.775	18.364	27.7	24.113	39.159	48.839	38.402	0.000
ChangeofTotalDurationDrivingBlindBA	-18.15	-8.655	-19.064	-22.363	-33.711	-33.87	41.881	0.000

Performance Indicators	R A C E						Kruskal-Wallis	
	Others	Vietnamese	Filipino	Chinese	Japanese	Korean	Chi-Square	Sig
Avg.FollowingIntervalB	3,816	4,944	3,695	4,168	4,869	5.77	13.706	0.018
Avg.FollowingIntervalA	5,106	7,161	4.53	5,214	5,919	6,525	19.183	0.002
ChangeofAvg.FollowingIntervalBA	-1,291	-2,206	-870	-1,027	-1,050	-754	6.917	0.227
LineEncroachmentIncidentB	0.91	0.72	1.00	1	0.92	0.84	2.150	0.828
LineEncroachmentIncidentA	3.66	4.78	3,050	2.55	5.42	4.61	8.809	0.117
ChangeofLineencroachmentIncidentsBA	-2.75	-4.06	-2.05	-1.55	-4.50	-3.76	9.664	0.085
TotalDurationDrivingBlindB	7,088	6,844	6,320	6,250	11,092	6,566	4.806	0.440
TotalDurationDrivingBlindA	24,828	43,106	25,765	29,605	41,685	33,622	14.242	0.014
ChangeofTotalDurationDrivingBlindBA	-17,731	-36,261	-19,440	-23,355	-30,592	-27,058	14.710	0.012

Performance Indicators	E D U C A T I O N						Kruskal-Wallis	
	ss high schc	High school	Some college	Associate	Bachelor	Graduate	Chi-Square	Sig
Avg.FollowingIntervalB	5.678	4.924	5.098	4.806	4,308	4,778	3.147	0.677
Avg.FollowingIntervalA	7.011	5.788	6.082	5.312	6.063	5.478	3.405	0.638
ChangeofAvg.FollowingIntervalBA	-1.344	-0.863	-0.989	-0.5	-1.75	-0.711	2.701	0.746
LineEncroachmentIncidentB	1.22	0.89	0.95	0.75	0.68	1.33	5.874	0.319
LineEncroachmentIncidentA	7.33	4.64	3.75	2.44	3.9	3.56	11.154	0.048
ChangeofLineencroachmentIncidentsBA	-6.11	-3.75	-2.8	-1.69	-3.23	-2.22	8.259	0.143
TotalDurationDrivingBlindB	13.156	6.871	5.705	5.019	8.715	8.978	7.072	0.215
TotalDurationDrivingBlindA	39.356	35.717	31.266	25.094	30.027	36.567	5.255	0.386
ChangeofTotalDurationDrivingBlindBA	-26.178	-28.846	-25.561	-20.081	-21.307	-27.589	6.857	0.231

Performance Indicators	E X P E R I E N C E					Kruskal-Wallis	
	<=5	5-9	10-19	20-29	30-55	Chi-Square	Sig
Avg.FollowingIntervalB	2,425	1.81	4,179	5,352	4,979	10.327	0.035
Avg.FollowingIntervalA	3.2	5	5,083	6,296	6,106	9.516	0.049
ChangeofAvg.FollowingIntervalBA	-0.825	-3.078	-0.913	-0.946	-1,124	258	0.992
LineEncroachmentIncidentB	0.5	0.75	1.42	0.83	0.82	905	0.924
LineEncroachmentIncidentA	1.5	4.38	2.46	3.7	4.83	14.355	0.006
ChangeofLineencroachmentIncidentsBA	-1	-3.63	-1.04	-2.87	-4.01	17.017	0.002
TotalDurationDrivingBlindB	2,525	6,387	6,858	5,711	8.15	3.101	0.541
TotalDurationDrivingBlindA	6.3	24,525	25,237	29.87	37,277	18.698	0.001
ChangeofTotalDurationDrivingBlindBA	-3,725	-18,113	-18,383	-24,159	-29,127	16.624	0.002

Avg.FollowingIntervalB: Average following interval "no text reading", Avg.FollowingIntervalA: Average following interval "text reading", ChangeofAvg.FollowingIntervalBA: Difference between average following interval "no text reading" and average following interval "text reading", LineEncroachmentIncidentB: Line encroachment incidents "no text reading", LineEncroachmentIncidentA: Line encroachment incidents "text reading", ChangeofLineencroachmentIncidentsBA: Difference between line encroachment incidents "no text reading" and line encroachment incidents "text reading", TotalDurationDrivingBlindB: Blind drive total time "no text reading", TotalDurationDrivingBlindA: Blind drive total time "text reading", ChangeofTotalDurationDrivingBlindBA: Difference between blind drive total time "no text reading" and blind drive total time "text reading"

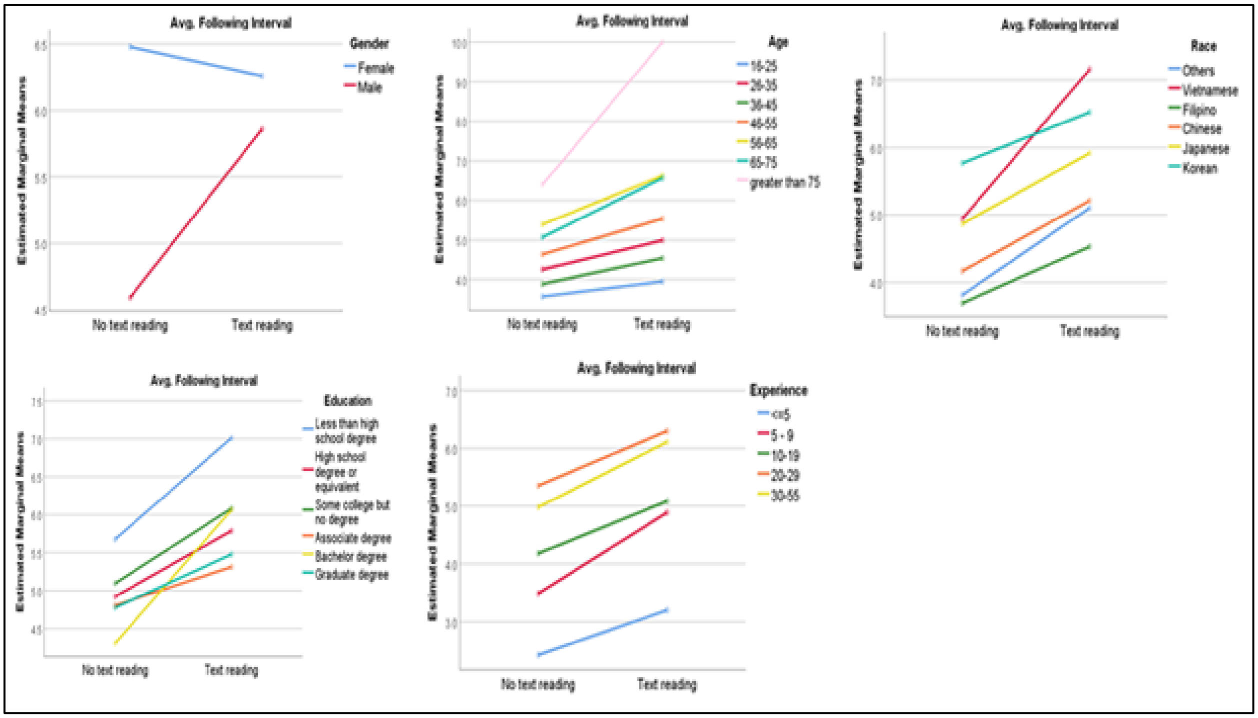

Figure 5. Effect of demographic characteristics on average following interval

When analyzing how intervals are affected by driving experience ($F_{(1,198)}$=3.173, p-value=0.015), it is shown that it was significant while the interaction between the effects of the scenarios and driving experience ($F_{(2,193)}$=0.096, p-value=0.984) was not significant. Both the scenario of no text reading (Chi-Square=10.327, sig=0.035) and scenario of text reading (Chi-Square=9.516, sig=0.049) presented mean values with significant differences.

Education or the interactions of the effects of education with the scenario on the intervals were not significant. Comparisons of average following interval between groups are depicted in Figure 5.

When studying line encroachment as affected by the scenarios of no text reading and text reading, (while controlling for gender, age, race, education, and driving experience,) it was observed that the impact of gender ($F_{(1,201)}$=0.053, p-value=0.819), and the interaction between the effects of the scenarios and gender on this variable ($F_{(2,199)}$=0.423, p-value=0.516) was not significant. No significant differences on the mean values were observed.

However, when analyzing line encroachment incident as affected by age ($F_{(1,197)}$=5.537, p-value=0.000) and the interaction between the scenario and age ($F_{(2,191)}$=4.390, p-value=0.000) on this variable were both significant. The mean values for the text reading scenario (Chi-Square=27.439, sig=0.000) and for the change of both scenarios (Chi-Square=22.742, sig=0.001) presented significant differences.

Also, results showed that line encroachment incident was not significantly affected by race ($F_{(1,197)}$=1.474, p-value=0.200) or by the interaction between the scenarios and race (F=2.098, p-value=0.068). As well as the variable was also not affected by education ($F_{(2,191)}$=2.183, p-value=0.058) or by the interaction between the scenarios and education (F=1.807, p-value=0.113). The mean values of the scenario of text reading (Chi-Square=11.154, sig=0.048) showed significant differences.

Similar to race and education, driving experience did not affect line encroachment, but the interaction between the scenarios and driving experience on line encroachment incident were significant ($F_{(2,193)}$=3.229, p=value=0.014). Significant differences were found for the mean values of the scenario of text reading (Chi-Square=14.355, sig=0.006) and the differences of both scenarios (Chi-Square=17.017, sig=0.002). The illustrative comparisons of line encroachment incidents between groups are depicted in Figure 6.

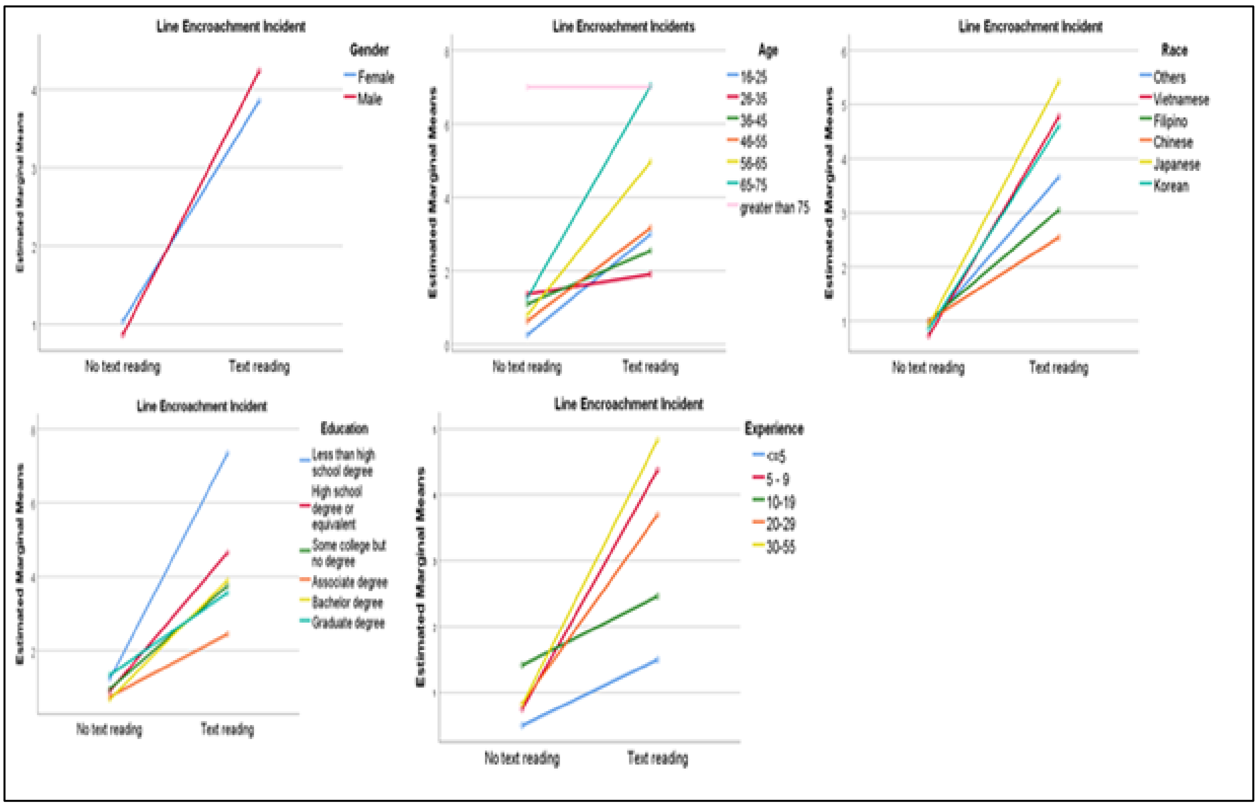

Figure 6. Effect of demographic characteristics on line encroachment incidents

When studying **driving blind total time** as affected by the scenarios of no text reading and text reading, (while controlling for gender, age, race, education, and driving experience,) it was observed that the impact of gender ($F_{(1,201)}$=1.429, p-value=0.233) and the impact of education ($F_{(1,197)}$=0.976, p-value=0.017) on this variable were not significant. The study also observed no significant differences on the mean values.

However, results showed that driving blind total time is significantly affected by all other demographics such as age ($F_{(1,197)}$=7.343, p-value=0.000), race ($F_{(1,197)}$=2.331, p-value=0.044), and driving experience ($F_{(1,198)}$=3.087, p-value=0.017), and also by the interaction between the scenarios and age ($F_{(2,191)}$=6.524, p-value=0.000), race ($F_{(2,191)}$=2.779, p-value=0.019), and driving experience ($F_{(2,193)}$=3.095, p-value=0.017). Regarding the difference of the mean values, it was observed that the driving blind total time mean values of age in no text reading scenario (Chi-Square=13.395, sig=0.037), text reading scenario (Chi-Square=38.402, sig=0.000), and change of the scenarios (Chi-Square=41.881, sig=0.000) presented significant differences.

For the mean values of race, the text reading scenario (Chi-Square=14.242, sig=0.014), and change of the scenarios (Chi-Square=14.710, sig=0.012) presented significant differences. Concerning driving experience, the text reading scenario (Chi-Square=18.698, sig=0.001) and the change of the scenarios (Chi-Square=16.624, sig=0.002) showed significant differences of the mean values. The illustrative comparisons of blind driving total time between groups are depicted in Figure 7.

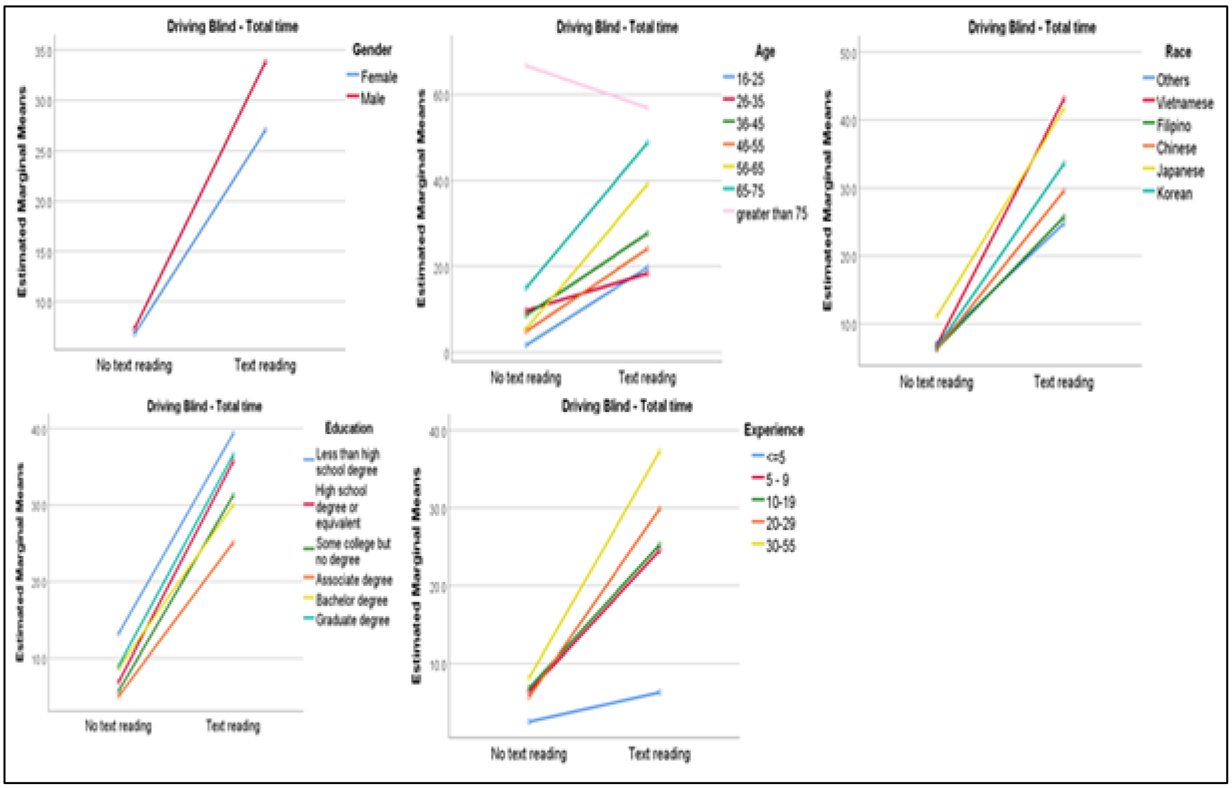

Figure 7. Effect of demographic characteristics on driving blind total time

Two behavioral attributes were used to examine the interactions of their effect with the scenarios on the driving performance indicators. Text reading and sending was reported by the survey participants in respect to the frequency they were conducting these tasks while driving. The results of this analysis are depicted in Figure 8.

Significant differences were observed in the average following interval owing to different read and send messages groups ($F_{(1,198)}$=2.257, p-value=0.065, and $F_{(1,198)}$=2.58, p-value=0.065, respectively). In this analysis, differences of blind drive time between no text reading and text reading were also significant ($F_{(1,197)}$=8.996, p-value=0.003).

Average following interval increases as the frequency of reading or sending messages decreases. This indicates that conservative drivers avoid getting involved in parallel tasks while driving. Similar trends follow the other two indicators. Line encroachment incidents increase for drivers who read and send messages less frequently. Likewise, conservative drivers are more distracted than other drivers under both scenarios of text reading. Finally, as it is expected, all three driving performance indicators deteriorate when drivers read text while driving.

Some interactions of the effects are observed between scenario and frequencies (Figure 7), however these are not significant.

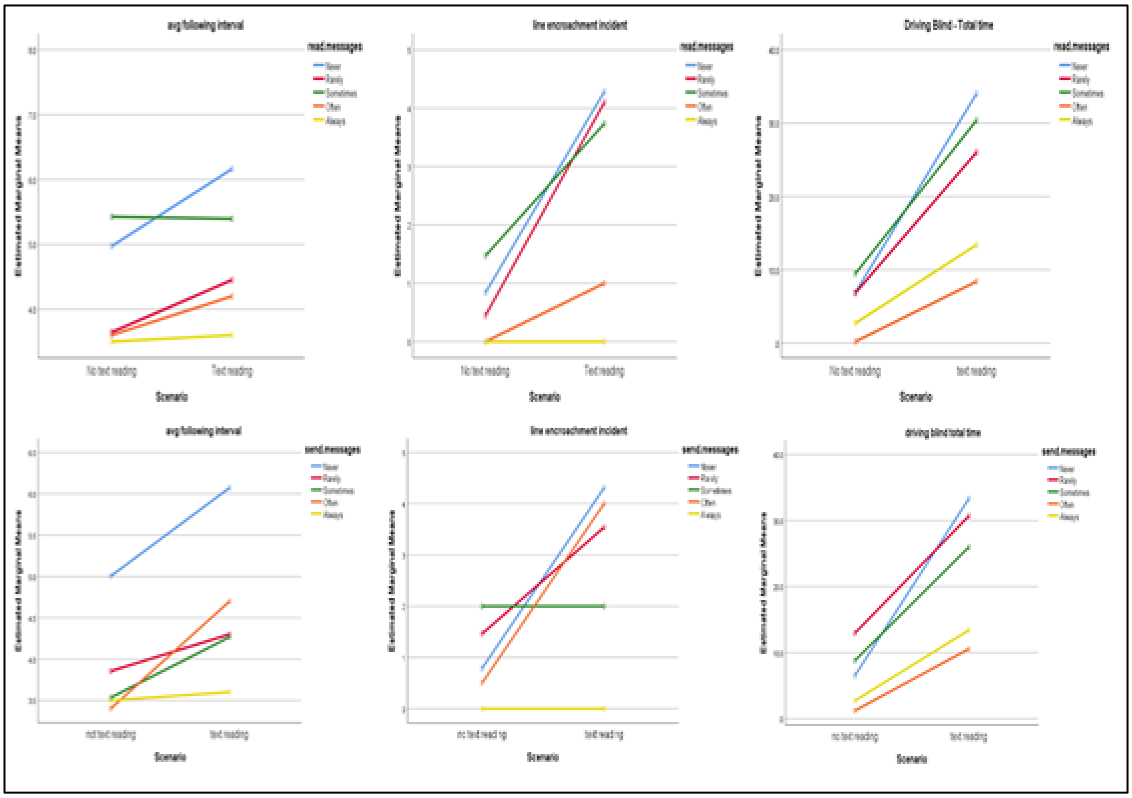

Figure 8. Effect of self-reported driving behavior on driving performance

CHAPTER 5. ADDITIONAL ANALYSIS: PREDICTING THE IMPACT OF TEXT-READING USING DECISION TREES

As shown in Chapter 3, drivers had to complete a questionnaire addressing two sets of attributes before their training and observation on the simulator. The first set included demographic questions on gender, age, education level and driving experience; the second, investigated behavioral aspects related to driving and following the principles of behavioral modelling described by Breiman et al [60]. The survey included the components, below; they are also shown in Table 4.

- Behavior: “While driving, how often do you make or take phone calls, read emails or text messages, send emails or text messages, surf the net or social media, use GPS or map service” (Attributes B1.1 – B1.5)
- Behavior: “What is your typical speed when you drive on a freeway with 55 mph speed limit and light traffic, on a major urban street with speed limit 25 mph and moderate traffic, on a rural highway with speed limit 45 mph” (Attributes B2.1-2.6)
- Control Beliefs: “What are the chances of getting arrested after drinking and driving in Hawaii”, “If all drivers are trained in safe driving, how safe would be the roads?”, “What are the chances of getting a speeding ticket?” (Attributes CB1-3)
- Descriptive Norms: “What are the chances of a driver in your area to get a speeding ticket?” (Attribute DN1)
- Risk Appreciation: “How many trips did you drive at night, in the last two weeks?” and “Do you drive less when it rains?” (Attributes R1-2)
- Behavioral Beliefs: “Do you think that enforcement is too strict in Hawaii?” (Attribute BB1)
- Past Behavior: “Have you been stopped by the police”, “issued a ticket”, “been involved in an accident”, been involved in an accident owing to using your cell phone” (Attributes PB1-PB6)

The subjects drove the simulator for 10-15 minutes, to familiarize themselves with the reaction of the various controls, such as steering wheel, accelerator and brakes. After given some explanations about the driving scenario of the experiment, all drivers drove along a rural highway with two lanes per direction and frequent merging and diverging sections with moderate traffic, for approximately 9 minutes. During their drive, subjects had to read the messages every time they were displayed on the mobile device installed on the dashboard. Three texts were displayed from low to moderate complexity, similar to the messages they receive on their business-as-usual. Their reactions were recorded, including maximum blind driving time and line encroachment incidents. These two were selected to be further analyzed here, as the first is the direct measurement of the distraction owing to text reading and the latter its impact.

The database was formulated containing the demographic, self-reported behavioral attributes and driving performance measurements with and without text reading. Some further analysis was done to the driving performance, to calculate their difference between the two conditions.

The analysis was based on Structure-Activity Relationships and it used decision trees. Decision tree models can be used to select the number and kind of variables required for the conduct of research, assess the relative importance of these variables and create non-linear decision boundaries that fit data very well. They handle any missing values in a dataset, predict outcomes based on past data and improve the handling of variables by allowing merging values when their number is too high [61]. Decision Trees are among the popular approaches to represent classifiers with extended applicability in many disciplines, such as statistics, data mining, machine learning etc. [62].

Table 4. Decision Tree Attributes

Code	Maximum blind drive time changes	Line encroachment	Attribute
DE1		node	gender
DE2	Root node	node	age
DE3			race
DE4	node	node	education
DE5	node	node	driving.experience.1
B1.1		node	phone.calls
B1.2	node		read.messages
B1.3			send.messages
B1.4			surf.the.net
B1.5	node	node	use.maps
B2.1		node	speed.on.freeway.with.speed.limit.of.55.mph.in.light.traffic
B2.2			more.than.speed.on.freeway.with.speed.limit.of.55.mph.in.light.traffic
B2.3			speed.on.a.major.city.street.with.speed.limit.of.25.mph.moderate.traffic.and.green.light
B2.4			more.than.speed.on.a.major.city.street.with.speed.limit.of.25.mph.moderate.traffic.and.green.light
B2.5	node		speed.on.a.rural.highway.with.a.speed.limit.of.45.mph
B2.6			more.than.speed.on.a.rural.hwy.with.a.speed.limit.of.45.mph
CB1		node	What.do.you.think.are.the.chances.of.arrest.after.drinking.and.driving.in.Hawaii
CB2		Root node	If.all.drivers.are.trained.in.safe.driving.the.roads.would.be.safer
CB3		node	chance.of.you.receiving.a.speeding.ticket.in.Hawaii
DN1			chance.for.the.typical.driver.in.your.area.of.receiving.a.speeding.ticket
R1			In.the.last.two.weeks.how.many.trips.did.you.drive.at.night
R2		node	Do.you.drive.less.when.it.rains
BB1		node	Do.you.think.that.blood.alcohol.level.is.too.strict.in.Hawaii
PB1			Have.you.taken.your.vehicle.for.inspection.and.maintenance
PB2			Have.you.been.stopped.by.the.Police
PB3		node	Were.you.issued.a.citation
PB4			Have.you.had.a.DUI
PB5			Have.you.been.involved.in.a.traffic.accident
PB6			did.any.of.these.accidents.involve.your.cell.phone.use
Total number of attributes	6	13	

The most commonly used decision trees are the CART and the C4.5 based models. However, C4.5. proves to be more flexible than CART, as it allows for more than binary decisions. For ranking tests, C4.5 uses information-based criteria, while CART the Gini diversity index. CART prunes trees using a cost-complexity model (the parameters of this model are estimated by cross-validation) while C4.5 uses a single-pass algorithm derived from binomial confidence limits. The greatest advantage of C4.5 is linked with its attitude when some case values are unknown, as it apportions the case probabilistically among the outcomes, while CART looks for surrogate tests that approximate the outcomes.

The J48 classifier is a decision tree implementation of the C4.5 algorithm in the open source software WEKA (Waikato Environment for Knowledge Analysis) [63 to 68]. It produces more correctly classified objects than the Naive Bayes classifier [64]. J48 is also shown to produce better results Support Vector Machines (SMVs), a supervised learning model, while having the same classification accuracy (100%) with Multilayer Perceptron (MLP), which is an artificial neural network model [19]. The C4.5 algorithm and its J48 WEKA version have been used in a wide range of cases across many disciplines [63, 66-68].

Changes of the two dependent variables, maximum blind driving time (mean values) and line encroachment incidents were calculated between the no texting and texting conditions. They were further transformed into nominal variables, following the specification of the classifier. Three values were considered, reflecting the decision tree class labels “more”, “null” and “less”, corresponding to higher, equal and less driving blind time or encroachment incidents, respectively, while texting as compared to the no texting. The dependent variables and influencing attributes are shown in Table 1.

The steps for building the classification tree models were as follows. Each decision tree is formulated by the main classifier (root node), which depicts the basic attribute for the classification, followed by other attributes, called interior nodes, and ending at the class labels (leaf or end nodes). Every class label is described by the correctly and the incorrectly classified instances (observations used by the tree) when following the specific path from the root to the leaf node. Paths starting at the same node are mutually exclusive, and the classification is such that it maximizes the information gain [69]. As a decision tree development may lead to a very large number of leaf nodes, the selected J48 classifier was set-up with a post-pruning method. Post-pruning is the process of evaluating the decision error (estimated % of misclassifications) at each decision junction and propagating this error up the tree. At each junction, the algorithm compared the weighted error of each child node versus the misclassification error if the child nodes were deleted and the decision node were assigned the class label of the majority class.

The tree developed for the maximum time driving blind change has 15 leaves and its size is 29 (total number of nodes). The main classifier (root node) is the age (DE2) and the branches formulated for subjects more years old and less or equal than 40 years old.

The tree has classified correctly 86% of the instances with a high statistical significance indicated in the value of the Kappa statistic 0.53. Table 5 depicts the summary of the tree statistics and Table 6 shows the performance of the tree for each of the three examined classes. Expected accuracy by class is high for more and less time, but there are no correctly classified instances for no change (null), as all 8 observed instances were classified in the other two classes. This is not considered as a problem, owing to the small proportion of null instances over the total (0.6%). For the other two classes, true positive rates range from 0.56 to 0.97 and class recall is high calculated to a weighted average of 0.86. The Receiver Operator Characteristic (ROC) under the curve is 0.806 on the average, indicating a high statistical dependence.

Table 5. Statistics for the Classification of Maximum Time Driving Blind Changes

Correctly Classified Instances	88.3249 %
Incorrectly Classified Instances	11.6751 %
Kappa statistic	0.7051
Mean absolute error	0.1251
Root mean squared error	0.2488
Relative absolute error	42.9391 %
Root relative squared error	65.4402 %
Total Number of Instances	197

Table 6. Decision Tree Accuracy by Class of Maximum Time Driving Blind Changes

Class	TP Rate[1]	FP Rate[2]	Precision[3]	Recall[4]	F-Measure[5]	MCC[6]	ROC Area[7]	PRC Area[8]
1 (null)	0.000	0.000	?	0.000	?	?	0.806	0.145
2 (more)	0.974	0.500	0.871	0.974	0.920	0.583	0.801	0.908
3 (less)	0.556	0.037	0.769	0.556	0.645	0.592	0.827	0.636
Weighted Avg.	0.858	0.395	?	0.858	?	?	0.806	0.827

The confusion matrix in Table 7 indicates the classification of the instances by actual observation class. The exact number of the correctly/not correctly classified instances is represented in the tree graph inside each parenthesis at the end nodes (Figure 9).

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[1] True Positive Rate (correctly identified)
[2] False Positive Rate (incorrectly identified)
[3] Precision is the probability that a (randomly selected) retrieved instance is relevant
[4] Recall is the probability that a (randomly selected) relevant instance is retrieved in a search
[5] F-Measure is the harmonic mean of precision and recall (F-Measure = 2* (Precision* Recall) /(Precision+Recall))
[6] Matthews Correlation Coefficient
[7] The area under the ROC curve as the Wilcoxon-Mann-Whitney statistic
[8] The area under the precision-recall curve

Table 7. Confusion Matrix of Maximum Time Driving Blind Changes

	Classified as		
Observations	Null	More	Less
Null	0	6	2
More	0	149	4
Less	0	16	20

The tree developed for the line encroachment incident change has 27 leaves and its size is 52 (total number of nodes). The main classifier (root node) is the control belief parameter (CB2) which examines the perception of the subjects on how to enhance road safety.

The tree has classified correctly 88% of the instances with a high statistical significance indicated in the value of the Kappa statistic 0.70. Table 8 depicts the summary of the tree statistics and Table 9 shows the performance of the tree for each of the three examined classes. Expected accuracy by class is also high. True positive rates range from 0.64 to 0.97 and class precision and recall are high in all classes with a weighted average of 0.88. Their harmonic mean (F-measure) is equal to 0.88 and the Receiver Operator Characteristic (ROC) under the curve is 0.92, indicating a high statistical dependence. The confusion matrix in Table 10 indicates the classification of the instances by actual observation class. The exact number of the correctly/not correctly classified instances is represented in the tree graph inside each parenthesis at the end nodes (Figure 10).

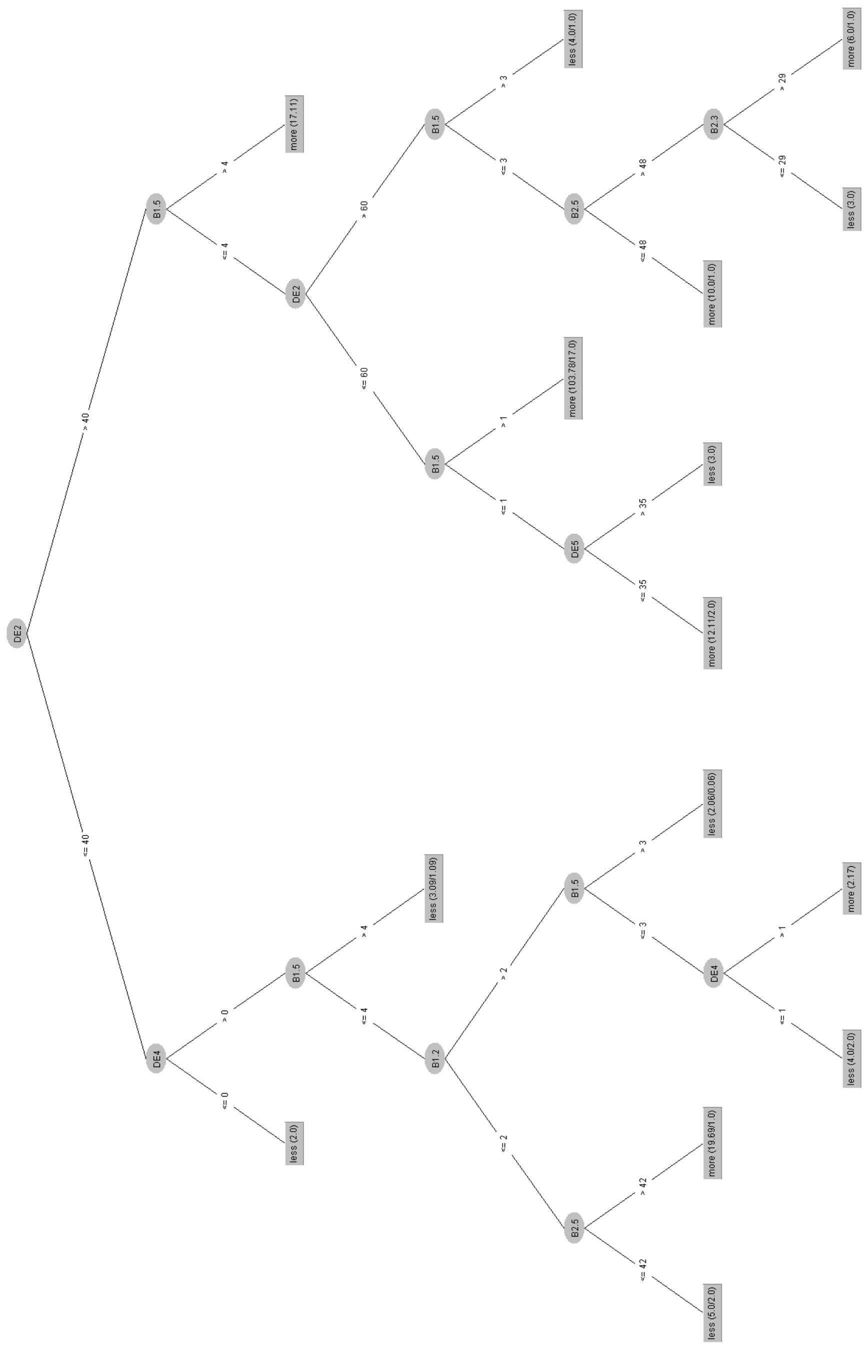

Figure 9. Decision tree of maximum blind driving time changes

Table 8. Statistics for the Classification of Line Encroachment Incident Changes

Correctly Classified Instances	88.3249 %
Incorrectly Classified Instances	11.6751 %
Kappa statistic	0.7051
Mean absolute error	0.1251
Root mean squared error	0.2488
Relative absolute error	42.9391 %
Root relative squared error	65.4402 %
Total Number of Instances	197

Table 9. Decision Tree Accuracy by Class of Line Encroachment Incident Changes

Class	TP Rate[9]	FP Rate[10]	Precision[11]	Recall[12]	F-Measure[13]	MCC[14]	ROC Area[15]	PRC Area[16]
1 (less)	0.667	0.023	0.778	0.667	0.718	0.690	0.963	0.781
2 (more)	0.972	0.315	0.891	0.972	0.930	0.722	0.906	0.947
3 (null)	0.636	0.012	0.913	0.636	0.750	0.726	0.932	0.781
Weighted Avg.	0.883	0.233	0.883	0.883	0.877	0.719	0.916	0.901

[9] True Positive Rate (correctly identified)
[10] False Positive Rate (incorrectly identified)
[11] Precision is the probability that a (randomly selected) retrieved instance is relevant
[12] Recall is the probability that a (randomly selected) relevant instance is retrieved in a search
[13] F-Measure is the harmonic mean of precision and recall (F-Measure = 2* (Precision*Recall)/(Precision+Recall))
[14] Matthews Correlation Coefficient
[15] The area under the ROC curve as the Wilcoxon-Mann-Whitney statistic
[16] The area under the precision-recall curve

Table 10. Confusion Matrix of Line Encroachment Incident Changes

	Classified as		
Observations	Less	More	Null
Less	14	7	0
More	2	139	2
null	2	10	21

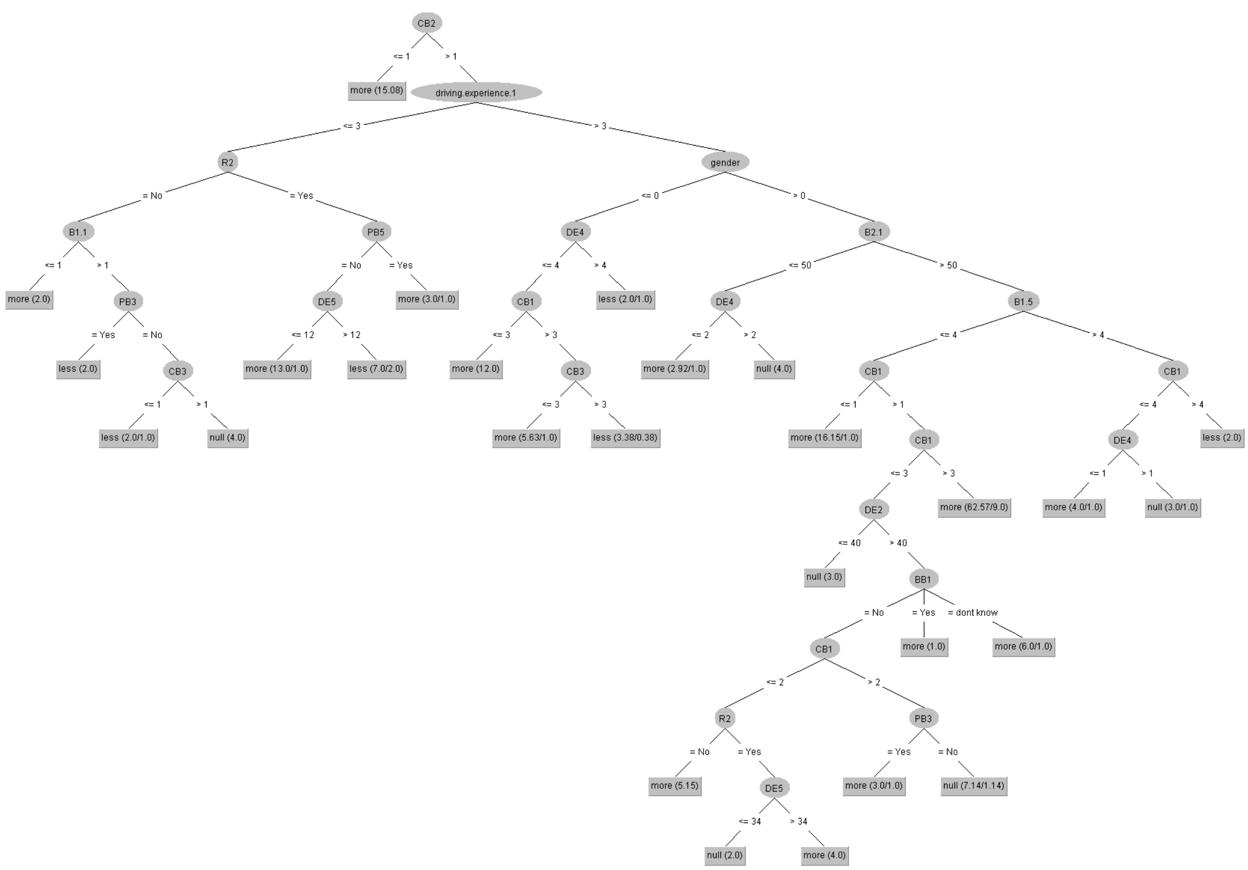

Figure 10. Decision tree of line encroachment incident changes

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

The goal of this research was to study the effect of text reading on the driving performance of professional taxi drivers. We had hoped to have a large sample of CSET minority drivers as in the FARS analysis report [70] but this was not the case with the pool of taxi drivers from our research partner CTL. 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 11.

Table 11. Comparison between Past Research and Our Research Results

Performance Indicator	Our Results	Results of Past Research		
Headway	↑	↑ 8,43	↓ 44	
Lane Deviation	↑	↑ 8,30,31,32	— 29	↓ 44
Lane Change Frequency	↓	↓ 8		
Driving Performance	↓	↓ 32,43		
Looking Away from Road	↑	↑ 8,30,32,33		
Speed Fluctuation	↑	↑ 31, 32		
Braking Aggressiveness	—	…..		
Driving Blind-Incidents	↑	…..		
Driving Blind-Travel Distance	↑	…..		

Key: ↑ = An increase; ↓ = A decrease; — = No Effect; 1, 2, 3 …………..44= Reference Numbers

Text messages to taxi drivers (i) are necessary for giving detailed information, (ii) can be read when it is safer to do so, (iii) maintain privacy compared to audio, and (iv) help overcome language or other communication barriers. The findings of this research are statistically significant and important. It 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.

Distraction caused by text reading has a significant effect on driving performance and safety. This research output suggests that taxi drivers (and drivers in general) should be discouraged from engaging in reading texts while driving.

Our study also provided additional insights on the association of demographic characteristics (age, gender, race, education, and driving experience) with driving performance while texting, as well as with self-reported driving behavior related to reading and writing messages while driving. Age, experience and race are the most important influencers in distraction prediction, under no text reading and text reading scenarios. Older drivers, although more experienced, in most cases get more distracted when involved into parallel tasks while driving.

Korean, Filipino and Vietnamese drivers had significantly different metrics compared to others and the driver averages. Drivers with higher levels of education seem to have a driving performance that is less affected by texting conditions. Gender also influences drivers' inattention. For example, women drivers followed traffic at longer intervals than men. Also, lane encroachment incidents in the no text reading scenario were more for women than for men, but this inverted while reading text which suggests that women are more conservative than men in their lane position.

Three examined indicators, average following interval, line encroachment incidents and time driving blind are inversely proportional to the frequency of the driver involvement in tasks with on-board devices. Self-reported behavior proved to be associated with driving performance in general and is a good predictor of the impact of text reading while driving. In general, our results are in agreement with findings reported in recent past literature, as depicted in Table 12.

Table 12. Summary of Significant Assessed Effects

Driving Performance Indicator	Influencing Attribute while Text Reading	Previous Literature
Average following interval	Gender, age, race, experience, driving behavior	Gender [71]
Line encroachment incidents	Age, education, experience	Age [72,73,74], gender [73]
Maximum time driving blind	Age, race, experience	N/A

Finally, decision trees were developed to estimate the impact of text reading while driving. Two main distraction variables were examined, maximum time driving blind, which is the direct effect of text reading; and line encroachment incidents, which is an additional consequence of distraction. A set of attributes was considered including demographic characteristics, and self-reported behavioral constructs; behavior, control beliefs, behavioral beliefs, descriptive norms, risk appreciation and traffic record.

We observed that during text reading 78% of the drivers increased the maximum time driving blind and the rest either reduced it or were not affected. Similarly, 73% of the drivers increased their line encroachment incidents while text reading than in the case of no reading, while 17% were not affected. Decision trees predicted these changes with an accuracy of 86% for the maximum time driving blind and 88% for the line encroachment incidents.

The associations built between these two variables and the attributes affecting them showed a strong impact of age on maximum time driving blind changes, supported by education and driving experience, and behavior. Line encroachment incident changes are mainly affected by the perception of the drivers about the measures to increase road safety, and also by most of the demographic characteristics and a combination of constructs related to behavior, control beliefs, behavioral beliefs, risk appreciation and past behavior. Associations of the attributes with the dependent variables indicated high statistical dependence with a high accuracy.

These outcomes suggest that the driving performance is not only affected by several demographic attributes, which are widely covered in the literature, but also the behavioral profile of each driver which should be collected and incorporated in the estimation of the impact of distractive tasks while driving. The behavioral profile includes driving preferences, control beliefs, behavioral beliefs, descriptive norms, risk appreciation and traffic record.

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APPENDIX: PROJECT PUBLICATIONS

Major findings of this task of CSET-supported research were published and presented as follows.

- Miah, Mintu M. and Panos D. Prevedouros, Effects of Reading Text While Driving: Analysis of 200 Honolulu Taxi Drivers on a Simulator, Paper 19-00176, 98th Annual Meeting of TRB, Washington, D.C., 2019.
- Nathanail, Eftichia,[17] Panos D. Prevedouros and Mintu M. Miah, Predicting the Impact of Text-Reading Using Decision Trees, Paper No. 245, EPIA Conference on Artificial Intelligence, Vila Real, Portugal, September 3-6, 2019.
- Prevedouros, Panos D., Eftihia Nathanail, Md. Mintu Miah and Rafaela De Melo Barros, Predicting Behavior of Professional Drivers while Text-Reading Using Cluster Modeling, Paper 185, Conference on Road Safety & Simulation (RSS2019.org), Iowa City, Iowa, USA, October 14-17, 2019.

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