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Driving Simulator Validation And Rear-end Crash Risk Analysis At A Signalised Intersection

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DRIVING SIMULATOR VALIDATION AND REAR-END CRASH RISK ANALYSIS AT A SIGNALISED INTERSECTION

by

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ABSTRACT

In recent years the use of advanced driving simulators has increased in the transportation engineering field especially in evaluating safety countermeasures. The driving simulator at UCF is a high fidelity simulator with six degrees of freedom. This research aims at validating the simulator in terms of speed and safety with the intention of using it as a test bed for high risk locations and to use it in developing traffic safety countermeasures.

The Simulator replicates a real world signalized intersection (Alafaya trail (SR-434) and Colonial Drive (SR-50)). A total of sixty one subjects of age ranging from sixteen to sixty years were recruited to drive the simulator for the experiment, which consists of eight scenarios. This research validates the driving simulator for speed, safety and visual aspects. Based on the overall comparisons of speed between the simulated results and the real world, it was concluded that the UCF driving simulator is a valid tool for traffic studies related to driving speed behavior. Based on statistical analysis conducted on the experiment results, it is concluded that SR-434 northbound right turn lane and SR-50 eastbound through lanes have a higher rear-end crash risk than that at SR-50 westbound right turn lane and SR-434 northbound through lanes, respectively. This conforms to the risk of rear-end crashes observed at the actual intersection. Therefore, the simulator is validated for using it as an effective tool for traffic safety studies to test high-risk intersection locations. The driving simulator is also validated for physical and visual aspects of the intersection as 87.10% of the subjects recognized the intersection and were of the opinion that the replicated intersection was good enough or realistic. A binary logistic regression model was estimated and was used to quantify the relative rear-end crash risk at through lanes. It was found that in terms of rear-end crash risk SR50 east-bound approach is 23.67% riskier than the SR434 north-bound approach.

I dedicate this work to my mother Jayamani

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1 . INTRODUCTION

The University of Central Florida driving simulator is a high fidelity simulator which means that it conforms to a high quality of standard which reproduces sounds or images in a very realistic manner. It is mounted on a motion base capable of operation with six degrees of freedom which makes the simulator move in up / down, and lateral (left / right) directions.

Figure 1-1: UCF Driving Simulator

It consists of 5 channels (1 forward, 2 side views and 2 rear view mirrors) of image generation; an audio and vibration system; steering wheel feedback; an operator/instructor console with graphical user interface; sophisticated vehicle dynamics models for different vehicle classes; a 3-dimensional road surface model; a visual database with rural, suburban and freeway roads, and an assortment of buildings and operational traffic control devices; and a scenario development tool for creating real-world driving conditions.

Abdel-Aty et al. on the safety issue at the intersection of Alafaya trail (SR-434) and Colonial Drive (SR-50) conducted an extensive research at UCF. This research was based on crash police reports between years 1999 to 2002. This intersection experienced more rear-end type of crashes with a frequency of 95 and a relative frequency of 57.9% followed by angle crashes with a frequency of 24 and a relative frequency of 14.6%, Left turn crashes, 12 or 7.3%, sideswipe, 10 or 6.1%, and right turn, 8 or 4.9% followed. From the severity point of view, during the research period there were 73 PDO crashes, 90 injury crashes, and 1 fatal crash. It concluded that the rear-end crash rate in the eastbound approach of the Colonial Drive (50EB) is highest and that in the northbound approach of the Alafaya Trail (434NB) is lowest.

According to the crash spot diagram (Figure 1-2), out of total 95 rear end crashes 24 crashes happened at Alafaya Trail right-turn lanes; 8 for southbound traffic and 16 for northbound traffic. During the same period, Colonial Drive right-turn lanes had only 6 rear-end crashes. Hence, it is clear that Alafaya Trail right-turn lanes have safety problems when compared to Colonial Drive. Moreover, out of sixteen accidents in Alafaya trail north bound right turn lane, driver age between 24 years and 64 years are involved in thirteen accidents and all accidents are evenly distributed among male and female gender groups.

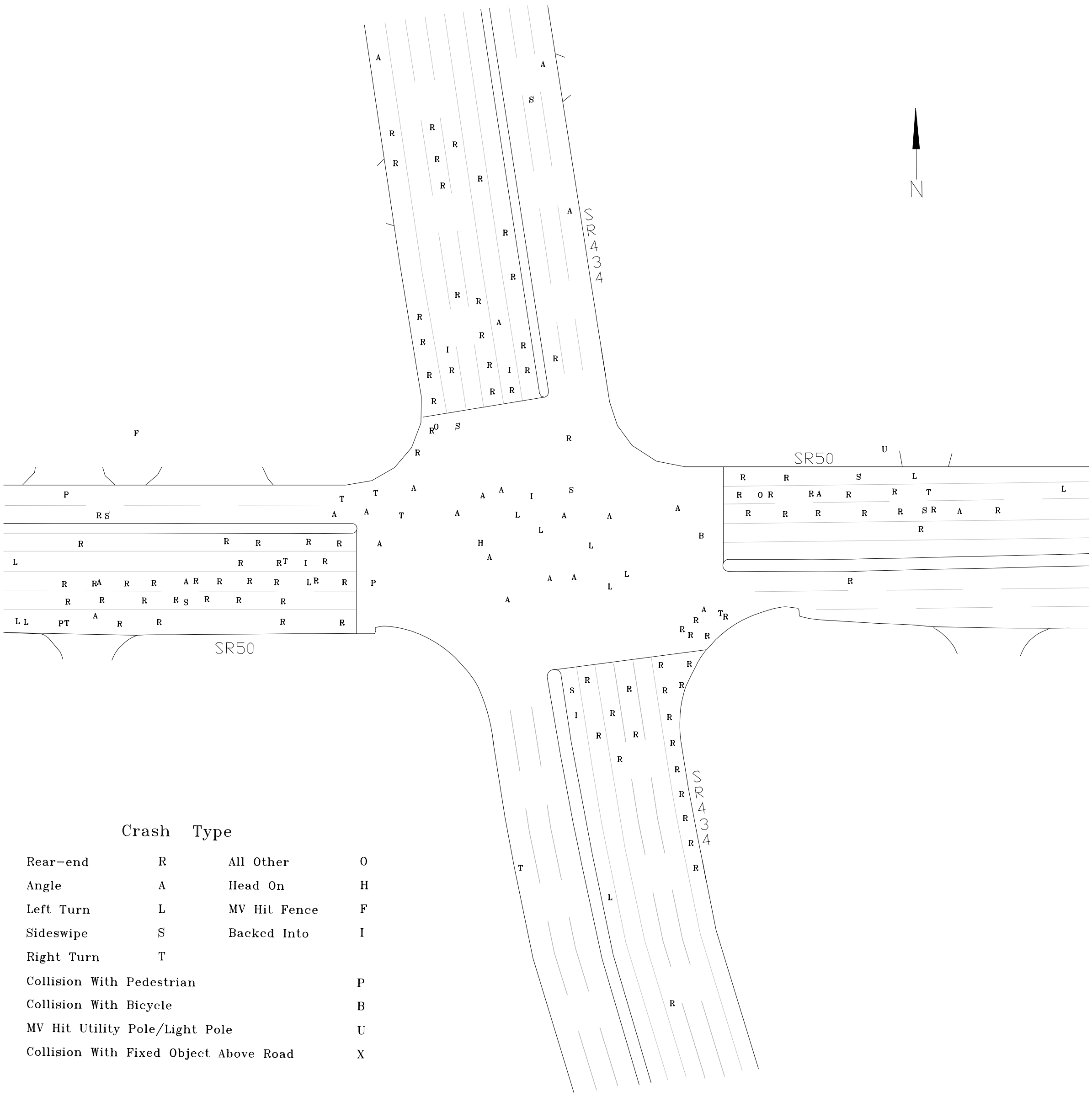

Figure 1-2: Crash spot diagram for years 1999 to 2002

In order to study the safety aspects at this intersection, the intersection is replicated in the Simulator and sixty subjects were employed to run the experiment. The primary objective of this research is to validate the simulator in order to use the simulator as a *test bed* for various traffic safety counter measure applications. This research is a unique application of Driving Simulator where the Simulator is validated for Speed and Safety and visual aspects.

2 . LITERATURE REVIEW

The driving simulator, lately, has emerged as a flexible high – fidelity research facility to assess and evaluate new systems for driver support and traffic management. It is also proven to be a cost effective tool to test real life like scenarios in a simulated environment. At this stage, along with the innumerous applications of the driving simulator it is equally important to validate the simulator. The purpose of many of the previous studies was to develop effective tools to validate the driving simulator with respect to factors such as safety, speed, human behavior, etc. A review of the literature for the applications and validation of driving simulators is given in the following sections.

2.1 Applications of Driving Simulators

Alexander et al. (2002) studied the factors influencing the probability of an incident at an intersection using an interactive driving simulator. They tried building a model for predicting the probability of an incident (a crash or a 'near miss') occurring as a result of a right-turn across traffic (note that right turn in the UK is equivalent to left turn in the US). This can be considered to be the product of two separate probabilities, the first being the probability that the gap between a pair of vehicles in the traffic stream is accepted, and the second the probability that the time needed to cross the on-coming stream of traffic causes the time-to-collision with the nearest vehicle in this traffic stream to be less than a second. The study identifies the factors, which might explain the reasons why elderly drivers are over represented in intersection crashes based on earlier studies. The sample population used consisted of 40 volunteers, 30 aged 65 and over and the rest below 65.The main part of the evaluation consisted of eight spells of driving, featuring different combinations of lighting condition (day/night), traffic speed (30/60 mph) and status of in-vehicle device (on/off). The device used for giving subjects advice on when to make a maneuver (designed specifically for the purposes of this evaluation) consisted of a small box with a display of two lights: a red light to indicate to the user that the current gap in the stream of traffic was less than a pre-set threshold, and therefore it was deemed that it was not safe to cross, and a green light that was illuminated when the gap was at or above this threshold. The effect of various factors (order of the gap, age, sex, velocity, vehicle size, vehicle color, the electronic device and day or night-time conditions) on the median acceptable gap was examined using Probit analysis. They found that as number of gaps rejected increased there is an overall increase in the median accepted gap. The speed of the on-coming vehicle had a great effect on the median accepted gap size. The drivers were found more reticent to turn left (in the US) across slower moving vehicles than faster moving vehicles at the same gap size. The probability of a crash or near miss at gap size is taken to be the product of the probability of gap size being accepted and the probability that time taken to cross is greater than gap size – 1 s (near miss). It was concluded that the probability that a driver will have a crash or a near miss when turning right across a stream of traffic is dependent on both the size of the gap that driver will accept in an on-coming stream of traffic and the time taken to cross the intersection once the gap has been accepted. The factors affecting size of gap and time taken to cross are age, sex, speed, size and color of the on-coming vehicle and the order of the gap.

Comte et al. (2000) made a comparison between four speed-reducing methods (a road-side Variable Message Sign displaying the advisory speed and their number plate, an in-car advice displaying the advisory speed for the curve (in-car), a speed limiter that automatically reduces driver speed to the advisory speed and transverse bars with decreasing spacing) against the baseline condition using a driving simulator. Fifteen males and 15 females took part in the experiment. The subjects were to drive a road network with equal number of left and right curves. For each segment average values of speed, acceleration, and lateral position were derived. The percentage of speed reduction completed before curve entry was calculated as measure of anticipatory behavior. Total heading errors (sum of the means of the difference between the simulator heading and the road heading over a 30 m section of the approach over the full distance of approach (270 m) was calculated as an indication of steering performance. The number of lane departures and minimum time-to-line crossing were also recorded in the curve, as an indication of controlled curve negotiation. The data were analyzed using multivariate analysis of variance. The percentage speed reduction at the curve approach was calculated for each system and was concluded that speed reduction was not at a constant rate in baseline condition. They found that of all the systems, the speed limiter surpassed all the other systems in terms of effectively reducing speed on approach to curves and consequently having additional positive effects on lateral control in curve negotiation.

Various studies were based on trying to find a correlation between driving performance in the older drivers with factors like vision, visual perception, cognition, reaction time, and driving knowledge. It was found that there was considerable relation among these factors. Ikeda et al. (2002) observed the effects of mental and physical deterioration of elderly drivers when facing an accident, using a driving simulator. Twelve subjects, three young (20-25), three middle aged (35-45) and six old (over 60) were made to drive 2km (10min) before the intersection, in the JARI driving simulator. In order to reproduce such deterioration in the aged drivers, the subjects were required to do multiple tasks while driving, e.g., following traffic signals and signs, preceding cars etc. The reaction time was measured in three categories detection time, recognition/judgment time, and operation time. They found that there are differences in reaction time between the old, the young and middle-aged 0.3 and 0.42 s on an average respectively, which showed an aging effect. It was concluded that once another vehicle is detected, the time required for recognition and judgment by the aged driver is rather shorter than that of the younger ones, compensating for the delay due to age. The older driver becomes not good at simultaneous processing of multiple tasks due to deterioration of information processing, but it seems that they have action patterns through experience to react to various recognized objects, which makes them able to complete recognition/judgment of individual tasks in a short time.

Roge (2001), France, made an attempt to confirm the existence of a relation between the occurrence of certain behaviors and the variations of the level of arousal during a monotonous simulated car drive. There exist two types of behavioral activities: those necessary to the performance of the task and those that are not directly imposed by the task. The latter are called non-specific activities, subsidiary activities, or collateral activities. Scientists distinguish five categories of such behaviors, which can be defined as follows. 'Postural adjustments' are movements of one or several parts of the body in space. 'Verbal exchanges' are exchanges that do not include any piece of information about the activity itself. 'Ludic activities' are movements implying the manipulation of objects. 'Self-centered' gestures are movements of one or both hands towards the body. Finally, 'non-verbal activities' are changes that can be observed on the face. The occurrence of a decrement in vigilance can be assessed by means of alpha and theta electroencephalographic indices, whose decreasing indicates the occurrence of dozing-off episodes during driving at work. Eight women and nine men, aged 20 – 30, drove for 2 hours on the Vigilance Analysis Driving Simulator. The effect of the 'driving duration' variable on the length of the low vigilance episodes and on the number of behavioral activities in each category was analyzed by means of non-parametric tests (Friedman's test). This result indicates a progressive decrease in the level of arousal, the low vigilance periods becoming longer as the experiment was prolonged. It was observed that drivers developed more behavioral activities as the experiment was prolonged. They concluded that duration of driving had a significant effect on self-centered gestures, on non-verbal activities, on ludic activities and on postural adjustments. Non-verbal activities are the only precursory signs of a decrease in vigilance in the context of monotonous car driving.

Mourant at al. (2000) studied the simulator sickness in virtual environments driving simulator. They examined whether the severity and type of simulator sickness differs due to the type of driving environment or the gender of the driver. Thirty subjects (15 males and 15 females) were told to drive in either a highway, rural or city environment. Simulator sickness Questionnaire and postural stability tests were used to gather data before and after participants drove the virtual environments based driving simulator. ANOVA was used to analyze the experimental design results. It was found that most of the subjects reported to have coulometer discomfort, i.e. eye strain, headaches, difficulty focusing, and blurred vision. Also vehicle velocity was found to be a factor in driving simulator sickness.

Lee et al. (1997) made a similar study on simulator sickness. They wanted to determine whether there was a relationship between simulator sickness and measures of driver inputs, vection (illusionary impression of self-motion), and postural sway. Eleven undergraduate students from University of Central Florida (four females and seven males) between the ages 19 and 28 were used as test subjects. Subjects drove the UCF driving simulator for five minutes at 30 miles per hour. Data were collected for four dependent measures: vection, postural stability, simulator sickness and driving performance. It was found that ten out of the eleven subjects reported sickness. Also eight of the nine subjects who reported vection also reported sickness. That is, subjects who experienced vection tended to have sickness as well.

Cheng et al. (2002) investigated driver's responses to a forward vehicle collision warning by driving simulator experiments. Thirty-six subjects were disposed randomly to the following three kinds of dangerous scenes while the subjects were intentionally distracted (like a subtask which was a mental arithmetic calculation etc): closing to a preceding vehicle, sudden cut-in of a vehicle from an adjacent lane, and lane departure of own vehicle. Audible means of warning were used consisting of different kinds of warning sounds corresponding to the scene. The response of each subject was measured a total of 10 times, which was twice for each of the five warning sounds. The responses of the subjects to the forward vehicle collision warning only in the cut-in scene were analyzed and were evaluated in two aspects: the correctness of the evasive action and the response time to the warning sound. It was confirmed that all of the subjects were able to identify the dangerous situation after the warning sound was issued and able to take the demanded evasive action to avoid a collision.

Kacir et al. (2003) made an extensive research on Permissive Display for Protective/Permissive Left-Turn (PPLT) Control. The experiment was conducted over a 7-year period, National Cooperative highway research program (NCHRP) Project3-54 if the most comprehensive study of PPLT displays to date. The project surveyed current practice: studied driver understanding of known permissive displays in the United States:

analyzed crash and operational data: studied the implementation of an experimental permissive display: and conducted a confirmation study using two-full driving simulators (located at university of Massachusetts and Texas A & M University) to assess driver understanding of the most promising permissive displays. The study evaluated 12 PPLT signal display scenarios-each with a different permissive indication, display face, location and through-movement indication. Each PPLT signal display included only the circular green indication and/or flashing yellow arrow permissive indication. Some of the findings related to the study recommendations were: the flashing yellow arrow indication and display was found to have a lower fail critical rate (drivers incorrectly assume the right of way) compared to the circular green permissive indication; the study showed that drivers interpreted the meaning of the flashing yellow arrow display correctly. Based on the findings, the research team recommended incorporating the flashing yellow arrow display into MUTCD as an optional alternative display to the circular green for PPLT operation and also restricting the use of flashing red indications.

Braking time is a critical component in safe driving, and various approaches have been applied to minimize it. In congested high-speed driving, braking time becomes critical. With short headways, the likelihood of rear-end collisions increases sharply. This is supported by simulator studies as well as from the high frequency of rear-end collisions (30% of all crashes according to the National Highway Traffic safety Administration, 1999). Shinar et al. (2002) analyzed the components of braking time in order to assess the effects of age, gender, vehicle transmission type, and event uncertainty, on its two primary components, perception-reaction time and brake-movement time. Perception-reaction time and brake-movement time were measured at the onset of lights for 72 subjects in a simulator. The six experimental conditions were three levels of uncertainty conditions (none, some, and some false alarms) and two types of transmission (manual and automatic). They found that transmission type did not significantly affect either perception-reaction time or brake-movement time. Also, perception-reaction time increased significantly as uncertainty increased and also with age while brake-movement time did not change.

Smith et al. (2002) proposed a crash avoidance database structure that is based on driver judgments. The structure comprises four driving conflict states (low risk, conflict, near crash, and crash) that correspond with advisory warning, crash-imminent warning, and crash mitigation countermeasures. The crash state and conflict and near-crash state boundaries estimation was carried out. Next, the reliability of this database structure and its use to develop a crash avoidance database was done using driver performance data from an on-road naturalistic driving study and a driving simulator-controlled experiment. It was found that in both scenarios, most drivers initiate their braking action in response to a stopped lead car in the low-risk driving state.

McGehee et al.(1998), used the Iowa driving simulator to study the effects of various rear-end crash warnings on driver behavior. They found warnings to be most effective when headways are shortest. They also found warnings to be confusing or aggravating when they are issued too early, when drivers are already braking, and when drivers are being distracted.

In another study, McGehee et al (1999) conducted research examining driver crash avoidance behavior and the effects of ABS, Antilock Braking System, on drivers' ability to avoid collision in a crash-imminent situation. The study was conducted on Iowa Driving Simulator and examined the effects of ABS versus conventional brakes, speed limit, ABS instruction and Time to Intersection on driver behavior and crash avoidance performance. Drivers' reactions in terms of steering and braking and their success in avoiding the incursion vehicle were recorded. This study found that alert drivers do tend to brake and steer in realistic crash avoidance situations and that excessive steering also occurs at times.

Martin et al. (2001) tested how a single data record may be used to characterize an impending two-car, rear-end collision in which a lead vehicle and following-vehicle are initially separated by a range. A set of seven single valued covariates (speed of both vehicles, deceleration of both vehicles, brake application time of both vehicles and range between the vehicles) was calculated to describe the actions of both vehicles. These seven covariates may be used to derive theoretical time-histories that match the experimental ones. The procedure makes use of only the experimental range and following vehicle speed data. Using these, the time-histories of speed and decelerations were computed. Using Marquardt's non-linear regression, seven covariates were deduced. They made a comparison between theoretical time-histories derived from the seven covariates and the experimental time histories for a typical Driving Simulator run. The same thing was done for an intelligent cruise Control test run. Also Time-to-Collision was evaluated using kinematics. It was found that theoretical time-histories fit all the covariates very well for the simulator run. For the intelligent Cruise control test, the fit was found to be reasonably good up to a point where the driver of the following vehicle lets off the brake. They concluded that good fits attest to the validity of the procedure and its ability to characterize naturalistic data.

Winsum et al. (1999) studied the relation between perceptual information and the motor response during lane-change maneuvers in a fixed-based driving simulator. Eight subjects performed 48 lane changes with varying vehicle speed, lane width and direction of movement. Three sequential phases of the lane change maneuver are distinguished. During the first phase the steering wheel is turned to a maximum angle. After this the steering wheel is turned to the opposite direction. The second phase ends when the vehicle heading approaches a maximum that generally occurs at the moment the steering wheel angle passes through zero. During the third phase the steering wheel is turned to a second maximum steering wheel angle in opposite direction to stabilize the vehicle in the new lane. Duration of the separate phases were analyzed together with steering amplitudes and Time-to-Line Crossing in order to test whether and how drivers use the outcome of each phase during the lane change maneuver to adjust the way the subsequent phase is executed. Using standard, ANOVA and regression techniques, it was found that steering actions were controlled by the outcome of previous actions in such a way that safety margins are maintained. The results also suggest that the driver uses visual feedback during lane change maneuvers to control steering actions, resulting in flexible and adaptive steering behavior.

Comte (2000) evaluated positive and negative outcomes of Intelligent Speed Adaptation (ISA) using University of Leeds Advanced driving simulator. Three variants of ISA - Driver select system; Mandatory system and Variable system were evaluated. The critical scenarios of interest were speed and speed adaptation, system use, gap acceptance, following behavior, overtaking, violations, and attention to surprise events, mental workload and acceptability. It was found that Mandatory system was the most useful of the systems, in terms of acceptability. While in terms of satisfaction, they found that the drivers preferred the idea of a Driver Select system even though the Mandatory system would be the most useful.

Philip et al. (2003) studied about the effect of fatigue on performance measured by a driving simulator in automobile drivers. One hundred and fourteen drivers who stopped at a rest area were recruited for the study. Also, the test was done on 114 control subjects who had normal sleep wake schedule and absence of long driving on the same day. The demographic information between experimental and control groups was analyzed using nonparametric tests. The steering error from the ideal curve on the driving simulator and its relation to sex, age and driving and sleeping behaviors was then studied through logistic regression analysis. It was found that drivers performed significantly worse than control subjects. They concluded that steering errors on a driving simulator could be used to measure fatigue.

Roge et al. (2003) studied the effect of sleep deprivation and driving duration on the useful visual field in younger and older subjects during simulator driving. Nine older subjects (40-51 years) and 10 younger subjects (18-30 years) took part in two one-hour driving sessions. The subjects had to respond to certain critical signals for both tasks- Central and Peripheral. Two control parameters lateral and longitudinal instability were also analyzed. It was found that sleep deprivation and duration of driving had a significant effect on lateral and longitudinal instability. Also sleep deprivation and duration of driving affected the number of correct responses in both the central and peripheral tasks.

The applications of the driving simulator are tremendous. It has been used extensively in speed reduction methods, gap acceptance criteria, in calculating braking time, steering angle, and perception reaction time. The driving simulator has made possible to study about human factors and driver characteristics in various traffic scenarios. There are many studies, which indicate a relation between driving performance in older drivers with factors like vision, visual perception, cognition, reaction time and driving knowledge. None of the studies have used the driving simulator as a test bed, trying to replicate the accident scenarios, for high-risk locations as signalized intersections or toll plazas, which make this study unique.

2.2 Validation of Driving Simulators

For a driving simulator to be a meaningful endeavor, it is essential that the correspondence between a real and simulated environment is sufficiently good. It is of special importance that road-user behavior is sufficiently similar in both situations; i.e., it is essential that the driving simulator is sufficiently valid with respect to driving behavior.

2.2.1 Speed Validation

Stuart T. Godley et al. (2001) performed a behavioral validation of driving simulator that being used for evaluating speed countermeasures. They chose matured drivers, 24 participants drove an instrumented car and 20 participants drove the simulator and conducted as two separate experiments. Participants drove on roads, which contained transverse rumble strips at three sites, as well as three equivalent control sites. The three pairs of sites involved deceleration, and were the approaches to stop sign intersections, right curves, and left curves. Numerical correspondence (absolute validity), relative correspondence (or validity), and interactive (or dynamic) relative validity were analyzed, the latter using correlations developed from canonical correlation. Participants reacted to the rumble strips, in relation to their deceleration pattern on the control road, in very similar ways in both the instrumented car and simulator experiments, establishing the relative validities. However, participants generally drove faster in the instrumented car than the simulator, resulting in absolute validity not being established.

Harms (1994) indicated that the predictive validity could be described from two aspects, absolute and relative validity. The former refers to the numerical correspondence between behavior data in the driving simulator and in the real situation, whereas relative validity refers to the correspondence between the effects of different variations in the driving situation. According to Tornros (1998), Sweden, for a driving simulator to be useful as a research tool it is necessary that the relative validity is satisfactory, i.e. the same, or at least similar, effects are obtained in both situations. Absolute validity is not a necessary requirement, since research questions uniquely deal with matters relating to effects of various independent variables. His aim was to validate driving behavior in a simulated road tunnel using Speed and lateral position. Twenty subjects (9 men, 11 women) participated as paid subjects in the study. For speed data the following two factors were studied: access to speed information from the speedometer and driving lanes. For lateral position, the independent variables were: location of the tunnel wall and curvature. All behavioral data were analyzed by ANOVA. A 95% Confidence Interval was adopted in all cases. For every statistically significant F value, omega squared was calculated as a measure explained variance. Analyzing simple effects followed up statistically significant interactions. It was found that there was no interaction between the simulator factor and the lane factor and also between the simulator factors – speedometer factor, which means that the effect of lane information and speed information applies to both situations, which indicates a good relative validation for speed. It was found that there was no interaction between the simulator factor and the tunnel wall factor, which can be seen as a sign of good relative validity for lateral position.

Blaauw (1982) proposed two levels of validity: Physical validity and Behavioral Validity. The physical validity corresponds to the simulator's components, layout, and dynamics with its real world counterpart. The behavioral validity is measured using two types of validity- absolute validity (when the numerical values between the two systems are the same), relative validity (when differences found between experimental conditions are in the same direction, and have a similar or identical magnitude on both systems. As most advanced driving simulators are developed independently of each other, validity information is required for individual simulators, because different simulators have distinct parameters, including the time delay between driver action and simulator response, the amount physical movement available, and the size and quality of the visual display.

Based on Blaaw's (1982) two-tired approach (as mentioned above), a three-tired approach was developed by Godley et al. (2002), which included the evaluation of absolute validation, relative validity, and interactive relative validity. Twenty four participants, 12 male and 12 female ranging in the age group 22 to 52 years were chosen.

They were made to drive both on-road and off-road (simulator) and a comparative study were made. The on-road (instrumented car) recorded driving performance through specified routes that included rumble strips at three sites, and three separate but equivalent control sites. These pairs of sites were a stop sign approach, a right curve approach, and a left curve approach. Two procedures were implemented to assess relative validity; the first being averaged relative validity. For each treatment and control site, every participant's mean speeds were averaged across the entire measurement area. A two-factor analysis of variance (ANOVA) was conducted, with the two cites (treatment and control) as a repeated measures factor, and two experiments as a between-participants factor. The second procedure for evaluating relative validity was called interactive relative validity. For each pair of sites, the speed profile across the entire data collection was established for each treatment site relative to its control site. The approach used determined whether measurements at the treatment site were decreasing and/or increasing compared to the control site as participants traveled through the data measurement area. For absolute validation, the data were averaged across the total measurement are for both the treatment and control sites. The ANOVA analyses for the averaged relative validity and the absolute validity included estimating the effect size using the omega squared statistic. It was found that average relative validity was established for the stop sign approach speed but absolute validity was not. He concluded that speed is a valid measure to use for experiments on the simulator-involving road based speeding countermeasures.

2.2.2 Driver Reaction

McGehee et al. (2000) validated the Iowa Driving Simulator on driver reaction and performance. This study was designed so that an unexpected intersection incursion scenario could be safely implemented on a test track. Comparisons were made between primary reaction times across both simulator and test track studies. The goal was to determine the cause(s) of the apparent increase in single-vehicle run-off-road crashes and the decrease in multi-vehicle on-road crashes as vehicles transition from conventional brakes to Antilock Brake Systems. The first study was conducted on the Iowa-driving simulator. Sixty males and 60 females between the ages 25 and 55 participated. The between-subjects factors were brake type (ABS or conventional), speed limit (45 or 55 mph), time to intersection (2.5 seconds or 3 seconds), and instruction. The test track study involved 192 subjects between 25 and 55 years of age. The between-subjects factors included type of brake system, ABS brake pedal feedback level, ABS instruction, braking practice, time-to-intersection, and vehicle. It was found that total break reaction time was similar in the both experiments (2.2 s on Driving Simulator and 2.3 s on test track). So was the case with time to initial steering (1.64 s on Driving simulator and 1.67 s on test track). They concluded that driver reaction time is a good factor of validation.

2.2.3 Driver Characteristics

Many studies have concluded that driving simulators can provide accurate observations on drivers' behaviors and functions. The driving simulator also allows testing of the driver's unsafe and risky driving behavior, which can have potentially dangerous consequences.

Lee et al. (2002) tried to validate a laboratory based driving simulator in measuring on-road driving performance. One hundred and twenty nine old age drivers between the ages 60 and 88 were used as test subjects. The assessment criteria were divided into two sets- Road skills and cognition/perceptual tasks. The measures- driving speed, use of indicator, decision and judgment, confidence on high-speed and attention task were automatically recorded by the simulator and the laboratory assistant collected the rest. The subjects were to drive the simulator and then also on the road for the comparison of the results. The measurement properties of the assessment criteria were examined by reliability analysis. Two indices (Simulated Driving Index and Road Assessment Index) were developed. They deduced a Pearson correlation as high as 0.8 was for some variables between the two. They concluded that the high positive correlation between the two overall index measures has validated the development of the driving simulator as a screening tool. It confirms the high transferability of observations between simulated driving and on-road assessment.

The validation of the driving simulator has been discussed extensively in many studies, yet there still remains a lot to be explored. Validation has been done mainly based on speed, driver reaction, and driver characteristics. Speed validation, as mentioned by Blaaw and Harms, has been broadly classified into Physical validity and Behavioral validity. Driving speed, use of indicator and brake reaction time are some of the factors used in validating a simulator.

2.3 Accident Analysis at Intersections

Previous studies show that a high percentage of crashes take place at the intersections and toll plazas. Identifying such crashes and the factors related to such crashes, like the age of the driver, weather conditions etc, is of vital importance to minimize future crashes. This review also includes studies related to the factors leading to various types of crashes.

2.3.1 Rear-End Crashes

Rear-end crashes are the most common type of crashes at a signalized intersection.

Wang et al. (2003) found studies that classified intersection vehicle to-vehicle accidents into 15 types according to vehicle movements before the collision and analyzed the frequencies of accident types rear end, sideswipe, etc. Their classification approach provided a microscopic perspective to analyzing intersection vehicle-to-vehicle accident frequencies. They deduced a model based on the occurrence-mechanism of rear-end crashes. They expressed the accident probability as the product of the probability of the lead vehicle decelerating and the probability of the driver in the following failing to respond in time to avoid a collision. Rear-end accidents are the result of a lead vehicle's deceleration and the ineffective response of the following vehicle's driver. Factors affecting driver's ability to perceive, decide, and act determine the effectiveness of drivers' reaction to obstacle vehicles, and thus rear-end accident probability. To incorporate perception/reaction time into a model of drivers' failure probability, researchers considered available perception/reaction time (APRT) and needed perception time (NPRT). The probability of a driver being involved in rear-end accident is the probability that NPRT is greater than APRT. The authors assumed Weibull distribution because of its empirical flexibility and close approximation to a normal distribution. The probabilities for lead vehicle decelerating and the driver in the following failing to respond in time to avoid a collision were calculated and hence the probability of a rear end accident was derived. The data collected for the intersections included the number of accidents on each approach over the 4-year time period from 1992 to 1995, daily traffic volume by direction, traffic signal control pattern, and other relevant factors. Over the period, there were 589 rear-end crashes. To account for the effect of driving environmental complexity, an index of visual noise level (with values ranging from 0 to 4) was used. Using data from hundreds of intersection approaches, the occurrence of rear-end accidents was studied considering the probability of encountering an obstacle vehicle and the probability of a driver failing to react quickly enough to avoid a collision with the obstacle vehicle. Also by considering the occurrence mechanism of rear-end accidents, the model can explicitly account for human factors.

Smith et al. (2003) made an analysis of braking and steering performance in car-following scenarios. They divided the performance map into four driving states: low risk, conflict, near crash, and crash imminent. Rough estimates of the boundaries between the low risk and conflict driving states, and between the conflict and near crash driving states, by making the test subjects drive on a test track in two braking studies. Data from driving simulator was used to deduce the boundary between the near crash state and the crash imminent state. In all the studies, braking and steering driver performances are examined into two-car following scenarios: lead vehicle stopped and lead vehicle moving with constant speed. The analysis of last-second braking performance showed that the quantified boundaries of the driving states strongly depend on the dynamic scenario encountered in the driving environment. On the other hand, the quantified boundaries seem independent of these two dynamically distinct scenarios based on the last-second steering performance.

Abdel-Aty and Abdelwahab (2003) investigated the role of LTV's in rear end crashes. They deduced statistic models including Multinomial logit model, Heteroscedastic extreme Value and Bivariate probit models. Four different categories of the rear-end crashes were modeled using the statistical approaches. It was found that there is a higher chance of rear-end crashes when a regular passenger car follows an LTV due to driver distraction and limited sight distance. The analysis also illustrated that probability of a regular car striking an LTV increases when the driver of the following has an obscured view.

2.3.2 Gap Acceptance

Gap acceptance is an important factor in evaluating delays, queue lengths and capacities at intersections. Gap acceptance may also be used to predict the relative risk at intersections, where smaller gaps generally imply higher accident rate. Hamed et al. (1997) developed a system of disaggregate models that accounts for the effect of intersection, driver, and traffic characteristics on gap acceptance for left-turn maneuvers at urban T-intersections controlled by stop signs on minor roads. The gap acceptance methodology is based on the hypothesis that a left-turning driver on the minor or major road will move into the intersection if the gap in the major traffic stream is acceptable (equal to or greater than the driver's critical gap). The methodology consists of three models: driver waiting time model generates expected waiting time at the head of the queue for each driver, binary probit model is used to determine the driver's gap acceptance and rejection probabilities and finally, mean critical gap model estimates the mean critical gap at an intersection based on the critical gaps of individual drivers. Data were collected at 15 isolated T-intersections in Jordan. A total of 592 drivers were observed at these intersections. For each intersection, the data included number of lanes in opposing direction, opposing approach width, and presence or absence of a median with a left turn lane on the major road. The models were estimated using standard maximum likelihood procedures, and the results were analyzed to determine the significant factors that affect gap-acceptance. It was found that the waiting time is expected to be larger as the gaps decrease in time. Also, it showed that drivers have a higher risk of ending the waiting time if there is a median with a left-turn lane in the major approach. The expected waiting time significantly influences the probability of accepting a gap. As the waiting time increases, the driver is likely to accept shorter gaps and move into the intersection. The results showed that maneuver type plays a significant role in the length of the mean critical gap. Also as the number of lanes in the opposing major road increases, the mean critical gap increases as expected. So was the case with speed.

Cooper et al. (2002), made a study on the specific linkage between communication-based distraction and unsafe decision-making. In a closed-course driving experiment, 39 subjects were exposed to approximately 100 gaps each in a circulating traffic stream of eight vehicles on an instrumented test track that was wet about half the time. The subjects were at the controls of an instrumented car, which was oriented in a typical left-turn configuration and with parking brake on and the transmission in neutral. The subjects were instructed to press on the accelerator pedal when they felt that a gap was safe to accept. Their performances were monitored and incentives were provided for balancing safe decision-making with expeditious completion of the task. For half of the gap exposures (randomly assigned), each subject was required to listen and respond to a complex verbal message. It was found that when not distracted, the subjects' gap acceptance judgment was found to be significantly influenced by their age, the gap size, and the speed of the trailing vehicle, the level of indecision and the condition of the track surface. However, when distracted, the subjects did not factor pavement surface condition into the decision process.

Gattis et al. (1999) performed a gap acceptance study at a T-intersection at which left-turn traffic on the through leg had the right-of-way. A number of methods (Siegloch Method (1994), Greenshields Method, Raff Method, Acceptance curve Method and Logit Method) were used to model the critical gap size at this intersection. It was found that the values found according to Raff Method often were lower than the others, and the logit method produced values that usually were higher than others. Siegloch and Logit are probabilistic models involving more rigorous computational efforts; outcomes from these methods were given higher precedence.

Brilon et al. (1999), made a comprehensive study on all the publications on the estimations of critical gaps. He found out that for saturated condition Siegloch Method, which uses linear regression model, was well suited. For unsaturated conditions, he made a comparison among Lag method, Raff method, Ashworth method, Harders' method, Logit method, Probit procedures, Hewitt's method and Maximum likelihood procedures. An extended simulation study was done to test the critical gap estimation procedures for consistency. He found out that Hewitt method fulfills the criteria of consistency, with rather high performance. Maximum likelihood function is the only other function that could be comparable to Hewitt.

From the literature it has been observed that rear-end collisions are the most common type of crashes, mainly at locations like signalized intersections or toll plazas. There have been many studies related to predicting the accident probability, analysis of braking and steering performance. The concept of gap acceptance in accident analysis has been widely researched.

2.4 Summary

The literature review could be summarized as follows:

- The sample size of the subjects varied from one driving simulator experiment to the other. There is no fixed number that could be used as a threshold. The point worth noticing here is that most of the experiments had as many males as there were females.
- The driving simulator is emerging as a very effective safety tool. Its use in simulating incidents, specially related to human factors like driver characteristics and driver performance, is of tremendous use. The variables that were most often measured were Braking time, perception-reaction time, brake movement and steering angle.
- The validation of a driving simulator is as important as its application. Validation has been mainly based on speed, driver characteristics (age etc) and driver reaction time. Validity has been broadly classified into two: absolute and relative. According to some of the studies a driving simulator is considered validated if the relative validity is justified.
- Analysis of Variance has been extensively used in almost all the driving simulator data analysis.

In conclusion, using the driving simulator as a test bed for high-risk locations- signalized intersections is an innovative research idea. Replicating a high-risk signalized intersection would be both a novel and challenging task. The validation in the study would be done based on speed, safety and visual aspects. The acceleration/deceleration rates of the vehicles can be measured both at the site and in the driving simulator, for various phases of the signal. This data can be used for speed validation. The concept of gap acceptance can very well be used in analyzing the scenarios.

3 . EXPERIMENTAL DESIGN

Alafaya Trail (SR-434) and Colonial Drive (SR-50) intersection is located in Orange County. It is a four-leg 6×4 signalized intersection, and has two left turn lanes and one right turn lane for every approach as shown in Figure 3-1. The crashes at this intersection for years 1999 through 2002 have been studied for the driver simulator research project. It was identified that this intersection has a high rear-end crash risk. For through traffic, the rear-end crash rate in the eastbound approach of Colonial Drive (50EB) is the highest and that in the northbound approach of Alafaya Trail (434NB) is the lowest. In case of right turn traffic, Alafaya Trail northbound right turn lane has the highest rear-end crash rate and Colonial Drive westbound has the least rear-end crash rate.

This chapter documents the design of a driving simulator experiment to achieve the research objective of validating the driving simulator by replicating the above discussed intersection. To validate the driving simulator using Speed and Safety as criteria, a total of eight scenarios were designed for the experiment, as listed in Table 3-1.

The eight scenarios are classified into three categories, which are described in the following sections. Note that although the scenarios AEBR and BNBR are classified into the safety validation category, they are also used for speed validation study. Because, in these scenarios the speed of the simulator vehicle at the though lanes for the two approaches can be collected at termination of green phase. These speeds can be considered as free flow speeds along the respective directions as the signal is still green. Thus, the speed data in the experimental scenarios will be used to be compared to the field speed data collected at the real intersection.

Table 3-1: Scenario Description for Speed and Safety Validation

Scenario Classification	**Scenario ID**	**Scenario description**
Speed validation	AWBS	Subjects drive the simulator to cross the intersection on the inner most through lane of the Colonial Drive (SR-50) westbound when the signal is green.
	BSBS	Subjects drive the simulator to cross the intersection on the inner most through lane of the Alafaya Trail (SR-434) southbound when the signal is green.
Safety validation - Rear-end risk test at right-turn lanes	BNBL	As a leading vehicle, subjects turn right on the Alafaya trail northbound right-turn lane into colonial drive east bound.
	AWBL	As a leading vehicle, subjects turn right on the Colonial Drive westbound right-turn lane into Alafaya trail north bound.
	BNBF	As a following vehicle, subjects turn right on the Alafaya trail northbound right-turn lane into colonial drive east bound.
	AWBF	As a following vehicle, subjects turn right on the Colonial Drive westbound right-turn lane into Alafaya trail north bound.
Safety validation - Crash risk test at through lanes	AEBR	Subjects drive the simulator to go through the intersection along the Colonial Drive east bound and encounter the yellow phase change.
	BNBR	Subjects drive the simulator to go through the intersection along the Alafaya Trail north bound and encounter the yellow phase change.

3.1 Driving Simulator Scenario Design for Speed Validation

In the real intersection, free flow speeds were recorded for vehicles entering the intersection through each approach during the green phase, using a Radar Gun. Two observers are placed around 50 m (164.04 ft) down stream of the approach of which the speeds are being recorded. The radar gun is pointed towards the opposing flow and then speeds are recorded. Vehicles are carefully selected such that they are under free flow conditions.

In the driving simulator, the four legs speed data is collected under free flow conditions when subjects are driving through the intersection in the scenarios AWBS, BSBS, AEBR, and BNBR, as shown in Figure 3-1. In those scenarios, the free-flow speed would be measured at the intersection to be compared to the measurements based on the field study. If the speed between simulator experiment and that at field measurements is statistically similar, then the driver's speed performance in the driving simulator environment is a valid measurement for traffic studies.

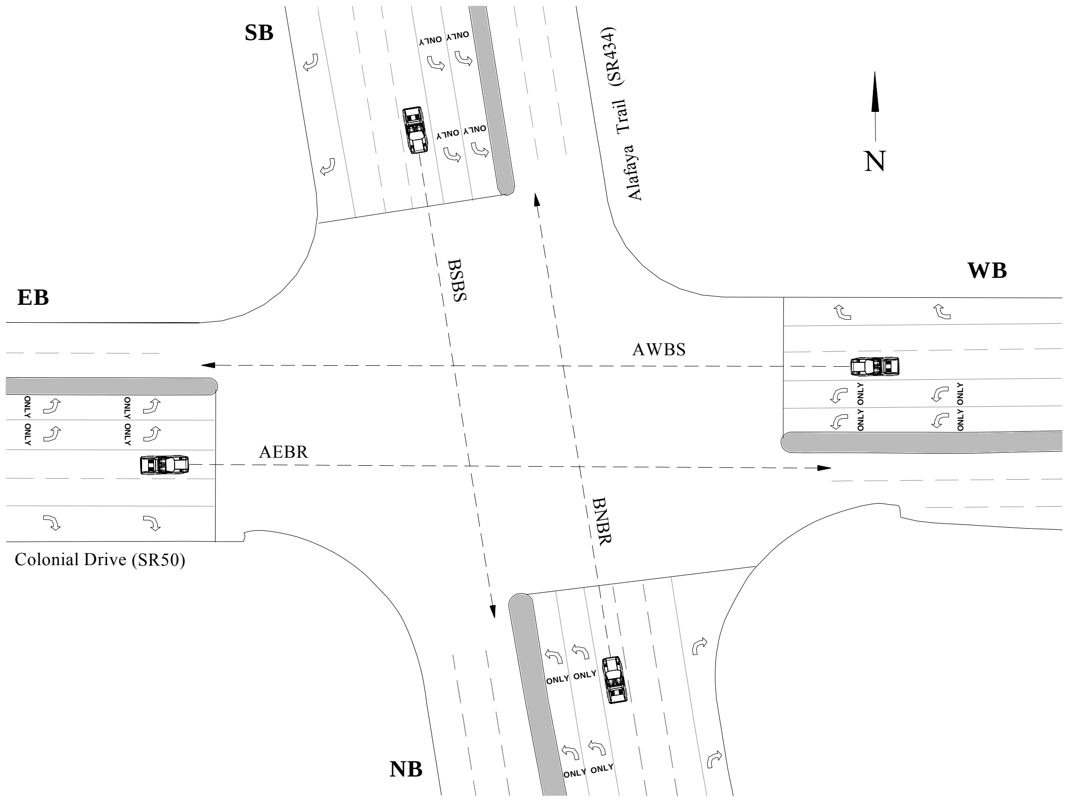

Figure 3-1: Scenarios for Speed Validation

3.2 Driving Simulator Scenario Design for Safety Validation

3.2.1 Safety Validation - Rear-End Risk Test at Right-Turn Lanes

For the right-turn movement, generally, there is a low rear-end risk during the green phase but a high risk during the permissive red phase. According to crash police reports, for most of Alafaya Trail right turn rear-end crashes, the struck (leading) vehicle yielded to the opposing traffic or signal and slowed to a stop; the striking (following) vehicle failed to stop simultaneously and it proceeded to hit the rear of the front vehicle. For the leading vehicle in a rear-end crash in the right-turn lane, a higher deceleration rate during the red phase and sudden stops due to emergent situation may play an important role in the crash happening. On the other hand, a proper space cushion is needed for the following vehicle to provide a driver enough reaction time to recognize a hazardous situation and make a stop decision. Following too close and maintaining higher speeds are generally associated with the risk of rear-end crash.

Based on the crash report analyses, it was found that the rear-end crash rate in the Alafaya northbound right-turn lane is much higher than the other approaches and the Colonial Drive westbound right-turn lane shows the lowest rear-end crash rate.

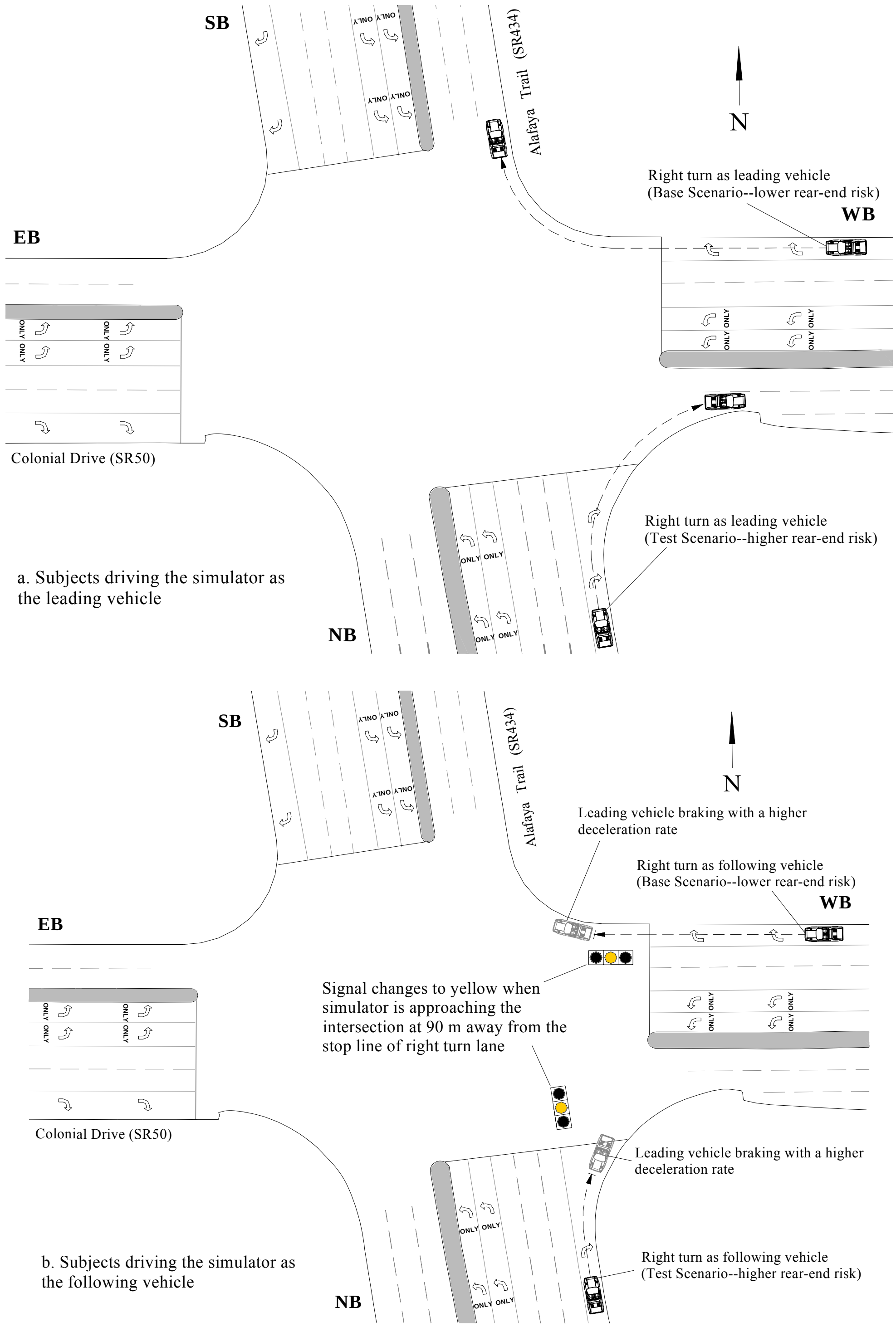

Figure 3-2: Right-turn rear-end risk scenarios for safety validation

If the driving simulator is a valid tool to diagnose traffic safety problem at the intersection, the driver's performance in the driving simulator environment should reflect a similar rear-end risk pattern or trend. Therefore, the right-turn movements from the Alafaya northbound are designed as test scenarios and the right-turn movements from the Colonial Drive westbound are designed as base scenarios. Moreover, both scenarios in which subjects drive the simulator as a leading car and as a following car to make a right turn should be tested, as shown in Figures 3-2 a and b.

In the scenarios BNBL and AWBL in which a subject is required to drive the simulator cab as the leading vehicle, when the subject approaches the intersection at 100 m (328.08 ft) away from the stop line, the green phase is terminated. Since right-turn-on-red is permitted at this intersection, a legal driving behavior for such a situation would be stopping at the intersection first and then turning right if there is no conflicting traffic. If the driving simulator is validated, it should be expected to find some patterns that lead to higher rear-end risks in the Alafaya northbound right-turn lane compared to that at the Colonial Drive westbound right-turn lane (See Figure 3-2 a). For example, the vehicle's violation rate and deceleration rate in the Alafaya northbound are higher.

From the crash report analysis, it was found that the rear-end crashes could occur at different locations in the right turn lanes; in another word, the queue length in front of the striking vehicle varies for rear-end crashes happening in the right-turn lane. Based on the earlier findings of the pilot study, since no significant difference was found at different locations of the simulator in the queue, the cab as a following vehicle could be the fourth or the fifth car in the queue. In scenarios BNBF and AWBF(See Figure 3-2 b) in which a subject is supposed to drive the simulator cab as the following vehicle, when the leading vehicle approaches the intersection at 60 m (196.85 ft) away from the stop line, the traffic signal will change from green to yellow; when the leading vehicle approaches the intersection at 50 m (164.04 ft) away from the stop line with a speed of 30mph, it would brake with a high deceleration rate 6.4 m/s^2 (0.65 g) or 21 ft/s^2 in the right turn lane. The driving behavior of the subject responding to the sudden stop would be measured to test the risk of rear-end crash. In order for the driving simulator is to be validated, one should find the conditional crash rate, and the relative driving speed, in the Alafaya northbound right-turn lane to be larger than that at the Colonial Drive westbound right-turn lane.

3.2.2 Safety Validation - Crash Risk Test at Through Lanes

From the crash report analysis, for the through traffic it was found that the rear-end crash rate for Colonial Drive eastbound traffic to be the highest and that for Alafaya Trail northbound traffic to be the lowest. Moreover, the angle crash rate related to the Colonial Drive eastbound through traffic is relatively higher than that related to other approaches. Whereas the angle crash rate related to the Alafaya Trail northbound through traffic is found to be least. This trend should be considered for driving simulator scenario design for the safety validation.

From the perspective of traffic operation and safety at signalized intersections, one of the main concerns of traffic engineers and researchers is the dilemma zone, which is a length of roadway in advance of the intersection wherein drivers may be indecisive and respond differently to the onset of the yellow signal. This region of roadway is commonly referred to as the ‘dilemma zone’. When vehicles are located in the dilemma zone, the drivers who decide to proceed through the intersection at the onset of yellow signal may run a red light and potentially result in right-angle collisions. In some cases, because of driver behavior variation in the dilemma zone, some drivers may stop abruptly while others may decide not to stop, which may contribute to the risk of a rear-end crash (Pline, 1999).

Therefore, the test scenario AEBR for crash risk test looks at the driver behavior in the dilemma zone. In this scenario, when the subjects drive the simulator to go through the intersection along Colonial Drive eastbound the signal light will change from green to amber. This signal change occurs when the subjects approaching the intersection are at 90 m (295.28 ft) ahead of the stop line. Amber period is provided for 4.3 s. For the base scenario BNBR which is used to compare with the test scenario, same procedure is adopted along Alafaya Trail northbound direction as shown in Figure 3-3. The driving performance responding to the signal change such as approaching speed, reaction time, red-light running rate, and brake deceleration rate will be measured to find if there is any risky traffic behavior associated with crash risk along Colonial Drive eastbound direction.

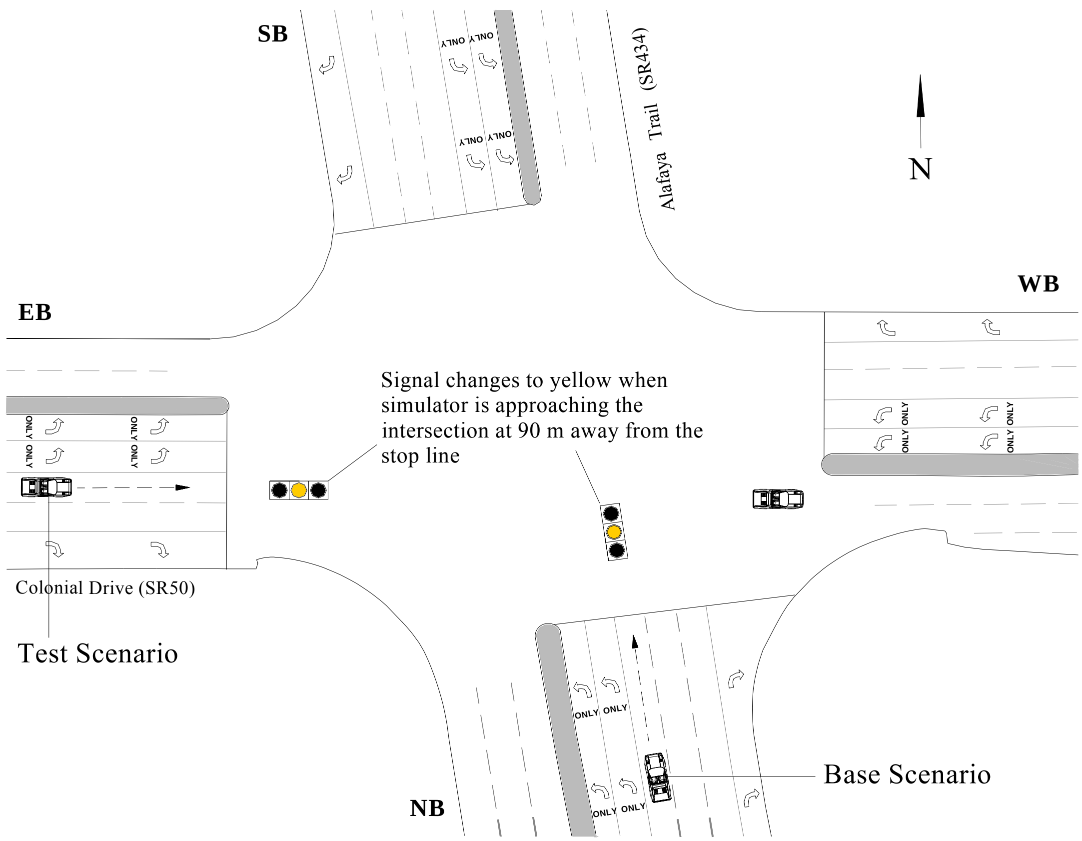

Figure 3-3: Crash risk test at through lanes for safety validation

3.3 Experimental Design

The experimental design used here is a simple within-subjects factorial design. Further, age group and gender of the subjects are two independent variables (factors) considered for this experimental design. Initially, the age groups have been classified as Very Young (16 to 19), Young (20 to 24) and Middle aged (25 to 64). Since very few crashes were found in the old age group, it has been discarded. This classification method was adopted on the basis of a previous study by Abdel-Aty et al. (1998). Since the middle age group is a large set, based on the crash analysis done using the crash reports, the Middle aged group has been further reduced to 3 ten years groups- Younger Middle aged (25 to 34), Middle Middle-aged (35 to 44), Older middle-aged (45 to 54) and Very old Middle-aged (55 to 64). Since no crashes were found in the very old middle-aged group, it is combined with the Older middle-aged group. Hence, the five age groups of interest are Very Young (15 to 19), Young (20 to 24), Younger Middle-aged (25 to 34), Middle Middle-aged (35 to 44) and Older middle-aged (45+). This age categorization follows the actual driver population using the intersection of interest. Therefore, the experimental setup results in a 5 X 2 within-subjects factorial design.

3.4 Experiment Procedure

Upon arrival, the subjects were given an informational briefing about the driving simulator. They were informed that the experiment is conducted to know their driving behavior at the intersection. They were specifically advised to adhere to traffic laws, and to drive as if they were in normal everyday traffic surroundings. A five-minute practice course was programmed in the driving simulator. Before the actual experiment scenarios each subject is made to run this training session. This was done in order for the subjects to get used to simulator's visual, steering and braking system.

Next, the subjects performed the formal experiment with the eight scenarios, which were randomly loaded for each driver so as to eliminate the time order effect and bias from subjects to the experiment results. Each scenario per subject took around five minutes, which includes loading and running the scenario. So, overall time for the experiment per subject was forty-five minutes including training session. During the course of the experiment subjects were routinely checked for simulator sickness. Whenever subject in a scenario reported sickness, the subject quit the experiment and the related data collected in the scenario was removed from the experiment result analysis.

After the subjects completed the formal experiment, a survey was used to gather information about their evaluations on the fidelity of the driving simulator and the intersection traffic safety. In the survey questionnaire, four questions were specifically designed, which is listed in Appendix. Finally each subject received ten dollars as an incentive for successfully completing the experiment. The subjects who experienced sickness were paid five dollars and are exempted from further experiment.

4 . DESCRIPTIVE STATISTICS and SIMULATOR VALIDATION

The main aim of this research is to validate the driving simulator in terms of Speed and Safety. For the speed validation, it is expected that the speed measurement in the driving simulator environment should be statistically similar to that at the real location, which corresponds to the absolute validity. For the safety aspects, if the driving simulator is a valid tool to diagnose traffic safety problem at the intersection, the driver's performance in the driving simulator environment should reflect a similar crash risk pattern or trend as what happens in the real world, which corresponds to the relative validity.

The original Data logging of the driving simulator experiment includes experiment sampling time, vehicle positions, speeds, accelerations**,** information of driver's braking behavior, and records of signal phase status. Based on those data, the independent measurements of driving behaviors in different scenarios need to be extracted. To organize and easily process data generated from the experiments, a C program was developed to manipulate the experiment data output files. The following sections documented the definitions of those independent measurements and related statistical analyses of the experimental results.

4.1 Speed Validation

4.1.1 Speed Measurements in the Field SR-50 & SR-434 Intersection

The test site considered is the Alafaya Trail (SR-434) and Colonial Drive (SR-50) intersection. Free flow speeds are recorded for vehicles entering the intersection through each approach during the green phase, using a Radar Gun. These recordings for all the approaches were taken on Tuesday dated 05/02/2006 from 9:30am to 5:00pm.Two observers are placed around fifty meters down stream of the approach of which the speeds are being recorded. The radar gun is pointed towards the opposing flow and speeds are recorded. Vehicles are carefully selected such that they are under free flow conditions. Vehicles in queue are disregarded for data collection. This method was followed for approaches namely; SR-434 north bound (434NB), SR-50 west bound (50WB), and SR-50 east bound (50EB). For the approach 434SB there were no vehicles under free flow conditions. This approach was always under over saturated conditions for the current signal phasing design. Hence for this approach speeds are recorded around fifty meters upstream of the intersection at which vehicles are in free flow conditions. There are 134 observations for 50WB approach, 104 observations for 50EB approach and 91 observations for 434SB and 434NB each. Table 4-1 shows the descriptive statistics of the data collected. Figures 4-1 (a, b, c, and d) illustrate the speed distributions of the vehicles entering the intersection from all the four approaches.

Table 4-1: Descriptive Statistics of Speed Data Collected in Field.

APPROACH	Mean Speed (mph)	N	Std. Deviation	Minimum (mph)	Maximum (mph)
434NB	43.7833	91	6.3348	29.8	62.79
434SB	42.2983	91	6.9296	26	60
50EB	45.8415	104	6.2663	29.8	62.79
50WB	45.0925	134	6.2919	22.35	64.91
Total	44.3889	420	6.5471	22.35	64.91

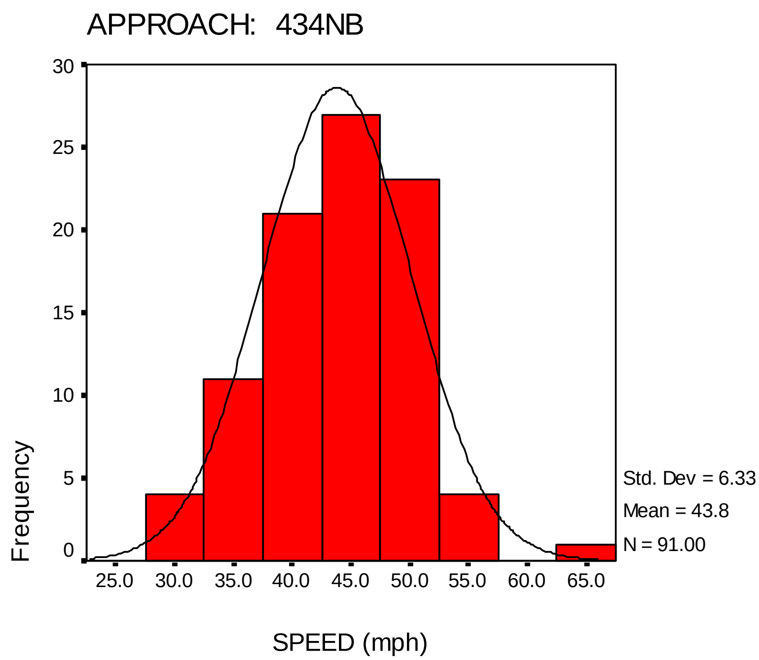

Figure 4-1a. Histogram of speed measurements in the field at the intersection for SR – 434 North Bound traffic

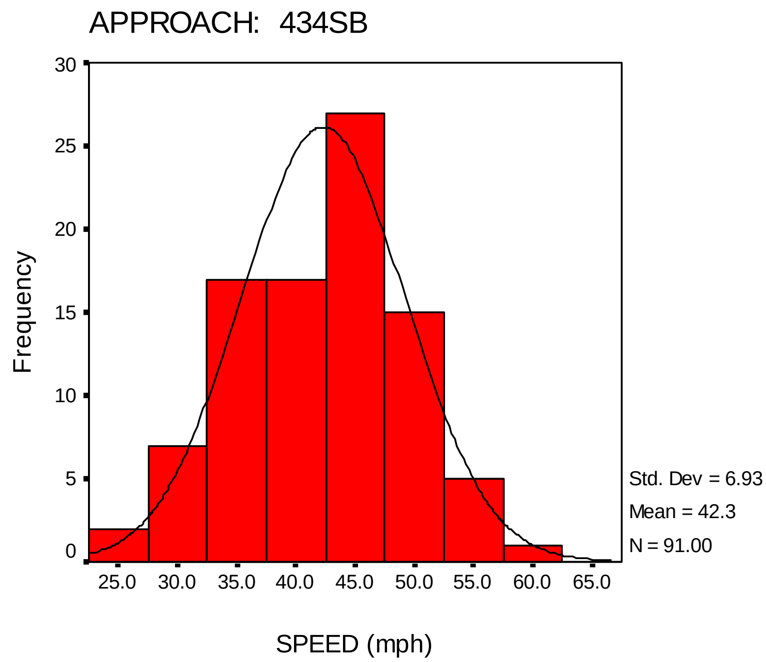

Figure 4-1b. Histogram of speed measurements in the field at 50m upstream of the intersection for SR – 434 South Bound traffic

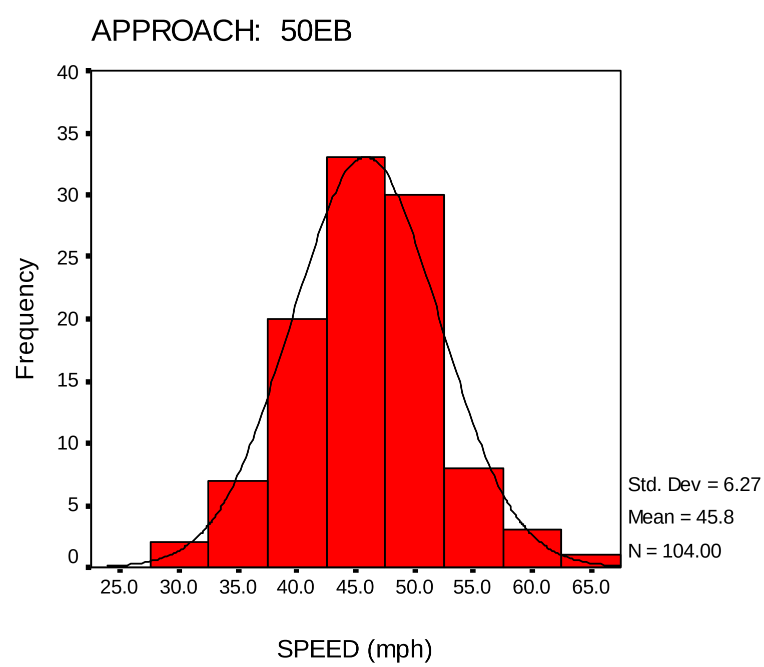

Figure 4-1c. Histogram of speed measurements in the field at the intersection for SR – 50 East Bound traffic

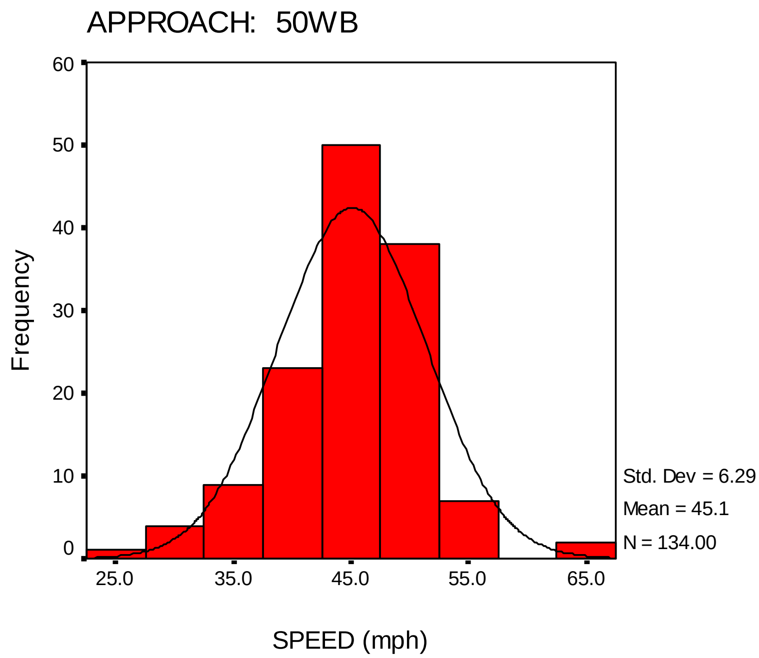

Figure 4-1d: Histogram of speed measurements in the field at the intersection for SR – 50 West Bound traffic

By visual inspection the speed distributions at all the approaches follow normal distribution. Kolmogorov – smirnov test of normality is used to test whether the data comes from normal distribution. The Kolmogorov-Smirnov test is defined by:

H_0: The data follow a normal distribution.

H_a: The data do not follow the normal distribution

If the P-value for the test statistic is less than the significance level $\alpha = 0.05$, then the null hypothesis, H_0, that the data follows normal distribution is rejected. The P-value (Asymp. Sig. 2-tail as shown in Table 4-2) for the test statistic Z for all the approaches is greater than 0.05. Therefore, the data follows normal distributions for all the approaches.

Table 4-2 :Kolmogorov – Smirnov Normality Test Statistics for Speeds Measured in the field

APPROACH			SPEED (mph)
434NB	N		91
	Normal Parameters	Mean	43.7833
		Std. Deviation	6.3348
	Most Extreme Differences	Absolute	.085
		Positive	.064
		Negative	-.085
	Kolmogorov-Smirnov Z		.808
	Asymp. Sig. (2-tailed)		.531
434SB	N		91
	Normal Parameters	Mean	42.2983
		Std. Deviation	6.9296
	Most Extreme Differences	Absolute	.081
		Positive	.064
		Negative	-.081
	Kolmogorov-Smirnov Z		.770
	Asymp. Sig. (2-tailed)		.594
50EB	N		104
	Normal Parameters	Mean	45.8415
		Std. Deviation	6.2663
	Most Extreme Differences	Absolute	.081
		Positive	.074
		Negative	-.081
	Kolmogorov-Smirnov Z		.829
	Asymp. Sig. (2-tailed)		.497
50WB	N		134
	Normal Parameters	Mean	45.0925
		Std. Deviation	6.2919
	Most Extreme Differences	Absolute	.094
		Positive	.064
		Negative	-.094
	Kolmogorov-Smirnov Z		1.091
	Asymp. Sig. (2-tailed)		.185

4.1.2 Speed Measurements in the Simulator System

Speed study was conducted using Driving simulator. A more or less exact location of the intersection was simulated in a computer environment and different subjects were asked to run the experiment. In order to keep the experimental speed measurements under the free flow traffic condition, the driving simulator is made to drive from 500 ft upstream of the intersection without any surrounding vehicles. By this process the subject attains free flow speed well before reaching the intersection. The experiment involves different subjects driving through the simulated intersection of Alafaya Trail and Colonial Drive. First, subjects were asked to run the training session for about five minutes so as to get used to the simulator's steering and braking system. Then, the subjects were asked to drive the eight intersection test scenarios. Subjects having motion sickness during the training session are exempted from further experiment and their data is discarded. The subjects were carefully selected in such a way that they belong to all age groups ranging from sixteen to greater than forty-five. And also the subjects were evenly distributed as much as possible among male and female gender groups. Each subject was paid $10 as an incentive for running the experiment. A total of sixty-one subjects ran the experiment. Due to some technical errors data was not recorded for three subjects. Table 4-3 shows the different age groups and number of subjects participated in the experiment.

Table 4-3: Number of subjects

Age group	Female	Male
16 – 19	6	7
20 – 24	6	8
25 – 34	5	8
35 – 44	5	7
45 +	1	5
Total	23	35

The experiment is designed for a total of eight scenarios namely; AWBS BSBS, AWBL, BNBL, AWBF, BNBF, AEBR, and BNBR. While scenarios AWBS, BSBS, AEBR and BNBR are used for speed validation, scenarios AWBL, BNBL, AWBF and BNBF are used for safety validation of rear end crash risk at right turn lanes. Scenarios AEBR and BNBR were also used for safety validation of crash risk at through lanes. Table 3-1 shows the description of these scenarios. Simulator records the position and speed of the vehicle for every 1/60th of a second. Table 4-4 shows the descriptive statistics for speed data collected. Figures 4-2 (a, b, c, and d) illustrate the speed distribution of traffic in each leg of the intersection in the simulator.

Table 4-4: Mean Speed at Intersection Using Driving Simulator.

APPROACH	Mean	Std. Deviation	95% Confidence Interval	
			Lower Bound	Upper Bound
434NB	43.6920	8.4863	40.892	44.957
434SB	43.9879	7.9723	40.755	44.904
50EB	46.7752	9.4548	43.941	47.933
50WB	47.5928	8.8915	44.502	48.561

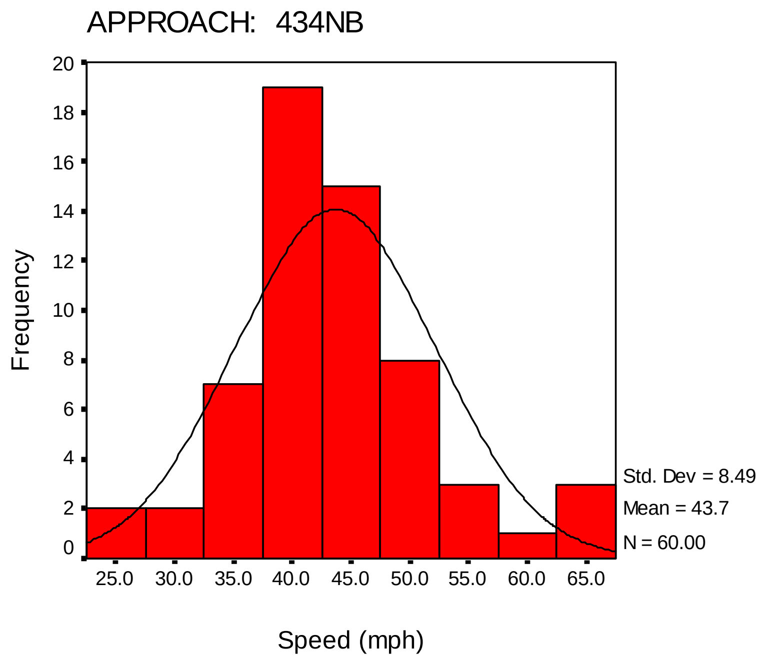

Figure 4-2a: Histogram of speed measurements in simulator for SR- 434 North Bound traffic

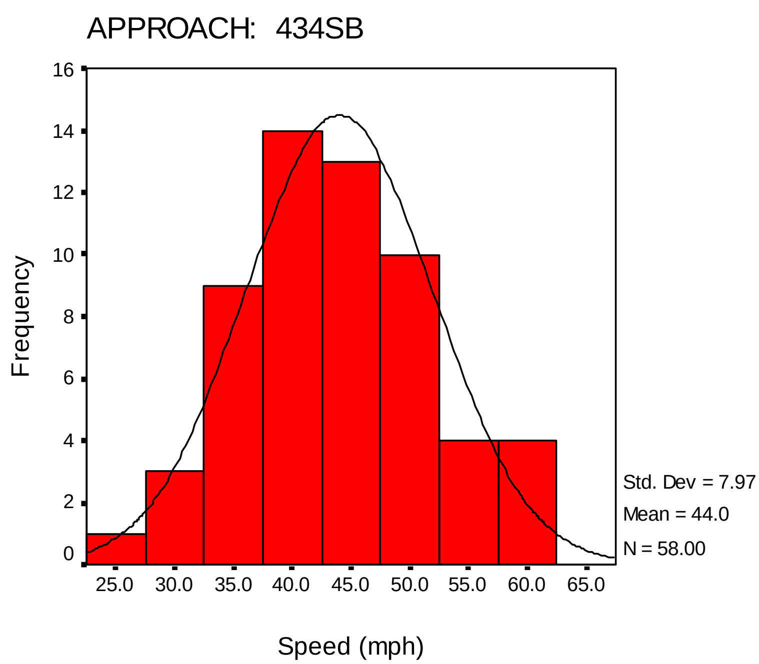

Figure 4-2b: Histogram of speed measurements in simulator for SR- 434 South Bound traffic

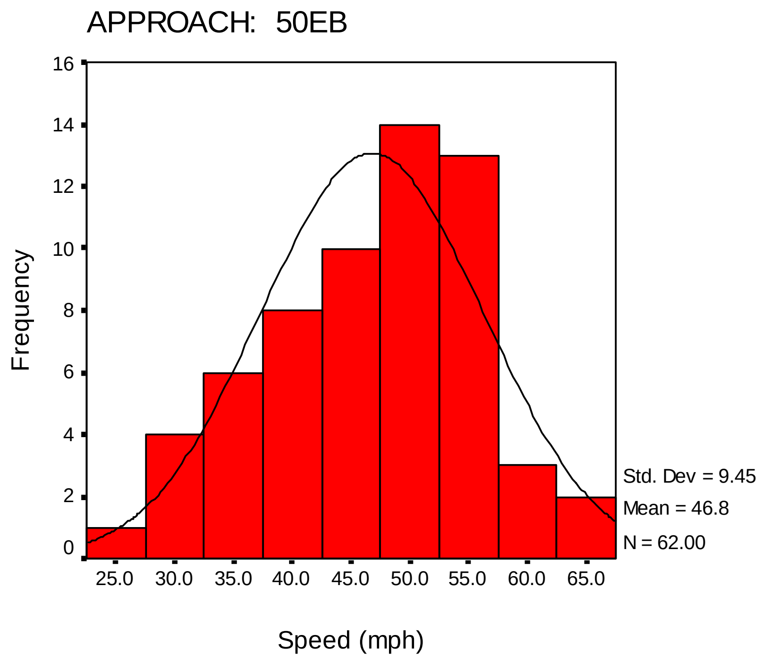

Figure 4-2c: Histogram of speed measurements in simulator for SR-50 East Bound traffic.

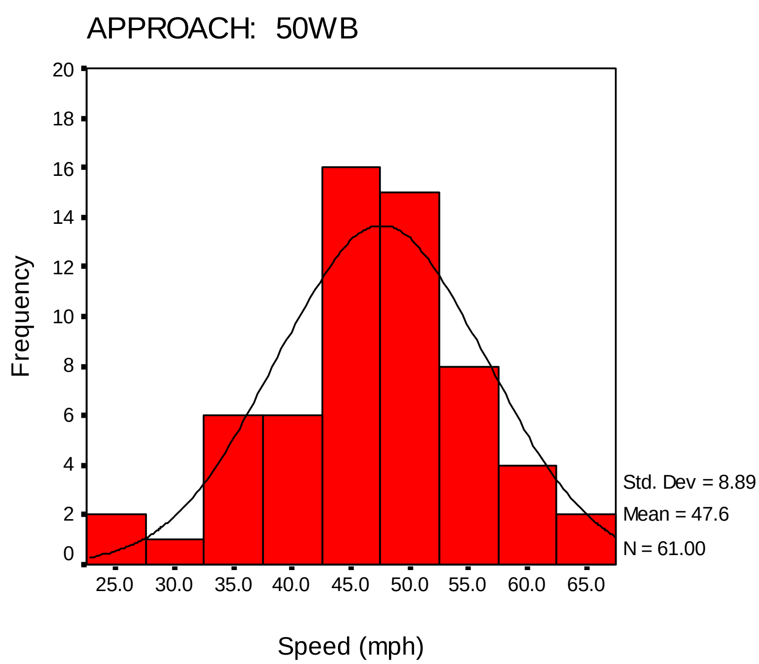

Figure 4-2d: Histogram of speed measurements in simulator for SR-WB West Bound traffic.

The Kolmogorov – Smirnov normality test shows that the P-value (Asymp. Sig. 2-tail as shown in Table 4-5) is greater than 0.05 for all the approaches. Therefore, the speed data in driving simulator follows normal distributions.

Figures 4-3a and 4-3b show the 95% confidence interval and mean speed across different age and gender groups. In the Figure 4-3a the X-axis represents age, where, 1619 represents age between 16years and 19 years inclusive, 2024 represents age between 20years and 24 years inclusive and so on. It clearly shows the decreasing trend of speed as the age increases after 20-24 years age group. It is also found that the mean speed for male is slightly higher than female as shown in Figure 4-3b. Both trend are statistically confirmed by F-test in the ANOVA analysis (see Table 4-6), which shows that the factors of driver age (P=0.000), driver gender (P=0.028), and intersection approach (P=0.012) are significantly associated with the operation speed.

Table 4-5: Kolmogorov – Smirnov Normality Test Statistics for Speed Measured in Simulator.

APPROACH			SPEED (mph)
434NB	N		60
	Normal Parameters	Mean	43.6919
		Std. Deviation	8.4936
	Most Extreme Differences	Absolute	.105
		Positive	.105
		Negative	-.082
	Kolmogorov-Smirnov Z		.810
	Asymp. Sig. (2-tailed)		.528
434SB	N		58
	Normal Parameters	Mean	43.9874
		Std. Deviation	7.9722
	Most Extreme Differences	Absolute	.040
		Positive	.040
		Negative	-.036
	Kolmogorov-Smirnov Z		.304
	Asymp. Sig. (2-tailed)		1.000
50EB	N		62
	Normal Parameters	Mean	46.7752
		Std. Deviation	9.4544
	Most Extreme Differences	Absolute	.080
		Positive	.065
		Negative	-.080
	Kolmogorov-Smirnov Z		.633
	Asymp. Sig. (2-tailed)		.817
50WB	N		61
	Normal Parameters	Mean	47.5928
		Std. Deviation	8.8911
	Most Extreme Differences	Absolute	.079
		Positive	.057
		Negative	-.079
	Kolmogorov-Smirnov Z		.619
	Asymp. Sig. (2-tailed)		.838

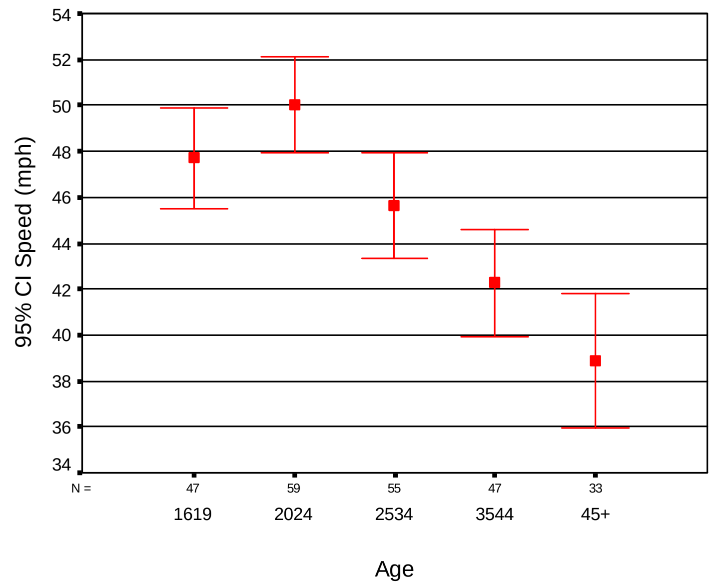

Figure 4-3a: Speed distribution by driver age

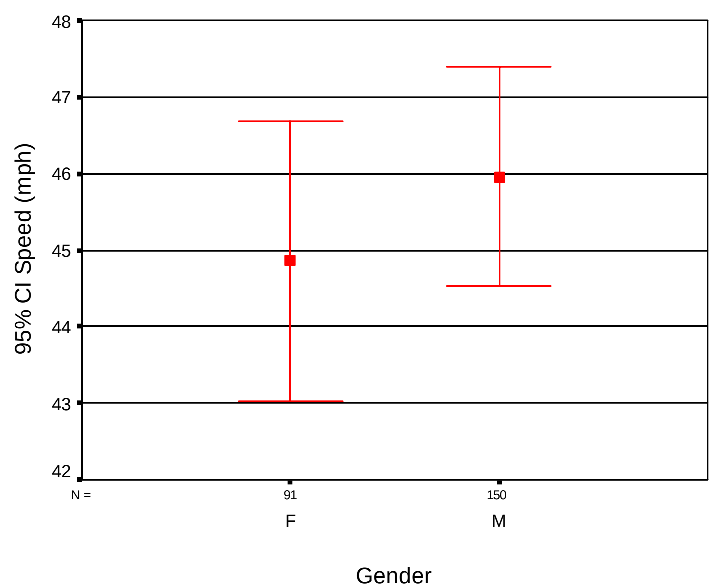

Figure 4-3b: Speed distribution by driver gender

Table 4-6: ANOVA Analysis for Speed as Dependent Variable

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	4380.998	8	547.625	8.829	.000
Intercept	425167.063	1	425167.063	6854.665	.000
AGE	3619.429	4	904.857	14.588	.000
GENDER	302.077	1	302.077	4.870	.028
APPROACH	688.477	3	229.492	3.700	.012
Error	14390.018	232	62.026		
Total	518658.241	241			
Corrected Total	18771.017	240			

a R Squared = .233 (Adjusted R Squared = .207)

According to a report that investigated drivers' speeding and unsafe attitudes and behaviors nationally (Royal, 2003), males (34%) are more likely than females (27%) to report that they would pass most other vehicles; and almost half of all drivers under age 30 say they tend to pass most drivers and the likelihood of this behavior drops off significantly with age. Those driving patterns related to speed are illustrated in Figure 4-4, which show very similar trends of speed distributions by gender and age from the simulator experiment results, as shown in Figures 4-3a and 4-3b.

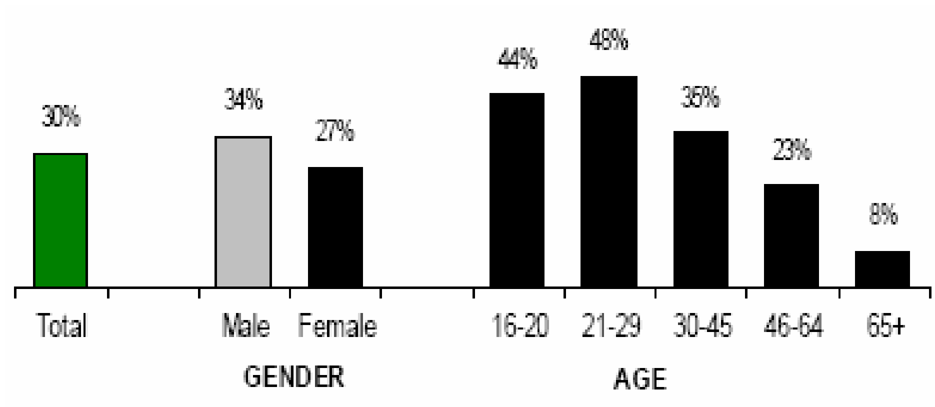

Figure 4-4: Distribution of drivers who tend to pass most other drivers by gender and age (Source: Royal, 2003)

4.1.3 Speed Validation of Driving Simulator

For speed validation of the driving simulator, the speed distributions in the Driving simulator and that in the field are found to follow normal distribution. This was tested using Kolmogorov – Smirnov normality test (see Table 4-2 and Table 4-5). Table 4-7 shows the comparison of mean speeds.

Table 4-7: Mean Speeds Using Simulator and from Field

	APPROACH	N	Mean Speed (mph)	Std. Deviation	Std. Error Mean
From Field	434NB	91	43.7836	6.3349	.6641
From Simulator		60	43.6920	8.4936	1.0965
From Field	434SB	91	42.2986	6.9293	.7264
From Simulator		58	43.9879	7.9723	1.0468
From Field	50EB	104	45.8420	6.2663	.6145
From Simulator		62	46.7752	9.4548	1.2008
From Field	50WB	134	45.0925	6.2915	.5435
From Simulator		61	47.5928	8.8915	1.1384

Figure 4-5 shows the graphical representation of comparison of speeds observed from field data and that from Simulator data. From the figure it can be observed that the mean speeds of both field data and simulator data are same for all approaches except for the approach 50WB.

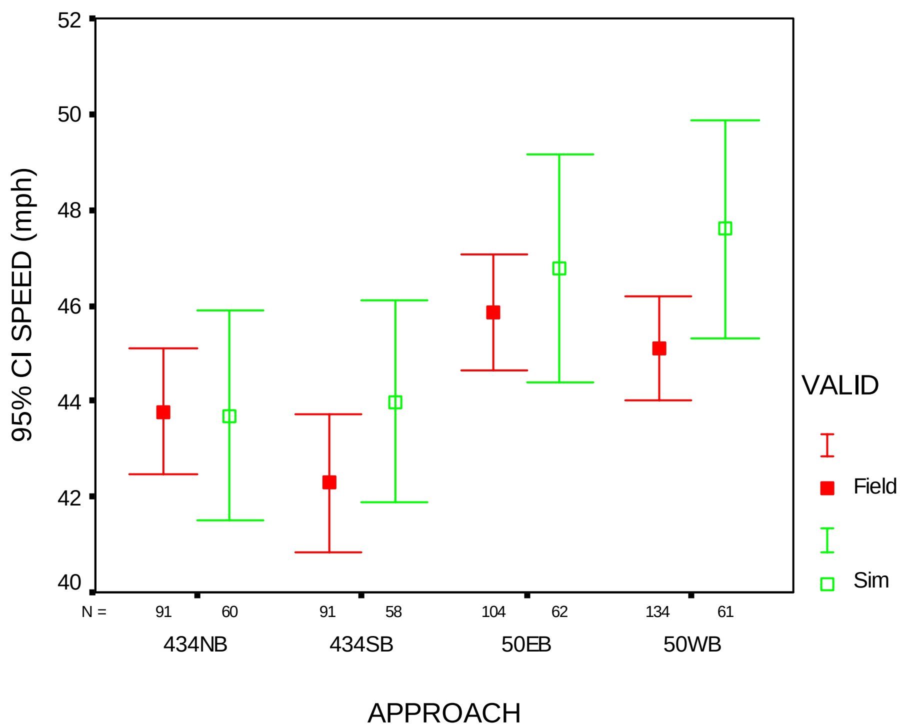

Figure 4-5: Mean speeds using simulator and from field.

The two means are tested statistically using two-sample student's t-test. The t - test is defined by:

H_0: Mean speeds from driving simulator and that from field data are equal.

H_a: Mean speeds are not equal.

The null hypothesis, H_0, is assumed to be true and is rejected if significance value is less than 0.05 with 95% confidence.

Table 4-8: F – test for Variance of Speed and t- test Results Mean Comparison of Speed

	Levene's Test for Equality of Variances			t-test for Equality of Means						
		F	Sig.	T	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% C.I. of the Difference	
APPROACH									Lower	Upper
434NB	Equal Var	2.446	.120	.076	149	.940	0.092	1.209	-2.296	2.480
	Unequal Var			.071	101.28	.943	0.092	1.282	-2.451	2.635
434SB	Equal Var	1.526	.219	-1.368	147	.173	-1.689	1.235	-4.130	.752
	Unequal Var			-1.326	109.08	.188	-1.690	1.274	-4.215	.836
50EB	Equal Var	12.36	.001	-.764	164	.446	-.9331	1.221	-3.344	1.478
	Unequal Var			-.692	93.339	.491	-.9331	1.349	-3.612	1.745
50WB	Equal Var	8.470	.004	-2.248	193	.026	-2.500	1.112	-4.694	-.307
	Unequal Var			-1.982	88.396	.051	-2.500	1.262	-5.007	0.007

Tables 4-8 show the results of both F-test and t-test for variance comparison and mean comparison. The standard two-sample t-test makes no assumption about the variances of the underlying populations. Hence it is referred as unequal variance test. But equal variance t-test is more powerful than unequal variance test. Therefore, the speed distributions are tested for equal variance. It is found that approaches, 434NB and 434SB have equal variances as they have significance values greater than 0.05, whereas, approaches 50EB and 50WB have unequal variances according to the F-test in Table 4-8.

Based on variance type (equal or unequal) respective t–test statistic values are looked upon for validation. From Table 4-8 the significance P-value is greater than 0.05 for all of four approaches. Therefore we accept the null hypothesis that the mean speeds measured in the field and that in the driving simulator are equal at all approaches of the intersection. Hence, the simulator is validated for speed at the intersection. However, note that the speed data from the driving simulator shows a larger variability for the higher operation speeds on the approaches along Colonial Drive.

4.1.4 Speed Validation Conclusions

From the Kolmogorov – Smirnov normality test statistics, the speed distributions observed from the field and that from the simulator follow normal distributions along all four approaches of the intersection with 95% confidence.

Based on the F-test, it is concluded that speed data observed from field and that from simulator have equal variances along approaches 434-North bound and 434-South bound, but they have unequal variances along approaches, 50-East bound 50-West bound with 95% confidence. Since the operation speeds for the highway are higher than those for the 434 highway, the speed data from the driving simulator shows a larger variability for the higher operation speeds.

According to two sample t-tests, the speed data observed from field and that from simulator have equal mean for each intersection approach with 95% confidence. Additionally, the distributions of mean speeds for driver age and gender based on the simulator experiment results are very close to the real distribution from the previous investigation data.

Therefore, based on overall comparisons of speed between simulation and real world, one can conclude that the UCF driving simulator is a valid tool for traffic study related to driving speed behaviors.

4.2 Safety Validation

4.2.1 Rear-End Risk Test at Right-Turn Lanes

As described in Chapter one, Alafaya trial (SR-434) experience higher rear-end crash risk at right turn lanes than colonial drive (SR-50). For safety validation of rear-end risk at right turn lanes four scenarios have been designed. In two scenarios, the driving simulator is used as a leading vehicle; and in the other two scenarios, it is used as a following vehicle. The four scenarios are as follows:

- SR-434 north bound driving simulator as leading vehicle (BNBL).
- SR-50 west bound driving simulator as leading vehicle (AWBL).

- SR-434 north bound driving simulator as following vehicle (BNBF).
- SR-50 west bound driving simulator as following vehicle (AWBF).

For safety validation of rear-end risk at right turn lanes, high risk scenarios namely, BNBL and BNBF are compared with base or lower risk scenarios namely, AWBL and AWBF, respectively.

4.2.1.1 <u>Driving Simulator as a Leading Vehicle</u>

In this section we look at the scenario where the driving simulator is used as a leading vehicle. Table 4-9 shows the description of the independent variables that are considered for this scenario.

Table 4-9: Independent Variables When Driving Simulator Turns Right as a Leading Vehicle

Independent variable	VARIABLE DESCRIPTION	
IN_app	Intersection approach	Categorical (WB=0; NB=1)
Spd100	Simulator speed measured at 100 m (328.08 ft) away from stop line in the right turn lane	Continuous (mph)
Spd80	Simulator speed measured at 80 m (262.47 ft) away from stop line in the right turn lane	Continuous (mph)
Spd60	Simulator speed measured at 60 m (196.85 ft) away from stop line in the right turn lane	Continuous (mph)
Spd40	Simulator speed measured at 40 m (131.23 ft)away from stop line in the right turn lane	Continuous (mph)
Spd20	Simulator speed measured at 20 m (65.62 ft)away from stop line in the right turn lane	Continuous (mph)
Spd0	Simulator speed measured at stop line in the right turn lane	Continuous (mph)
FullSTOP	Did driver fully stop at the right turn lane?	Categorical (Yes=1; No=0)
Ave_DEL	The average deceleration rate in the right turn lane	Continuous (ft/s^2)
Max_DEL	The maximum deceleration rate in the right turn lane	Continuous (ft/s^2)
Speedup	Did driver speed up to beat the red light in the right turn lane? (Yes=1; No=0)	Categorical (Yes=1; No=0)
Max_ACC	The maximum acceleration rate for the driver who speeds up	Continuous (ft/s^2)
Reatime	Driver's brake response time to the signal change in the right turn lane.	Continuous (s)
Age	Driver age	Categorical
Gender	Driver gender	Categorical (M=1; F=0)

4.2.1.1.1 Brake Deceleration Rate Analysis

Table 4-10 shows the descriptive statistics of the independent variables, average deceleration and maximum deceleration. It can be observed that average deceleration rate is higher for 434 north bound approach than for the approach 50 west bound whereas, maximum deceleration rate is higher for approach 50 WBL than for the approach 434 NBL. The means of these independent variables are tested for statistical significance, using two sample student's t-test. Table 4-11 shows the results of two-sample t- test for means of average deceleration rate. It can be inferred that the means of average deceleration rate are significantly different for the two approaches 434-north bound and 50-west bound with 95% confidence. Average deceleration rate is higher for approach 434-NB than 50-WB. By taking average deceleration rate as surrogate measure for rear-end right turn lane crashes, it can be concluded that 434-north bound approach is more risky than 50-west bound approach with respect to rear-end right turn crashes. This result validates the driving simulator. On the contrary, Table 4-12 reveals that maximum deceleration rate is not statistically higher for approach 50-WB than that for 434-NB at 0.05 significance level.

Table 4-10: Descriptive statistics of Average deceleration and Maximum Deceleration.

Approach	Variable Deceleration	N	Mean (ft/s^2)	Std Dev	Minimum (ft/s^2)	Maximum (ft/s^2)	Range
50 WB Leading	Ave_Del	57	2.6181	2.1186	0.1326	10.737	17.044
	Max_Del	57	16.277	4.2039	7.671	26.082	19.529
434 NB Leading	Ave_Del	56	5.9113	3.9248	0.7739	17.818	10.604
	Max_Del	56	14.722	4.263	6.542	26.071	18.411

Table 4-11: Hypothesis Test - Two Sample t- test for Means of Average Deceleration Rate

Group	N	Mean of Ave_del (ft/s^2)	Std. Dev.	Std. Error
434nbl	56	5.911272	3.9248	0.5245
50wbl	57	2.618131	2.1186	0.2806
Hypothesis Test				
H_0, Null hypothesis:		Mean 1 - Mean 2 = 0		
H_a, Alternative:		Mean 1 - Mean 2 ≠ 0		
If Variances Are		t statistic	Df	Pr > t
Equal		5.563	111	<.0001
Not Equal		5.536	84.22	<.0001

Table 4-12: Hypothesis Test – Two Sample t- test for Means of Maximum Deceleration Rate

Group	N	Mean of Max_del (ft/s^2)	Std. Dev.	Std. Error
434nbl	56	14.72193	4.263	0.5697
50wbl	57	16.27666	4.2039	0.5568
Hypothesis Test				
H_0, Null hypothesis:		Mean 1 - Mean 2 = 0		
H_a, Alternative:		Mean 1 - Mean 2 ≠ 0		
If Variances Are		t statistic	Df	Pr > t
Equal		-1.952	111	0.0535
Not Equal		-1.952	110.89	0.0535

4.2.1.1.2 Non-Stop Turn Rate Analysis

Table 4-13 shows the frequency of subjects, driving as a leading vehicle, who stopped fully at the stop line along the two approaches i.e. SR-434 north bound right turn lane and SR-50 west bound right turn lane. The definition of ‘Full-STOP’ is given in the Table 4-9. From Table 4-13, Overall 69.75 % of the subjects did not stop at the stop line. This shows the general careless driving behavior of the subjects when they make right turns during the red phase.

81.67% of the subjects that drove along the 434-north bound right turn lane did not stop fully at the stop line; whereas, only 57.63% of the subjects that drove along the 50-west bound right turn lane did not stop. This is statistically tested by Chi-square test of independence. This test assumes the null hypothesis that full stop behavior and intersection approaches are independent. Since P-value of Chi-square statistic came out to be 0.0045, which is less than significance level of 0.05 (from Table 4-14), null hypothesis that full stop behavior and intersection approaches are independent, is rejected with 95% confidence.

Table 4-13: Contingency Table between Intersection Approach and Full Stop

Table of IN_app by Full-Stop				
Intersection approach	Full-Stop		Total	
	No	Yes		
434NBL	49	11	60	Frequency
	41.18	9.24	50.42	Overall Percent
	81.67	18.33		Row Percent
	59.04	30.56		Column Percent
50WBL	34	25	59	Frequency
	28.57	21.01	49.58	Overall Percent
	57.63	42.37		Row Percent
	40.96	69.44		Column Percent
Total	83	36	119	Frequency
	69.75	30.25	100	Percent

Table 4-14: Chi-Square Test of Independence

Statistic	DF	Value	Prob
Chi-Square	1	8.1475	0.0043

The drivers who did not stop fully at the stop line could make a sudden stop in emergency situations, such as yielding the right of way for pedestrians crossing or traffic from other approaches, so as to increase the risk of rear end collision with the vehicle following. Since non-stop rate is higher for 434NBL (81.67%) than that for 50WBL (57.63%), approach SR-434-north bound right turn has more rear-end crash risk than approach 50-west bound right turn. This also validates the point that intersection is well designed in the simulator same as in the real world since it showed the same safety pattern as in the real world.

The location of stop line also determines the driver's stopping behavior at the stop line. For SR-434 north bound traffic, stop line is located at the middle of the curve. The distance for making right turns which is between the stop line, pedestrian crossing, and the edge of SR-50 east bound is very short (see Fig 3-2b). Therefore, it requires less time to make a right turn and drivers tend to quickly watch the traffic from other approaches and make a right turn quickly without stopping. Whereas, in case of SR-50 west bound traffic, the stop line is located well before the beginning of the right turning curve. For this case, the distance for making right a turn that is between the stop line, pedestrian crossing, and the edge of SR-434 north bound lane is comparatively very longer. Hence, it requires longer time to make a right turn. This will tend the drivers to drive very slowly or stop at this area between the stop line and the edge of the SR-434 north bound lane to search for a chance to make a safe right turn. This behavior was observed in the experiment as only 11 subjects stopped fully at 434NB right turn lane but 25 subjects stopped fully at 50WB right turn lane. Therefore, full stopping behavior of the drivers could be dependent on the location of stop line at the approach, which could be one of reasons that explained why rear end collisions were over-presented in the 434NB right turn lane compared to the 50WB right turn lane.

4.2.1.1.3 Analysis of Speed Distribution Along the Right Turn Lane

Table 4-15 and Figure 4-6 show descriptive statistics distribution of speed measured along the right turning lane on both approaches namely, SR-50 west bound and SR-434 north bound. The X-axis of Figure 4-6 shows the location of the vehicle, upstream of the stop line, and Y-axis shows the mean speed of all the subjects at a particular location. In the Figure 4-6, Spd100 indicates mean speed of the subjects at 100m (328.08 ft) upstream of the stop line; Spd80 indicates the mean speed of the subjects at 80m (262.47ft) upstream of the stop line and so on. Finally Spd0 indicates mean speed of the subjects at the stop line. It can be observed from the Figure 4-6 that, the mean speeds are consistently higher along 50WB right turn lane than that along 434NB at locations 100m (328.08 ft), 80m (262.47 ft), 60m (196.85 ft), 40m (131.23 ft) and 20m (65.62) but are lower at the stop line.

Table 4-15: Descriptive Statistics of Speeds at Different Locations Upstream of the Stop Line

Approach	Location	N	Mean Speed(mph)	Std Dev	Minimum (mph)	Maximum (mph)	Range
50wbl	Spd100	58	37.979	7.6676	22.433	57.317	34.884
	Spd80	58	37.048	7.6604	21.023	55.486	34.463
	Spd60	58	34.063	7.8515	18.852	51.026	32.173
	Spd40	58	28.239	8.5719	11.251	49.904	38.654
	Spd20	58	20.577	7.11	8.1096	42.936	34.827
	Spd0	58	9.1225	3.7505	2.8008	25.978	23.178
434nbl	Spd100	60	32.221	8.3341	16.207	51.304	35.097
	Spd80	60	31.285	7.3989	18.425	48.657	30.233
	Spd60	60	29.063	7.2091	13.772	45.166	31.394
	Spd40	60	24.754	8.4913	4.5206	43.515	38.995
	Spd20	60	17.072	7.0651	4.8041	38.257	33.453
	Spd0	60	11.419	5.5273	3.2859	37.827	34.541

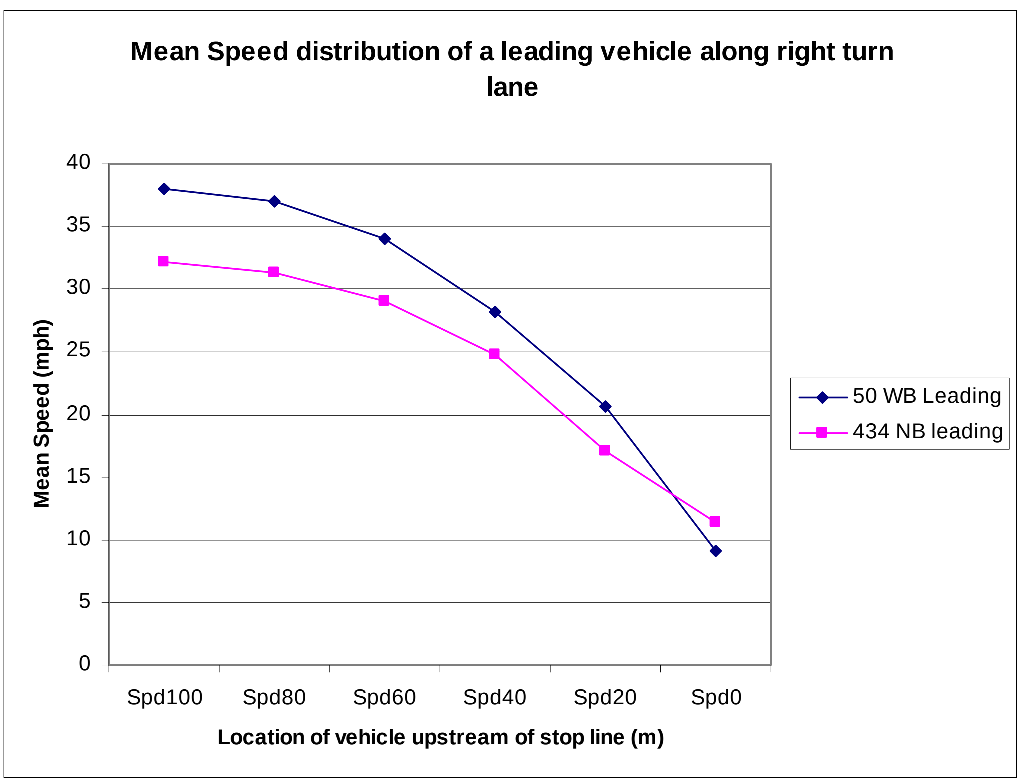

Figure 4-6: Mean speed distribution of a leading vehicle along the right turn lanes

From Table 4-16, mean speeds at stop line of approach 50WB and approach 434NB are found to have unequal variances (since p-value for F-statistic is less than 0.05) and are significantly different at 0.05 significance level (since p-value for t-statistic is less than 0.05) with 95% confidence. Mean speed at the stop line of approach SR-434NB is significantly greater than that of the approach SR-50WB. This means that when drivers make right turns in a situation where, pedestrians crossing the intersection, it requires faster deceleration rate at SR- 434 north bound right turn lane than that at SR-50 west bound right turn lane, to avoid collision with pedestrians. This might lead to rear end crashes. Hence, approach SR-434NB is found to be more risky than the approach SR-50WB with respect to rear end crashes at right turn lanes. By treating speeds at stop line as surrogate measure for rear-end risk at right turn lanes, the conclusion that approach SR-434 northbound is more risky than the approach SR-50 west bound, validates the driving simulator.

Table 4-16: Two-Sample F-Test for Variances and Two-Sample t-Test Assuming Unequal Variances for Mean Comparison of Speeds at the Stop Line

Two-Sample F-Test for Variances		
	Spd0_50WB_Leading	Spd0_434NB_Leading
Mean (mph)	9.12246	11.41883
Variance	14.06648	30.55117
Observations	58	60
Df	57	59
F	0.460424	
P(F<=f) one-tail	0.001883	
F Critical one-tail	0.646272	
Two-Sample t-Test Assuming Unequal Variances		
	Spd0_50WB_Leading	Spd0_434NB_Leading
Mean (mph)	9.12246	11.41883
Variance	14.06648	30.55117
Observations	58	60
Hypothesized Mean Difference	0	
Df	104	
T Stat	-2.6486	
P(T<=t) one-tail	0.004671	
T Critical one-tail	1.659637	
P(T<=t) two-tail	0.009342	
T Critical two-tail	1.983037	

4.2.1.2 Driving Simulator as a Following Vehicle

Table 4-17 shows the independent variables that are considered for safety validation in the case where driving simulator is used as a following vehicle.

Table 4-17: Independent Variables When Driving Simulator Turns Right as a Following Vehicle

Independent variable	VARIABLE DESCRIPTION	
IN_app	Intersection approach	Categorical (WB=0; NB=1)
Spd50	Simulator speed measured when the leading vehicle is 50 m (164.04 ft) away from stop line in the right turn lane	Continuous (mph)
Fdis50	Following distance measured when the leading vehicle is 50 m (164.04 ft) away from stop line in the right turn lane	Continuous (ft)
Ave_DEL	The average deceleration rate in the right turn lane	Continuous (ft/s^2)
Max_DEL	The maximum deceleration rate in the right turn lane for each vehicle.	Continuous (ft/s^2)
Ye_retime	Driver's brake response time to the signal change in the right turn lane.	Continuous (s)
Ve_retime	Driver's brake response time to leading vehicle's brake light in the right turn lane.	Continuous (s)
Crash	Is there a rear-end crash happening in the right turn lane?	Categorical (Yes=1; No=0)
Age	Driver age	Continuous
Gender	Driver gender	Categorical (M=1; F=0)

In this scenario each subject has driven the simulator cab as a vehicle following another vehicle in the right turn lane of both 434-North bound and 50-West bound approaches. When the leading vehicle approaches the intersection at 60 m (196.85 ft) away from the stop line, the traffic signal changes form green to yellow; when the leading vehicle approaches the intersection at 50 m (164.04 ft) away from the stop line with a speed of 30mph, it brakes with a high deceleration rate of 6.4 m/s^2 (0.65 g) or 21 ft/s^2 in the right turn lane. The driving behavior of subject responding to the sudden stop would be measured to test the rear-end risk. It is expected to find that the crash rate and relative driving speed in the Alafaya north bound (434NB) right-turn lane should be larger than that in Colonial Drive (50WB) west bound right-turn lane while following distance should be vice versa.

4.2.1.2.1 Rear-End Crash Rate Analysis

Figure 4-7 shows comparative graph of rear-end crashes that occurred in the simulator experiment between approaches 434NB right turn lane and 50WB right turn lane. It can be observed that, total rear-end crashes occurred in the right turn lane of 434NB are higher than that of 50WB. This is tested statistically by 'Two sample test of equality of proportions'.

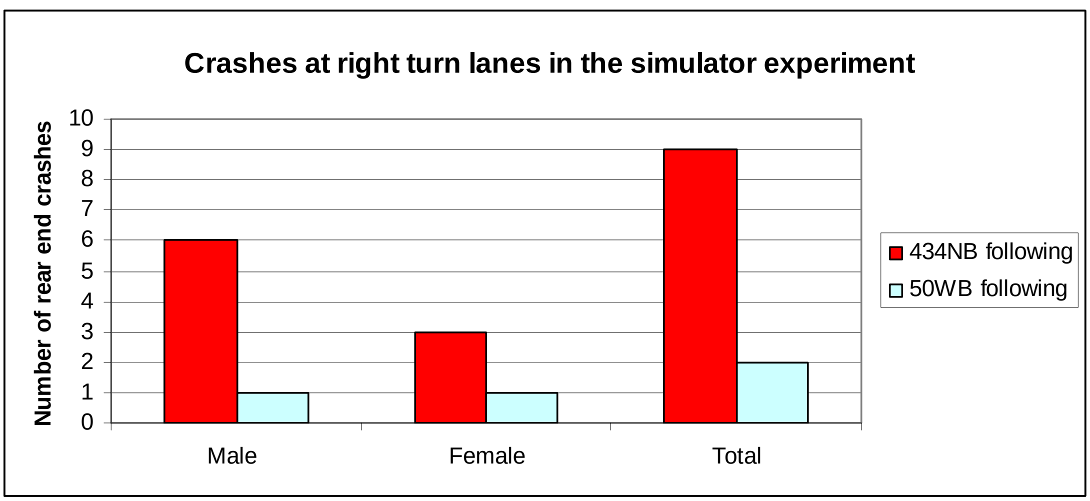

Figure 4-7: Rear-end crashes at right turn lanes in the experiment.

Two-sample test of equality of proportions:

H_0: $P_1 = P_2$

H_a: $P_1 \neq P_2$

Where, P_1 = Proportion of Crashes at Intersection approach 434NBF

P_2 = Proportion of Crashes at Intersection approach 50WBF

Since P-value is 0.0248 which is less than 0.05 (see Table 4-18), rear-end crash occurrence at the approaches 434 north bound right turn lane is significantly higher than rear-end crash occurrence at approach 50 west bound right turn lane. Therefore, approach 434NB right turn lane is more risky than approach 50WB right turn lane with respect to rear-end crashes. This result directly validates the driving simulator.

Table 4-18: Two Sample Test of Equality of Proportions of Crashes between Right-turn Lanes of Approaches 434NB and 50WB.

Proportion of crashes at each intersection approach in %		Z- statistic	Prob>z
434NBF	50WBF		
15.25	3.33	2.24	0.0248

From Chapter one, based on research done at UCF, it is found that, in real world from crash data between years 1999 to 2002, male and female are equally involved rear end crashes along the approach 434NB right turn lane. This pattern is also observed in the experiment. Assuming null hypothesis of having equal proportion of crashes along the approach 434NB right turn lane, using two sample equality of proportions test between male and female gender groups, it is found that P-value is 0.78 (see Table 4-19) which is greater than 0.05. Therefore, null hypothesis is accepted which states that there is no significant difference in proportion of crashes between male and female gender groups, with a 95% confidence level. This also validates the driving simulator in terms of rear-end crash risk rate on a gender basis.

Table 4-19: Two Sample Test of Equality of Proportions of Crashes between Male and Female

Proportion of crashes at approach 434NB right turn lane (%)			
Male	Female	Z- statistic	Prob>z
16.22	13.64	-0.27	0.7898

4.2.1.2.2 Following Distance Analysis

Table 4-20 shows the descriptive statistic of the independent variables. All the independent variables are defined in the Table 4-17. From Table 4-20 it is observed that the following distance when leading vehicle is at 50 m (164.04 ft) upstream of stop line (Fdis50) is smaller for approach 434NB right turn lane than that for approach 50WB right turn lane. This is tested statistically by two-sample t-test. Since P-value (0.0304) from Table 4-21 is less than 0.05, there is significant difference between means of Fdis50 between two approaches 434NB right turn lane and 50WB right turn lane. Therefore, the mean of Fdis50 is significantly lesser for approach 434NB right turn lane than that for approach 50WB right turn lane with a 95% confidence level. In case of leading vehicle decelerating faster, following vehicle will not get enough gap to stop if the following distance is small. This leads to a rear end crash. Since distance following is significantly lesser along approach 434NB right turn lane than that along 50WB right turn lane, considering Fdis50 as a surrogate measure for safety, the 434NB right turn lane shows a higher rear-end crash risk than the 50WB right turn lane. This validates driving simulator, as, in real world from crash data analysis, 434NB right turn lane is at high rear-end crash risk than 50WB right turn lane. Other independent factors namely; average deceleration rate, maximum deceleration rate, yellow reaction time and Spd50 (see Table 4-17) are found to be not significantly different between the two approaches 434NB right turn lane and 50WB right turn lane.

Table 4-20: Descriptive Statistics of Independent Variables

IN_app	N	Variable	N	Mean	Std Dev	Min	Max	Range
434NB Following	59	Spd50(mph)	59	27.59	2.725	18.745	33.11	14.365
		Fdis50(ft)	59	99.027	44.05	36.31	303.45	267.144
		Ave_Del(ft/s^2)	59	14.22	7.062	1.9885	23.792	21.803
		Max_Del(ft/s^2)	59	20.81	3.432	8.0897	26.012	17.923
		Ye_retime(s)	58	1.789	0.482	1.05	3.4667	2.4167
50WB Following	60	Spd50(mph)	60	28.66	2.080	22.922	36.411	13.489
		Fdis50(ft)	60	116.71	43.98	43.332	237.10	193.77
		Ave_Del(ft/s^2)	60	13.34	6.745	2.8178	24.081	21.263
		Max_Del(ft/s^2)	60	20.42	3.779	9.0822	26.1	17.018
		Ye_retime(s)	60	1.674	0.519	0.5333	2.9833	2.45

Table 4-21: Two Sample t-test for the Means of Fdis50 within IN_app

Group	N	Mean (ft)	Std. Dev.	Std. Error
434nbf	59	99.027	44.049	5.7347
50wbf	60	116.708	43.98	5.6778
Hypothesis Test				
H_0, Null hypothesis:	Mean 1 - Mean 2 = 0			
H_a, Alternative:	Mean 1 - Mean 2 ≠ 0			
If Variances Are		t statistic	Df	Pr > t
Equal		-2.191	117	0.0304
Not Equal		-2.191	116.96	0.0304

4.2.1.3 Conclusion

The purpose of the experiment study in this section is to validate the UCF driving simulator as a test bed from the safety aspect of rear end crash risk happening at right turn lanes. In comparison between driving simulator experiment results and real world crash record, it showed very similar pattern of rear end crash risks. Considering the driving simulator as a leading right turn vehicle, it was found that the deceleration rate at the 434NB approach is higher than that at the 50WB approach; non-stop rate is higher for 434NB approach than that for 50WB approach; and mean speed at the stop line of the 434NB approach is significantly greater than that of the 50WB approach. Using these three variables as key surrogate measuring rear end risk, one can conclude that the leading vehicles are more likely to contribute to the rear-end crashes at the right turn lane of the 434NB approach compared to at the right turn lane of the 50WB approach.

On the other hand, considering drivers' following behaviors at right turn lanes, the following distance at the moment when the leading vehicle started braking is significantly lesser along 434NB right turn lane than that along the 50WB right turn lane. Using the following distance as a surrogate measure for safety, the 434NB right turn lane shows a higher rear-end crash risk than the 50WB right turn lane. This conclusion was further verified by the evidence that the rear-end crash rate in the right turn lane of 434NB (15.25%) are significantly higher than that of 50WB (3.33%).

Based on the above findings for the right turn rear end crash risk analysis, it can be concluded that the experiment results validated that the UCF driving simulator could be an effective tool for traffic safety studies to test high risk locations at intersections.

4.2.2 Safety Validation - Crash Risk Test at Through Lanes

For through lanes at the intersection, the crash report analysis showed a crash pattern that the rear-end crash rate in the eastbound approach of the Colonial Drive (50EB) is highest and that in the northbound approach of the Alafaya Trail (434NB) is lowest. Moreover, the angle crash rate related to the through traffic from 50EB is obviously higher than that from 434NB. To validate the driving simulator with respect to this crash risk at through lanes, two scenarios had been tested as follows:

1) SR-50 East bound (AEBR) - Subjects drive the simulator to go through the intersection along Colonial Drive (SR-50) eastbound. The signal changes from green to amber when the vehicle is at 90 m (295.28 ft) upstream from the stop line. This is high risk location.

2) SR-434 North bound (BNBR) - Subjects drive the simulator to go through the intersection along Alafaya Trail (SR-434) northbound. The signal changes from green to amber when vehicle is at 90 m (295.28 ft) upstream from the stop line. This is low risk location.

If the above two scenarios are compared to get the same pattern as in the real world, the experiment results can validate the driving simulator with respect to crash risk at through lanes. The following Table 4-22 defines all the independent variables for safety validation at the intersection.

Table 4-22: Independent Variables for Crash Risk at Through Lanes

Independent Variable	VARIABLE DESCRIPTION	
IN_app	Intersection approach	Categorical (NB=0; EB=1)
Stop	Did driver stop at the intersection after signal change?	Categorical (Yes=1;No=0)
Redlight	Did driver run a red light if he crossed the intersection?	Categorical (Yes=1;No=0)
Treac	Driver's brake response time to the signal change in the through lane.	Continuous (s)
Speed	Approaching speed measured at termination of the green phase	Continuous (mph)
Decel	The deceleration rate of the stopping vehicle	Continuous (ft/s^2)
Gap	Driver's traveling time to the stop line based on the approaching speed at the termination of green phase.	Continuous (s)
Age	Driver age	Categorical
Gender	Driver gender	Categorical (M=1; F=0)

4.2.2.1 Driver's Stop/Go Decision During Signal Change

Driver's stop/go decision is the most essential behavior at signalized intersections because wrong stop/go judgments are directly related to traffic crashes happening such as red-light running (angle crashes) or rear-end crashes. Table 4-23 shows the proportions of stopping and crossing decisions at intersections related to independent factors viz., intersection approach, driver gender, and driver age. At the onset of yellow phase, drivers at the 50-eastbound approach are more likely to cross the intersection compared to those drivers at the 434-northbound approach (37.1% vs. 13.3%). The Chi-square test showed that the p-value is 0.003 ($\chi_{1,122}{}^2 = 9.085$) and the drivers' stop/cross is statistically dependent on the two approaches based on 0.05 significance level. There is also a significant dependence of drivers' stop/cross decision at the onset of yellow phase ($\chi_{1,122}{}^2 = 5.958$, P = 0.015) on gender. It appears that male drivers are more likely to cross the intersection compared to those female drivers (32.9% vs. 13.0%). However, there is no statistically significant dependence of stop/go decision on driver age based on the simulator experiment results ($\chi_{4,122}{}^2 = 1.866$, P = 0.761).

Table 4-23: Decision of Stop/cross Vs Independent Factors

Independent Factor	Level	Cross	Stop	Total	Chi-square test
Approach	434 NB	8	52	60	$\chi_{1,122}^{2} = 9.085$ P = 0.003
		13.33 %	86.67 %	100 %	
	50 EB	23	39	62	
		37.1 %	62.9 %	100 %	
Gender	Female	6	40	46	$\chi_{1,122}^{2} = 5.958$ P = 0.015
		13.04 %	86.96 %	100 %	
	Male	25	51	76	
		32.89 %	67.11 %	100 %	
Age	16-19	5	16	21	$\chi_{4,122}^{2} = 1.866$ P = 0.761
		23.81 %	76.19 %	100 %	
	20-24	9	22	31	
		29.03 %	70.97 %	100 %	
	25-34	7	21	28	
		25 %	75 %	100 %	
	35-44	7	15	22	
		31.82 %	68.18 %	100 %	
	>=45	3	17	20	
		15 %	85 %	100 %	
Total		31	91	122	
		25.41 %	74.59 %	100 %	

Table 4-24 shows that the mean speed at the 50-eastbound approach is larger than that at the 434-northbound approach, although the speed limits for both approaches are 45 mph. Note that the speed limit design at this intersection is unbalanced and the speed limit for the 50 westbound approach is 50 mph but those for the other three approaches are 45 mph. Moreover, speed limits for most segments of the 50 highway is 50 mph, which may cause drivers not fully reduce their traveling speeds to 45 mph. It was explained that drivers at the 50-eastbound approach are less likely to stop at the intersection during the signal change. Therefore, drivers at the 50-eastbound approach are more likely to speed. Generally, when speeding drivers encounter a yellow signal at 90 m (295.28 ft) away from the stop line of the intersection, they are more likely to fall into dilemma and possibly to run the red light. Using no-stop rate as a surrogate for angle collisions, it can be concluded that SR-50 eastbound vehicles are more likely to run the red light so as to result in a higher angle collision rate compared to that along SR-434 northbound direction. This experimental finding is consistent with the conclusion that was based on the crash report analysis. Furthermore, according to the experiment results, there was only one red light running observation out of 60 subjects along SR-434 northbound approach and three observations out of 62 subjects along SR-50 eastbound approach. Since red-light running is a rare event, no conclusion could directly be drawn based on the limited sample size.

Table 4-24: Mean Speed of the Simulator

Factor	Level	N	SPEED	
			Mean (mph)	Std Dev (mph)
Approach	434 NB	60	43.6919146	8.49360464
	50 EB	62	46.7752333	9.45439999
Age	16-19	21	48.4025982	8.53913339
	20-24	31	48.9463740	8.34174975
	25-34	28	45.2389876	8.80949795
	35-44	22	42.6116730	8.09195378
	>=45	20	39.1819365	8.76765054

On the other hand, the no-stop rate also can be considered as a surrogate for rear-end collisions, because within 90 m (295.28 ft) upstream of the stop line of the intersection, there is a potential conflict between the stopping drivers and crossing drivers during signal change. Therefore, a higher no-stop rate at the through lanes of the 50-eastbound approach may result in more rear-end crashes compared to the 434-northbound approach.

4.2.2.2 **Analysis of Stopping Behavior at Intersection During Signal Change**

Table 4-25 shows the descriptive statistics of the independent variables for the data of subjects that stopped at the intersection during the period of signal change. The mean of each independent variable for high risk approach i.e. 50-East bound through (50EBR) is compared for statistical significant difference with the corresponding mean of the independent variable at low risk approach i.e. 434-North bound through (434NBR). Two sample t - test is used for making this comparison which is defined as follows:

Hypothesis Test:

Null hypothesis: Mean 1 - Mean 2 = 0

Alternative: Mean 1 - Mean 2 ≠ 0

Where, Mean1 = Mean of each independent variable of all subjects driving along SR-434 North bound through.

Mean2 = Mean of each independent variable of all subjects driving along SR-50 East bound through.

Table 4-25: Descriptive Statistics of Independent Variables for Subjects Stopped

IN_app	N Obs	Variable	N	Mean	Std Dev	Min	Max	Range
50EBR	39	TREAC (s)	33	0.8313	0.5919	0.1	3.4333	3.3333
		SPEED (mph)	39	42.567	7.942	23.718	55.994	32.275
		DECEL (ft/s^2)	39	8.2275	3.7152	2.8006	14.863	12.063
		GAP (s)	39	4.9496	1.0879	3.6165	8.5377	4.9212
434NBR	52	TREAC (s)	45	0.6315	0.3196	0.0833	1.65	1.5667
		SPEED (mph)	52	41.846	6.752	22.383	54.243	31.86
		DECEL (ft/s^2)	52	7.5277	3.0685	0.4075	15.541	15.133
		GAP (s)	52	4.9891	0.9866	3.7332	9.0471	5.3139

The results of two-sample t-test (Table 4-26) show that, P-value of no independent variable is less than 0.05. Therefore, this test fails to reject null hypothesis at a significance level of 0.05. Hence, there is no significant difference between the mean of each independent variable of the two approaches namely 50-East bound and 434-North bound with 95% confidence. Generally, at the onset of the yellow phase, the length of the yellow phase, the potential distance to the intersection and approaching speed play key roles on drivers' stop decision and brake behavior. Note that at this intersection, both yellow phases of 50EB and 434NB are 4.3 s; for each scenario, signal changes from green to yellow when the vehicle is at 90 m (295.28 ft) upstream from the stop line; and from the experiment results, there is no significant difference in approaching speeds for those who decided to stop between 50EB and 434NB. Based on the above facts, their reaction time to the signal change and deceleration rate should be expected to be similar for both approaches.

Table 4-26: Results of Two Sample t-test for Means between Approaches

Independent variables	If Variances Are	t statistic	Df	Pr > t
Speed (mph)	Equal	0.468	89	0.6413
	Not Equal	0.457	74.13	0.6492
Treac (s)	Equal	1.918	76	0.0589
	Not Equal	1.760	45.63	0.0851
Decel (ft/s^2)	Equal	0.983	89	0.3281
	Not Equal	0.957	72.66	0.3419
GAP (s)	Equal	-0.181	89	0.8569
	Not Equal	-0.178	77.40	0.8589

Furthermore, the same data is looked into for significant difference of independent variables between gender groups at the high risk approach 50-East bound using the same two sample t-test and are compared with real world crash data.

Hypothesis Test:

Null hypothesis: Mean 1 - Mean 2 = 0

Alternative: Mean 1 - Mean 2 ≠ 0

Where, Mean1 = Mean of each independent variable for female at approach SR-50 East bound.

Mean2 = Mean of each independent variable for male at approach SR-50 East bound.

Table 4-27 shows the descriptive statistics of independent variables for subjects stopped on red at approach SR-50 East bound. From Table 4-28, at 0.05 significance level, there is no significant difference in independent variables Speed and Gap between gender groups; male and female. However there is significant difference in independent variables reaction time (Treac) and deceleration rate (Decel). Reaction time is found to be significantly longer for females than that for males. Therefore, females take longer time to react and hence they have less time to stop eventually decelerating at a faster rate than males. This is further strengthened by the result that the deceleration rate for females is significantly higher than that for males (see Table 4-28).

Table 4-27: Descriptive Statistics of Independent Variables for Subjects Stopped on Red at Approach SR-50 Eastbound

Gender	N Obs	Variable	N	Mean	Std Dev	Min	Max	Range
Female	20	TREAC (s)	17	0.7304	0.3607	0.3667	1.65	1.2833
		SPEED (mph)	20	40.236	7.2986	22.383	47.716	25.333
		DECEL (ft/s^2)	20	7.8909	2.9364	2.6603	13.119	10.459
		GAP (s)	20	5.2485	1.2812	4.2439	9.0471	4.8032
Male	32	TREAC (s)	28	0.5714	0.2819	0.0833	1.4167	1.3333
		SPEED (mph)	32	42.852	6.2958	30.699	54.243	23.544
		DECEL (ft/s^2)	32	7.3007	3.1729	0.4075	15.541	15.133
		GAP (s)	32	4.827	0.7244	3.7332	6.5963	2.8631

Table 4-28: Results of Two Sample t-test for Means between Gender Groups for Approach 50-Eastbound.

Independent variables	If Variances Are	t statistic	Df	Pr > t
Speed (mph)	Equal	-0.059	89	0.9531
	Not Equal	-0.058	78.90	0.9537
Treac (s)	Equal	2.086	76	0.0403
	Not Equal	1.889	42.57	0.0657
Decel (ft/s^2)	Equal	1.920	89	0.0581
	Not Equal	1.920	84.02	0.0582
GAP (s)	Equal	0.435	89	0.6649
	Not Equal	0.415	65.04	0.6796

4.2.2.3 <u>Conclusions</u>

Driver's stop/go decision is the most essential behavior at signalized intersections, which is related to both angle and rear-end collisions. The crash report analysis showed that the eastbound approach of Colonial Drive (50EB) has a higher crash rate for both types of collisions than the northbound approach of the Alafaya Trail (434NB). Using no-stop rate during the signal change as a crash surrogate in the driving simulator experiment, it was found that drivers at the 50-eastbound approach are more likely to cross the intersection compared to those drivers at the 434-northbound approach (37.1% Vs. 13.3%) because the mean speed at the 50EB was found to be larger than that at the 434NB. This finding implied that 50EB should be expected to have a higher crash rate for both angle and rear-end collisions at this intersection. Therefore, the experiment validated that the UCF driving simulator could be employed as a test-bed for the traffic safety studies.

4.3 Questionnaire Analysis of the Driving Simulator Experiment

All subjects after completing the experiment were asked to fill out a questionnaire consisting of four questions. Figures 4-8, 4-9, and 4-10 show the opinion of subjects for questions 1, 3 and 4. Questions 2, 3 and 4 are valid only if the subjects recognize the intersection. For the second question, which is “Can you say which intersection it was?”, all subjects, who were able to recognize the intersection, were also able to say which intersection it was i.e. ‘Colonial Drive and Alafaya Trail intersection’.

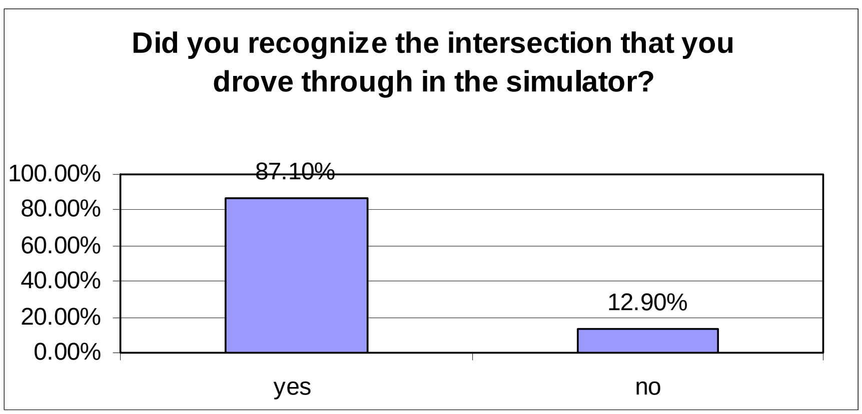

Figure 4-8: Question 1

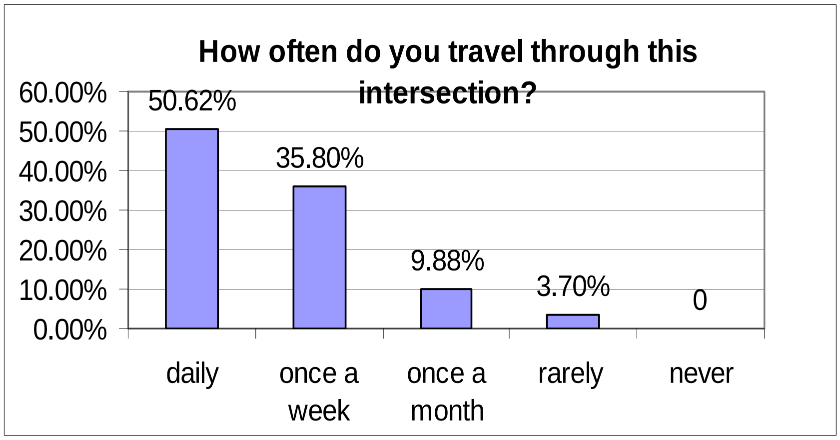

Figure 4-9: Question 3

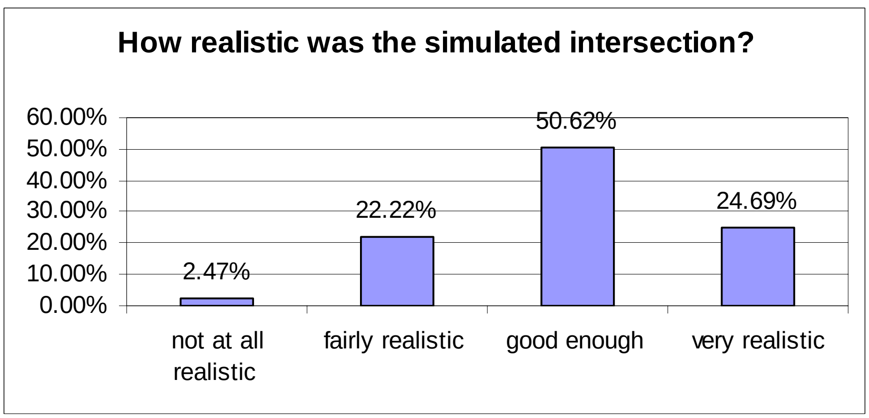

Figure 4-10: Question 4

From Figure 4-8, 87.10% of the subjects recognized the intersection. And out those who identified the intersection, from Figure 4-9, 50.62% drive daily, 35.8% drive once in a week, 9.88% drive once in a month, through the intersection. From Figure 4-10, seventy five percent of the subjects, who recognized the intersection, thought that the simulated intersection was good enough or realistic. Therefore, the driving simulator is also validated for physical and visual aspects of the intersection.

5 . LOGISTIC REGRESSION MODELS

5.1 <u>A Measure for Comparing 'Rear End Crash Risk' at Through Lanes of the Intersection SR-434 North Bound and SR-50 East Bound</u>

Rear end crashes can happen in the event of both the leading and the following vehicles come at the same time with contradicting behavior of stopping at the stop line and not stopping, respectively. The decision of stop/go is of important in and around the dilemma zone, which is at the onset of yellow light (or at the termination of green phase); where the driver has to decide whether to stop or not. At the onset of yellow signal, the time the driver has, to reach the intersection with the current speed, plays an important role in deciding the stop/go decision. In the experiment, the yellow signal is flashed when the vehicle is at 90m upstream of the intersection. Based on this distance and the approaching vehicle speed at the onset of the yellow signal, a variable GAP is designed; which is defined as the traveling time taken by the vehicle to reach the intersection from time of onset of yellow signal. Therefore, at the onset of yellow light, the joint probability of the decision of leading vehicle to stop and the decision of following vehicle to go ahead i.e., accepting the gap, is considered as a measure of rear end crash risk. Using this measure relative rear end crash risk can be computed. The experiment considered many other independent variables for calculating the stop probability. Table 5-1 shows the different independent variables and their definitions.

Table 5-1: Independent variables and its description

Independent Variable	VARIABLE DESCRIPTION	
IN_app	Intersection approach	Categorical (NB=0; EB=1)
Stop	Did driver stop at the intersection after signal change?	Categorical (Yes=1;No=0)
Redlight	Did driver run a red light if he crossed the intersection?	Categorical (Yes=1;No=0)
Treac	Driver's brake response time to the signal change in the through lane.	Continuous (s)
Speed	Approaching speed measured at termination of the green phase	Continuous (mph)
Decel	The deceleration rate of the stopping vehicle	Continuous (ft/s^2)
Gap	Driver's traveling time to the stop line based on the approaching speed at termination of the green phase .	Continuous (s)
Age	Driver age	Categorical
Gender	Driver gender	Categorical (M=1; F=0)

The following is a method to calculate STOP probability:

Let,

Probability of stopping at the onset of yellow light = π

Probability of not stopping i.e. accepting the gap = $1 - \pi$

For calculating this probability of stopping at the onset of yellow signal (π), 91 subjects ran the driving simulator experiment. A binary variable STOP is designed which is defined as:

STOP = 1 for stop i.e. rejecting gap

= 0 for go i.e. accepting gap

Since the dependent variable (STOP) is binary, the Multi-variate binary logistic regression method is used to model the probability of stopping at the onset of yellow. In this model, the log of Probability of Stopping at the onset of yellow signal is related linearly using logit link function, to the independent variables shown in Table 5-1. It is mathematically represented as,

$$\log_e\left(\frac{\pi}{1-\pi}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots\cdots + \beta_n X_n$$

where, X_i, i = 1, 2, ... n are the independent variables.

β_0, β_1, β_2, ……………. β_n are the parameters that are estimated by 'Maximum Likelihood Estimates' method described in the textbook 'Applied logistic Regression'. From the model, e^{β_i} is interpreted as the odds ratio of response variable with increase in one unit of X_i keeping all other variables unchanged.

By letting

$$g(X) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots\cdots + \beta_n X_n$$

$$\pi = \frac{e^{g(X)}}{1 + e^{g(X)}}$$

The model building is done using 'Statistical Analysis Software (SAS)'. The variables are selected into the model using backward elimination variable selection algorithm. Based on this method, out of the seven independent variables considered for modeling, three variables viz. intersection approach, Speed at the onset of yellow signal and gender were found to be statistically significant at alpha = 0.05 significance level. Table 5-2 shows the maximum likelihood estimates for these variables.

Table 5-2: Maximum likelihood estimates of parameters for stop/go analysis at the onset of yellow light.

Analysis of Maximum Likelihood Estimates						
Parameter		DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept		1	14.43	2.7456	27.624	<.0001
SPEED		1	-0.241	0.0517	21.832	<.0001
IN_app	50ebr	1	-1.385	0.6205	4.981	0.0256
Gender	M	1	-1.31	0.6363	4.2393	0.0395

5.1.1 Logistic Regression Model

$$\log_e\left(\frac{\pi}{1-\pi}\right) = 14.43 - 0.241 * speed - 1.385 * In\_App - 1.31 * Gender$$

$$\pi = \frac{e^{14.43-0.241*speed-1.385*In\_App-1.31*Gender}}{1+e^{14.43-0.241*speed-1.385*In\_App-1.31*Gender}} \text{ ---------------- (1)}$$

5.1.2 Model Interpretation

Table 5-3: Odds Ratio Estimates

Odds Ratio Estimates			
Effect	Point Estimate	95% Wald Confidence Limits	
SPEED	0.786	0.71	0.869
IN_app 50ebr vs 434nbr	0.25	0.074	0.845
Gender m vs f	0.27	0.078	0.939

Table 5-3 shows the odds ratio of the estimates and its 95% confidence interval limits. The model can be interpreted based on the three parameters of the three independent variables that found to be significant. Firstly, the odds of stopping at the intersection becomes 0.786 times the odds of stopping at the intersection with an increment of 1mph in speed which is measured at the onset of yellow time, keeping gender and intersection approach constant. In other words, the odds of stopping at the stop line of intersection on the onset of yellow signal increases by 27.3% with every 1mph decrease in speed, keeping other variables unchanged and this percentage is as low as 15.07% and as high as 40.85%. Secondly, the odds of stopping at the SR-50 east bound approach becomes 0.25 times the odds of stopping at the approach SR-434 North bound approach with other variables kept unchanged. That means the odds of stopping at the approach SR-434 north bound on the onset of yellow signal are four times the odds of stopping at the approach SR-50 east bound on the onset of yellow light with other variables remained unchanged and this odds ratio is as low as 1.18 and as high as 13.51. Thirdly, the odds of male drivers stopping at the intersection on the onset yellow light are 0.27 times than that of female drivers which means odds of female drivers stopping are 3.7 times the odds of male drivers stopping at the intersection on the onset of yellow signal with the other independent variables remained unaltered. And the odds female drivers stopping are as low as 1.06 times and as high as 12.82 times the odds of male drivers stopping keeping other variables constant.

From the above interpretations, it is concluded that drivers stopping behavior is dependent on the intersection approach, the drivers speed and gender. The following section describes a method to assess the rear end crash risk and compare quantitatively rear end crash risk of the two intersection approaches.

5.1.3 A Comparative Measure of Rear-End Crash Risk at Two Approaches of a Signalized Intersection:

As described in the preceding section rear end crash happening mainly depends upon the driver's judgment to assess the *GAP*. At signalized intersections, rear end crash occurs at the joint occurrence of leading vehicle stopping at the intersection prematurely and the following vehicle trying to cross the intersection or trying to run the red light. The following method describes the measure of rear end crash risk at signalized intersections.

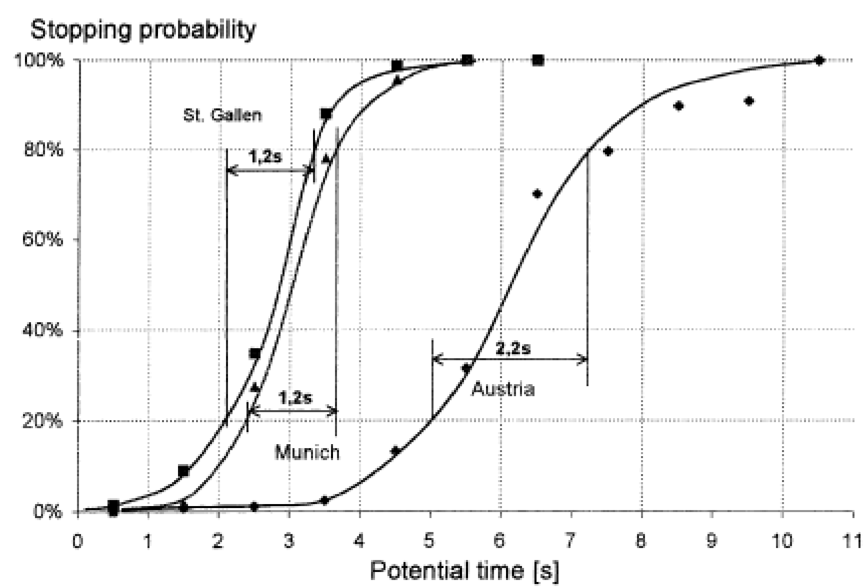

Figure 5-1: Sopping probability as a function of potential time by country/city
(Source: Koll, 2002)

Koll et al. (2002) conducted a study to compare the driver's stopping behavior during flashing green before amber at intersections across different cities in Europe. He used the potential time (see Fig 5-1) to stop (which we defined as *GAP* in our case) as a measure to compare the stopping behavior at signalized intersections across different cities.

If the GAP between 20% and 80% of stop probability is large then it means that there is a high chance of a rear end crash. But how to compare if both approaches have the same potential time to stop but they are separated by a fixed time and how to quantify the rear end crash risk even if they have different potential time to stop. The following is the method to measure quantitatively the rear end crash risk.

From the previous section *STOP* behavior is dependent upon the intersection approach, driver speed and gender. Based on this stopping behavior rear end crash risk is measured and compared between the two approaches of the intersection. Therefore, now the independent variables are driver's speed and gender. Gender behavior is studied separately in the later sections. The variable *SPEED* (measured at 90 m (295.28 ft) upstream of the intersection) is converted into *GAP* by dividing it by 90 m. Based on the speed of each vehicle there are get different gaps. A logistic regression model is fitted with variable *STOP* as dependent variable and *GAP* as independent variable to calculate the probability of stopping at the onset of yellow signal (π).

Now, considering behavior of stopping and not stopping as two independent events, the probability of rear ending for any one particular *GAP*, is defined as,

$$P_r = \pi * (1 - \pi)$$

For the entire region of probable *GAP*s,

$$\text{the probability of rear ending} = \int_a^b \pi(1-\pi) \text{----------------------(2)}$$

Using logit transformation for a binary response variable or dependent variable,

STOP = 1 for stop i.e. rejecting *GAP* (defined in Figure 5-1)

= 0 for go i.e. accepting *GAP* (defined in Figure 5-1),

$$\pi = \frac{e^{g(x)}}{1 + e^{g(x)}} \text{ ---------------------------------- (3)}$$

where, $g(x) = \beta_0 + \beta_1 * (x)$ --------------------(4)

where, x = dependent variable i.e. GAP

π = Probability of stopping at the onset of yellow light.

Table 5-4a: Response variable (STOP) for different approaches

Response Profile			
Intersection approach	Response	STOP	Total Frequency
SR-434 North bound	Stop	1	52
	Go	0	8
SR-50 East bound	Stop	1	39
	Go	0	23

Table 5-4b: Global null hypothesis testing for different approaches

Testing Global Null Hypothesis: BETA=0				
Intersection approach	Test	Chi-Square	DF	Pr > ChiSq
SR-434 North bound	Likelihood Ratio	19.315	1	<.0001
	Score	10.43	1	0.0012
	Wald	9.3421	1	0.0022
SR-50 East bound	Likelihood Ratio	26.383	1	<.0001
	Score	16.396	1	<.0001
	Wald	11.335	1	0.0008

Table 5-4c: Estimates of parameters β for different approaches

Analysis of Maximum Likelihood Estimates						
Intersection approach	Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
SR-434 North bound	Intercept(β_0)	1	-11.71	4.2505	7.5861	0.0059
	GAP (β_1)	1	3.1813	1.0408	9.3421	0.0022
SR-50 East bound	Intercept(β0)	1	-10.26	3.1072	10.896	0.001
	GAP(β1)	1	2.5552	0.7589	11.335	0.0008

Table 5-4a shows the observations for response variable STOP. Variable GAP is statistically significant for stop/go behavior along the through lanes at the intersection for both the approaches as shown in Table 5-4b (P-values for all tests are less than 0.05). Table 5-4c shows the estimates of the parameters β for approaches SR-434 north bound and SR-50 east bound respectively.

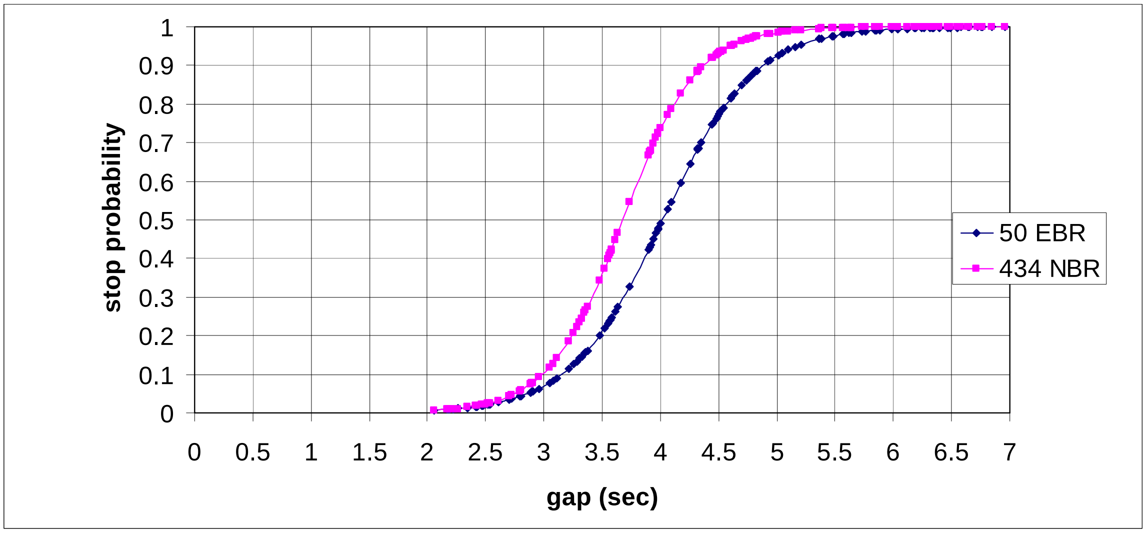

Figure 5-2: Stop probability Vs GAP for different approaches

Figure 5-2 shows the stop probability for different gaps ranging between 2 sec to 6 sec for both the approaches. For a given gap the probability of stopping is higher for the approach 434-North bound than that the approach 50-East bound. In the experiment yellow time of 4.3 sec was provided. So, vehicles having a gap of 4.3 sec have to stop in order to avoid red light running and for gaps less than 4.3 sec should continue to go. From the figure 5-2, for a gap of 4.3 sec, the non-stop probability (1 - stop probability) is higher for 50-east bound (0.3) than that for 434-north bound (0.1). Therefore, SR-50 east bound has the high risk of red light running.

Rear end Crash risk:

Form equation (1)

Probability of rear ending = $\int_a^b \pi(1-\pi)$

Substituting eq. 2

$$= \int_2^6 \frac{e^{g(x)}}{1+e^{g(x)}}\left(1-\frac{e^{g(x)}}{1+e^{g(x)}}\right)$$

$$= \int_2^6 \frac{e^{g(x)}}{\left(1+e^{g(x)}\right)^2}dx \quad \text{------------------------------------} \ (5)$$

Let, $e^{g(x)} = t$ -------------------- (6)

$e^{\beta_0+\beta_1 x} = t$ (by substituting eq-3)

Taking derivative on both sides,

$$\beta_1 e^{\beta_0+\beta_1 x}\, dx = dt$$

$$\beta_1 t \ dx = dt$$

$$dx = \frac{dt}{\beta_1 t} \quad \text{----------------------} \ (7)$$

Substituting eq-5, eq-6 in eq-4,

$$\text{Probability of rear ending} = \int_a^b \frac{t}{(1+t)^2}\frac{dt}{\beta_1 t} \text{ , where, } a=e^{\beta_0+\beta_1*2}, \ b=e^{\beta_0+\beta_1*6}$$

$$= \frac{1}{\beta_1}\int_a^b \frac{dt}{(1+t)^2}$$

$$= -\frac{1}{\beta_1}\left(\frac{1}{1+t}\right)\Bigg|_a^b$$

$$\text{Probability of rear ending} = \frac{1}{\beta_1}\left(\frac{1}{1+e^{\beta_0+\beta_1*2}} - \frac{1}{1+e^{\beta_0+\beta_1*6}}\right) \text{----------} \ (8)$$

Substituting β_0, β_1 from Table 4c in eq-(8), we get the probability of rear ending for the approaches 434-north bound and 50-east bound.

For a GAP range of 2 sec to 6 sec, the probability of rear ending,

along approach SR-434 north bound near intersection = 0.31265

along approach SR-50 east bound near intersection = 0.38666.

$$\text{Relative rear ending risk} = \frac{\text{probability of rear ending near approach 50 - east bound}}{\text{probability of rear ending near approach 434 - north bound}}$$

$$= \frac{0.38666}{0.31265}$$

$$= 1.2367$$

Therefore it can be concluded that SR50-east bound approach is 23.67% more rear end riskier than SR434-north bound. This supports the findings from real crash data that SR-50 east bound is more risky with respect to rear end crashes than the approach 434-north bound.

5.2 Rear End Crash Risk Based on Gender

From the logistic model in equation-(1), gender was also found to be significant factor for the probability of rear end crashes. This section computes quantitatively, the rear-end crash risk for different gender groups. A logistic regression model is fitted for the data for both genders separately, by taking variable STOP as dependent variable and GAP as independent variable. Table 5-5a shows the frequency of stopping under gender classification.

Table 5-5a: Response profile for variable STOP based on gender

Response Profile			
Ordered Value	STOP	Total Frequency	
		Female	Male
1	1	40	51
2	0	6	25

Table 5-5b shows the results of three statistical tests. The results show the rejection of null hypothesis (P-value <0.05) at α = 0.05 that probability of stopping on the onset of yellow light is independent of gender.

Table 5-5b: Results of Global null hypothesis testing based on gender

Testing Global Null Hypothesis: BETA=0				
Gender	Test	Chi-Square	DF	Pr > ChiSq
Female	Likelihood Ratio	13.073	1	0.0003
	Score	4.944	1	0.0262
	Wald	5.9658	1	0.0146
Male	Likelihood Ratio	35.682	1	<.0001
	Score	26.001	1	<.0001
	Wald	16.267	1	<.0001

Table 5-5c: Maximum likelihood estimates of parameters based on gender

Analysis of Maximum Likelihood Estimates						
Gender	Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Female	Intercept (β_0)	1	-14.06	6.2713	5.0286	0.0249
	GAP (β_1)	1	3.7708	1.5438	5.9658	0.0146
Male	Intercept (β_0)	1	-10.57	2.7115	15.183	<.0001
	GAP (β_1)	1	2.6437	0.6555	16.267	<.0001

Table 5c show the estimates of the parameter β for both the models based on gender groups. Table 5d shows the estimates of the odds ratio for male and female gender groups and their 95% confidence limits.

Table 5-5d: Odds Ratio estimates for male and female gender groups.

Odds Ratio Estimates				
Gender	Effect	Point Estimate	95% Wald Confidence Limits	
Female	GAP	43.413	2.106	894.8
Male	GAP	14.065	3.892	50.826

From Figure 5-3, for any particular gap the probability of stopping is higher for female population than that for male population.

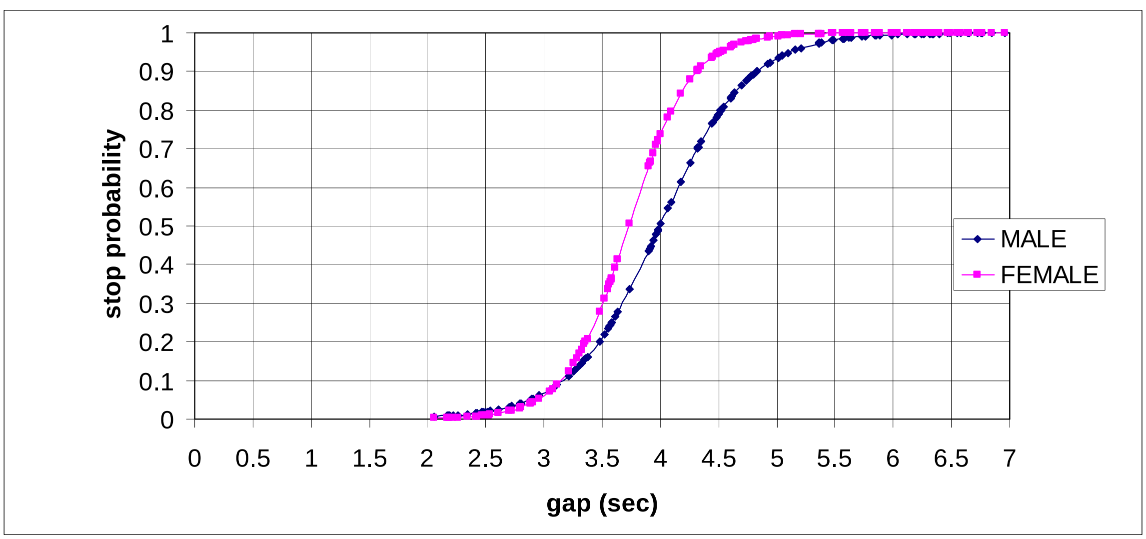

Figure 5-3: Stop probability Vs GAP for different gender group

Using the derived equation-(8) and substituting β_0, β_1 from Table 5c we get the probability of only male population involving in a rear end crash and probability of only female population involving in rear end.

For a GAP range of 2 sec to 6 sec, the probability of,

$$\text{only male population involving in rear end} = 0.3744$$

$$\text{only female population involving in rear end} = 0.2648.$$

Relative rear ending risk between only male and only female groups =

$$\frac{\text{probability of only male population involving in a rear - end crash}}{\text{probability of only female population involving in a rear - end crash}}$$

$$= \frac{0.3744}{0.2648}$$

$$= 1.4143$$

It can be concluded that male population are 41.43% more risky in involving in a rear end crash than that of female population.

5.3 Car Following Cases at Right Turn Lanes

This section deals with crash risk at right turn lanes. The scenario is designed in such a way that the simulator car would be following a car which is traveling at a speed of 30 mph on a right turn lane of the approach of the intersection. In this scenario, when the leading vehicle approaches the intersection at 60 m (196.85 ft) away from the stop line, the traffic signal will change from green to yellow; when the leading vehicle approaches the intersection at 50 m (164.04 ft) away from the stop line with a speed of 30mph, it would brake with a high deceleration rate 6.4 m/s^2 (0.65 g) or 21 ft/s^2 in the right turn lane. The scenario is designed along two approaches viz., SR-434 north bound right turn lane and SR-50 west bound right turn lane.

Table 5-6: List of independent variables for the Car Following Scenarios

Independent variables	Variable description	
IN_app	Intersection approach	Categorical (WB=0; NB=1)
Spd50	Simulator speed measured when the leading vehicle is 50 m (164.04 ft) away from stop line in the right turn lane	Continuous (mph)
Fdis50	Following distance measured when the leading vehicle is 50 m (164.04 ft) away from stop line in the right turn lane	Continuous (m)
Ave_DEL	The average deceleration rate in the right turn lane	Continuous (ft/s^2)
Max_DEL	The maximum deceleration rate in the right turn lane for each vehicle.	Continuous (ft/s^2)
Ye_retime	Driver's brake response time to the signal change in the right turn lane.	Continuous (s)
Ve_retime	Driver's brake response time to leading vehicle's brake light in the right turn lane.	Continuous (s)
Crash	Is there a rear-end crash happening in the right turn lane?	Categorical (Yes=1; No=0)
Age	Driver age	Categorical
Gender	Driver gender	Categorical (M=1; F=0)

Table 5-6 above shows the list of independent variables that were recorded or calculated from the recorded data. There are mainly two factors that cause a rear end when the leading vehicle suddenly stops or decelerates. 1) The speed of the following vehicle. 2) The following driver's inability in assessing the gap in front of him. Since the leading vehicle starts to decelerate when it is 50 m (164.04 ft) ahead of intersection, the following vehicles speed is measured at this time. It is designated as Spd50 as shown in Table 5-6. At the same time the distance followed by the following vehicle is also measured and is designated as Fdis50 as shown in Table 5-6. Apart from these factors age, gender, yellow reaction times are considered for model building. Logistic regression model is fitted for the data with *crash* as dependent variable and the rest of the variables in Table 5-6 as independent variables. Stepwise selection method is used for selecting significant variables.

Table 5-7a: Results of testing of null hypothesis for car following cases

Testing Global Null Hypothesis: BETA=0			
Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	44.122	2	<.0001
Score	19.376	2	<.0001
Wald	10.187	2	0.0061

Table 5-7b: Estimates of parameters for variables effecting crash risk atright turn lanes

Analysis of Maximum Likelihood Estimates					
Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	-23.3	8.9267	6.8123	0.0091
Spd50	1	1.0327	0.3628	8.1034	0.0044
Fdis50	1	-0.427	0.1374	9.6486	0.0019

Table 5-7a shows the results of the null hypothesis that crash occurrence is not dependent (i.e. all $\beta = 0$) on all the independent variables listed in table 5-6. From Table 5-7a, since P-value for all the statistical tests is less than 0.05 null hypothesis is rejected at alpha = 0.05. Table 5-7b gives the maximum likelihood estimates of the parameters of the significant variables. Only variables *Spd50* and *Fdis50* are found to be significant. The final logistic model:

Probability of crash occurrence, $\pi = \dfrac{e^{-23.3+1.0327*Spd50-0.427\,Fdis50}}{1+e^{-23.3+1.0327*Spd50-0.427\,Fdis50}}$

Table 5-7c: Odds ratio estimates for car following case

Odds Ratio Estimates			
Effect	Point Estimate	95% Wald Confidence Limits	
Spd50	2.809	1.379	5.719
Fdis50	0.653	0.499	0.854

Interpretation:

The odds of crash occurrence increases by 2.809 times with every 1mph increase in speed of following vehicle at the time when leading vehicle starts to decelerate, keeping all other variables constant as shown in table 5-7c. The odds of crash occurrence become 0.653 times the crash occurrence at 1m lesser following distance. In other words, the odds of crash occurrence decrease by 34.7% with the increase of 1m (3.28ft) in following distance.

6 . CONCLUSIONS

The driving simulator validation experiment was successfully completed to validate its use as a test bed for measuring the traffic safety scenario and speed at the intersection of Alafaya trail (SR-434) and Colonial drive (SR-50). It is validated in terms of speed and safety.

6.1 Speed Validation

- The speed distributions observed from the field and that from the simulator follow normal distributions along all the four approaches of the intersection with 95% confidence.
- The speed data from the driving simulator shows a larger variability for the higher operation speeds.
- The speed data observed from the field and that from simulator have equal mean for each intersection approach with 95% confidence.

Therefore, based on overall comparisons of speed between simulation and real world, one can conclude that the UCF driving simulator is a valid tool for traffic study related to driving speed behaviors.

6.2 Safety Validation at Right Turn Lanes

Considering the driving simulator as a leading right turn vehicle, it was found that the deceleration rate at the 434NB approach is higher than that at the 50WB approach; non-stop rate is higher for 434NB approach than that for 50WB approach; and mean speed at the stop line of the 434NB approach is significantly greater than that of the 50WB approach. Using those three variables as key surrogate measuring rear end crash risk, one can conclude that the leading vehicles are more likely to contribute to the rear-end crashes at the right turn lane of the 434NB approach compared to at the right turn lane of the 50WB approach.

On the other hand, considering drivers' following behaviors at right turn lanes, the following distance at the moment when the leading vehicle started braking is significantly lesser along 434NB right turn lane than that along the 50WB right turn lane. Using the following distance as a surrogate measure for safety, the 434NB right turn lane shows a higher rear-end crash risk than the 50WB right turn lane. This conclusion was further verified by the evidence that the rear-end crash rate in the right turn lane of 434NB (15.25%) are significantly higher than that of 50WB (3.33%).

Based on the above findings for the right turn rear end crash risk analysis, it can be concluded that the experiment results validated that the UCF driving simulator should be an effective tool for traffic safety studies to test high risk locations at intersections.

6.3 Safety Validation at Through Lanes of the Intersection:

The crash report analysis showed that the eastbound approach of the Colonial Drive (50EB) has a higher crash rate for both types of the collisions (rear end and angle) than that at the northbound approach of the Alafaya Trail (434NB). Using no-stop rate during the signal change as a crash surrogate in the driving simulator experiment, it was found that drivers at the 50-eastbound approach are more likely to cross the intersection compared to those drivers at the 434-northbound approach (37.1% Vs. 13.3%) because the mean speed at the 50EB was found to be larger than that at the 434NB. This finding implied that 50EB should be expected to have a higher crash rate for both angle crashes and rear-end collisions at this intersection. Therefore, the experiment validated that the UCF driving simulator should be employed as a test-bed for traffic safety studies.

87.10% of the subjects recognized the intersection. Seventy five percent of the subjects, who recognized the intersection, thought that the simulated intersection was good enough or realistic. Therefore, the driving simulator is also validated for physical and visual aspects of the intersection.

6.4 Logistic Regression Models

The following conclusions are drawn from the logistic regression models developed:

- At through lanes of the intersection, on the onset of yellow signal, drivers stopping behavior is dependent on the intersection approach, the driver's speed and gender.
- The rear end crash risk is measured as joint occurrence of the leading vehicle stopping and following vehicle trying to go through the intersection.
- From the model developed it is concluded that SR50-east bound approach is 23.67% riskier than SR434-north bound for rear end crashes. This supports the findings from the real crash data that SR-50 east bound is riskier with respect to rear end crashes than the 434-north bound approach.
- Male populations are 41.43% riskier in rear end crashes than that of female population.
- At right turn lanes, the odds of crash occurrence increases by 2.809 times with every 1mph increase in speed of following vehicle at the time when the leading vehicle starts to decelerate, keeping all other variables constant. The odds of crash occurrence decrease by 34.7% with an increase of 1m in following distance.

LIST OF REFERENCES

Abdel-Aty, M. A. and Abdelwahab H.T. (2003), Configuration Analysis of Two Vehicle Rear-End Crashes, Transportation Research Record, 1840, pg. 140-147.

Alexander J., Barham P. and Black I. (2002), Factors influencing the probability of an incident at a junction: results from an interactive driving simulator, Accident Analysis and Prevention 34, pg 779–792.

Blaauw, G.J., 1982. Driving experience and task demands in simulator and instrumented car: a validation study. Human Factors 24 (4), 473–486.

Brilon W., Koenig R. and Troutbeck R.J. (1999), Useful estimation procedures for critical gaps, Transportation Research Part A Vol 33 pg 161-186

Cheng B., Hashimoto M. and Suetomi T. (2002), Analysis of Driver Response to Collision Warning during Car Following, JSAE review Vol 23, pg 231 –237.

Comte S.L and Jamson A.H (2000), Traditional and innovative speed-reducing measures for curves: an investigation of driver behaviour using a driving simulator, Safety Science Vol. 36, pg 137-150

Comte S.L. (2000), New systems: new behaviour, Transportation Research Part F Vol. 3, pg 95- 111

Cooper P.J. and Zheng Y. (2002), Turning gap acceptance decision-making: the impact of driver distraction, Journal of Safety Research, Vol. 33, pg 321-335.

Gattis J.L. and Low S.T. (1999), Gap Acceptance At Atypical Stop-Controlled Intersections, Journal of Transportation Engineering, Vol. 125, No. 3, May/June, 1999.

Godley S.T., Triggs T.J. and Fildes B.N. (2002), Driving simulator validation for speed research, Accident Analysis and prevention, Vol 34, pg 589-600

Hamed M.M., Easa S.M. and Batayneh R.R. (1997), Disaggregate Gap-Acceptance Model for Unsignalized T-intersections, Journal of Transportation Engineering, Vol. 123, No. 1, January/February, 1997.

Harms, L. (1994) Driving performance on a real road and in a driving simulator: results of a validation study, Vision in vehicles, Vol. V. Elsevier, North Holland.

Ikeda A., Katou T., Kinoshita M. and Aihara M. (2002), Study of driver characteristics using driving simulator considerations on difference in accident avoidance performance due to age, JSAE Review Vol. 23, pg 219–222

Kacir K., Brehmer C.L. and Noyce D. (2003), A Recommended Permissive Display for Protective/Permissive Left-Turn Control, ITE Journal, December 2003, pg 32-40.

Koll.H, Bader.M, Axhausen.K.W (2002) Driving behavior during flashing green before amber: a comparative study, Accident Analysis and Prevention Vol 36, pg 273-280.

Lee G.C.H, Yoo Y. and Jones S. (1997), Investigation Of Driving Performance, Vection, Postural Sway, And Simulator Sickness In A Fixed Based Driving Simulator, Computers and Industrial Engineering, Vol. 33, Nos. 3-4, pg 533-536.

Lee H.C, Cameron, Andy H. Lee (2003), Assessing the driving performance of older drivers: on-road versus simulated driving, Accident Analysis and Prevention, Vol 35, pg 797-803.

Lee H.C. (2002), The Validity of Driving Simulator to Measure On-Road Driving Performance of Older Drivers, Proceedings of CAITR-2002

Martin P.G. and Burgett A.L. (2001), Rear-end Collision Events: Characterization of Impending Crashes, Proceedings of the 1st Human-Centered Transportation Simulation Conference, The University of Iowa, Iowa City, Iowa, 2001 (ISSN 1538-3288).

McGehee D.V., Brown T., Wilson T.B. and Burns M. (1998), Examination of Driver's collision avoidance in a lead vehicle stopped scenario using a front-to-read-end collision warning system, NHTSA Tech. Report.

McGehee D.V, Mazzae E.N. and Baldwin G.H.S (2000), Driver Reaction Time In Crash Avoidance Research: Validation Of A Driving Simulator Study On A Test Track, Proceedings of the IEA 2000/HFES 2000 Conference.

McGehee D.V., Mazzae E.N. and Baldwin G.H.S (1999), Driver Crash Avoidance Behavior with ABS in an Intersection Incursion Scenario on the Iowa Driving Simulator, NHTSA Tech. Report.

Mourant R.R. and Thattacheny T.R. (2000), Simulator Sickness in a Virtual Environments Driving Simulator, Proceedings of the IEA2000/ HFES 2000 Congress.

Philip P., Taillard J.,Klein E., Sagaspe P., Charles A., Davies W.L., Guilleminault C. and Bioulac B.(2003), Effect of fatigue on performance measured by a driving simulator in automobile drivers, Journal of Psychosomatic Research Vol 55 , pg 197– 200

Roge J., Pebayle T. and Muzet A. (2001), Variations of the level of vigilance and of behavioural activities during simulated automobile driving, Accident Analysis and Prevention Vol. 33, pg 181–186

Roge J., Pebayle T., Hannachi S.E. and Muzet A. (2003), Effect of sleep deprivation and driving duration on the useful visual field in younger and older subjects during simulator driving, Vision Research Vol 43, pg 1465–1472

Royal, D., 2003, National Survey of Speeding and Unsafe Driving Attitudes and Behaviors: 2002. Volume II – Findings Report. NHTSA. Report No. DOT HS 809 688, October, 2003.

Shinar D. and Warshawsky-Livne L. (2002), Effects of uncertainty, transmission type, driver age and gender on brake reaction and movement time, Journal of Safety Research Vol 33, pg 117– 128

Smith D.L, Najm W.G. and Glassco R.A. (2002), Feasibility of Driver Judgment as Basis for a Crash Avoidance Database, Transportation Research Record 1784 Paper No. 02-3695

Smith L., Najam W.G. and Lam A.H. (2003), Analysis of Braking and Steering Performance in Car-Following Scenarios, NHTSA Tech. Record SAE 2003-01-0823

Tornros J. (1998), Driving Behaviour In A Real And A Simulated Road Tunnel- A Validation Study, Accident Analysis and prevention, Vol 30, No.4, pg 497-503.

Wang Y., Ieda H. and Mannering F. (2003), Estimating Rear-End Accident Probabilities at Signalized Intersections: Occurrence-Mechanism Approach, Journal of Transportation Engineering, Vol. 129, No. 4, July 1, 2003.

Winsum W.V, Waard D. and Brookhuis K.A (1999), Lane Change maneuvers and safety margins, Transportation Research Part F, Vol 2, pg 139-149.