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Using the UCF Driving Simulator as a Test Bed for High Risk Locations

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16. Abstract

UCF driving simulator could be a powerful tool to be used as a traffic safety test bed to identify potential problems of intersection design, explain interaction between drivers and roadway surroundings, and explore effective countermeasures to reduce traffic crash rates. To develop the UCF driving simulator as a safety test bed, this project focused on validating the driving simulator from two perspectives, Speed and Safety. To achieve this research objective, a signalized intersection that has one of the highest crash frequencies in Central Florida was replicated in the driving simulator system. Eight scenarios were designed at the intersection in a driving simulator experiment. Subjects based on gender classification and five age groups of interest including 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+) were recruited to test the eight scenarios. The experimental measurements based on subjects' performances in the simulator were compared to those measured in the field and police crash report analysis. It was found that drivers have similar driving performances and traffic risk patterns as found at the real intersection. Therefore, the experiment results validated that the UCF driving simulator could properly be employed as a test bed for driving behavior research and traffic safety studies.

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EXECUTIVE SUMMARY

The UCF driving simulator has a potential to be used as a traffic safety test bed to identify potential problems of intersection design, explain interaction between drivers and roadway surroundings, and explore effective countermeasures to reduce traffic crash rates. As an initial step to develop the UCF driving simulator as a safety test bed, this project focused on validating the driving simulator from two perspectives, Speed and Safety. To achieve this research objective, a signalized intersection of Alafaya Trail (SR 434 highway) and E. Colonial Drive (SR 50 highway) that has one of the highest crash frequencies in Central Florida was replicated in the driving simulator system. To validate the driving simulator in Speed and Safety, eight scenarios were designed in a driving simulator experiment. Subjects were recruited based on gender classification and five age groups of interest including 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. The experimental measurements based on subjects' performances in the simulator were compared to those measured in field and police crash report analysis to conclude that if drivers have same driving performances and traffic risk patterns.

Comparing speed data observed from field to those from the simulator experiments, showed that both follow normal distributions and have equal mean for each intersection approach. Furthermore, the distributions of mean speeds by driver age and gender based on the simulator experiment results are very close to the real speed distribution from the previous investigation

data. However, it was found that the speed variances are only equal for the two lower operation speed locations but unequal for the two higher operation speed locations in which the speed data from the driving simulator shows a larger variability. 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 studies related to driving speed behaviors.

For the safety validation, the crash report analysis showed two important risk patterns at the intersection: one is that the rear-end crash rate at the Alafaya northbound (434NB) right-turn lane is much higher than the other approaches and the Colonial Drive westbound (50WB) right-turn lane has the lowest rear-end crash rate; the other is that the through traffic at the eastbound approach (50EB) of Colonial Drive involved the highest rear-end crashes rate and a higher angle crash rate while the through traffic from 434NB are less likely to involve both rear-end and angle crashes.

For the right-turn rear-end risk study, it was found that considering the driving simulator as a leading right turn vehicle in the experiment, the deceleration rate at the 434NB approach is higher than that at the 50WB approach; the non-stop rate is larger 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 measures for 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 when the leading vehicle made a sudden stop in front of the subjects, the rear-end crash rate in the right turn lane of 434NB (15.25%) are significantly higher than that of 50WB (3.33%). Therefore, the drivers' performances in the simulator experiment showed the same risk pattern as that based on the police crash report analysis for the real intersection.

For the through-lane crash risk study, driver's stop/go decision can be considered as the most essential behavior at signalized intersections, which is related to both angle and rear-end crashes. Using no-stop rate during the signal change as a crash surrogate measure in the driving simulator experiment, it was found that drivers at the 50EB are more likely to cross the intersection compared to those drivers at the 434NB (37.1% Vs. 13.3%) to beat the red light. The trend is attributed to that the mean speed at the 50EB approach was found to be larger than that at the 434NB in both simulator experiment and field study. This finding implied that the through traffic at the 50EB approach should be expected to have a higher crash rate for both angle crashes and rear-end collisions at this intersection. This conclusion is consistent with the crash trend based on the police crash report analysis for the real intersection.

In summary, the experiment results validated the UCF driving simulator. It therefore could be employed as a test bed for driving behavior research and traffic safety studies.

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CHAPTER 1. INTRODUCTION

1.1 UCF Driving Simulator

With the progress of computer science and electronic engineering in recent years, driving simulators used for training and research are being rapidly developed. A modern driving simulator can provide drivers a very realistic impression by predicting vehicle motion caused by driver input and feeding back corresponding visual, motion, and audio cues to the driver. The UCF (University of Central Florida) driving simulator (see Figure 1-1) housed in the Center for Advanced Transportation Systems Simulation (CATSS) is an I-Sim Mark-III system with a high driving fidelity and immense virtual environments. The simulator cab is a Saturn model that has an automatic transmission, a left back view mirror and a center back view mirror inside the cab. The simulator is mounted on a motion base capable of operation with 6 degrees of freedom. It includes 5 channels (1 forward, 2 side views and 2 rear view mirrors) of image generation, an audio and vibration system, steering wheel feedback, operator/instructor console with graphical user interface, sophisticated vehicle dynamics models for different vehicle classes, a 3-dimensional road surface model, visual database with rural, suburban and freeway roads plus an assortment of buildings and operational traffic control devices, and a scenario development tool for creating real world driving conditions. The output data include steering wheel, accelerator, brake, every car's speed and coordinates, and a time stamp. The sampling frequency is 60Hz.

Figure 1-1: UCF driving simulator-Saturn cab

The UCF driving simulator is a virtual reality tool which enables researchers to conduct multi-disciplinary investigations and analyses on a wide range of issues associated with traffic safety, highway engineering, Intelligent Transportation System (ITS), human factors, and motor vehicle product development. The use of a modern advanced driving simulator for traffic engineering research has many advantages over similar real world or on-road driving research. These advantages include experimental control, efficiency, expense, safety, and ease of data collection. In addition, many researchers (Alicandri, 1986 and Stuart, 2002) indicated that simulator measures are valid for sign detection and recognition distances, speed, accelerator position changes and steering wheel reversals, because of a high correspondence between real world and simulator data sets.

1.2 Driving Simulator – Safety Test Bed

The UCF driver simulator allows testing different high risk highway locations without posing any risk to the drivers. A special ability of a simulation experiment is to reproduce dangerous driving conditions and situations in a safe and controlled environment to test driver behaviors. High risk locations could be replicated in the simulator and driven by different drivers' groups. This will enable researchers at UCF to identify the safety problems and risk situations that would lead to traffic crashes. Therefore, the UCF driving simulator has a potential to be used as a traffic safety test bed to identify potential problems of design, explain interaction between drivers and roadway surroundings, and explore effective countermeasures to reduce traffic crash rates.

1.3 Driving Simulator Validation

To develop the UCF driving simulator as a test bed, appropriate validity research is important to further driving simulator studies that intends to carry forward conclusions based on driving simulator experiments. 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). To verify that the UCF driving simulator should be a proper and powerful experiment tool as a test bed, this project focused on validating the driving simulator from two perspectives that represent a traffic and a safety parameter (Speed and Crash history). For the speed validation, it is expected that the speed measurement in the driving simulator environment should be statistically similar as that at the real locations, which is corresponding to the absolute validity. For the safety aspects, if the driving simulator is a valid tool to diagnose traffic safety problems at the intersection, the driver's performance in the driving simulator environment should reflect a similar crash risk pattern or trend as what happen in the real word, which is corresponding to the relative validity.

Previous research has shown increased risk of traffic crashes at signalized intersections (about half the crashes occur at an intersection or its approach). Therefore, in the current study, a signalized intersection was used to validate if the UCF driving simulator can be applied to identify the safety problems and risk situations that would lead to traffic crashes. In Orlando, the Alafaya Trail (SR 434 highway) and E. Colonial Drive (SR 50 highway) intersection was chosen to be replicated in the driving simulator system. The intersection was selected because it is a major intersection (4X6) of state roads, and it has one of the highest crash frequencies in Central Florida. The simulated intersection was replicated in the driving simulator system with as many important features of the real intersection as possible including intersection geometrics, pavement texture and markings, traffic devices and signs, and three-dimensional environments (buildings and plants) around the intersection.

1.4 Research Objective

The main objective of this study is verify if the UCF driving simulator should be a proper and powerful experiment tool as a test bed based on two aspects of validation, Speed and Safety. To achieve this goal, the following efforts were conducted in this study:

- Analyzing three years crash reports for the test signalized intersection to identify significant crash patterns and high risk locations;
- Replicating the test signalized intersection in the UCF driving simulator system to create a visual database with a high driving fidelity;
- Designing and running a driving simulator experiment to test the location and to evaluate the driving performance in the driving simulator experiment;
- Comparing speed measures based on experimental results to those from data collection in a field study to conclude if drivers have same driving performances; and
- Comparing crash trends or patterns based on experimental results to those from crash report analyses to conclude that if the UCF driving simulator can effectively identify traffic safety problem at high risk locations.

CHAPTER 2. LITERATURE REVIEW

2.1 Driving Simulator Applications and Validation

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.

2.1.1 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/judgement 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 judgement 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/judgement 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 oculomotor 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. Conducted over a 7-year period, National Cooperative highway research program (NCHRP) Project3-54 surveyed the current PPLT Control 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. Support for this comes both from 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 kinematic equations. 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 upto 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, 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 of 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 makes this study unique.

2.1.2 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.

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. Statistically significant interactions were followed up by analyzing simple effects. It was found that there was no interaction between the simulator factor and the lane factor and also between the simulator factor – 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 was 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.

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.

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.

2.2 Crash 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.

2.2.1 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.

2.2.2 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, 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 s 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.

2.3 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 in the experiment 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 a thing 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 said to be validated if the relative validity is justified.

- The concept of gap acceptance has been widely used, in situation where a vehicle turns left at an intersection, comes across a through vehicle from the opposite direction. Gap acceptance can be used to predict the relative risk of accidents at an intersection. This could be incorporated in building scenarios.
- There have not been many studies on toll plazas related to traffic safety and driving simulator. Most part of the literature was dealt with operational benefits of toll plazas. It would be a very new idea to replicate the Toll plaza in a driving simulator environment to identify the safety problems and risk locations.
- Analysis of Variance has been extensively used in almost all the driving simulator experimental design.

In conclusion, using the driving simulator as a test bed for testing high-risk locations at signalized intersections is an innovative research idea. Replicating a high-risk signalized intersection in a driving simulator would be both a novel and challenging task. The validation in the study would be done based on speed performance as well as traffic safety analysis. The drivers' behaviors, such as decisions to critical events, acceleration/deceleration rates of the vehicles, and violation frequencies, can be measured as effective surrogate for safety evaluation in the driving simulator experiment, for different intersection locations and traffic situations. Those data can be used for safety validation. Moreover, it is still necessary to compare speed measures from experiment to those from field study to conclude that if drivers have same driving performances in the driving simulator as in the real world.

CHAPTER 3. CRASH REPORT ANALYSES OF THE ALAFAYA TRAIL AND E. COLONIAL DRIVE INTERSECTION

Alafaya Trail (SR434) and E. Colonial Drive (SR50) intersection is located in Orange County, which was selected because it is a major intersection (4X6) of state roads, and it has one of the highest crash frequencies in Central Florida. It is a four-leg 6×5 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. The crash information contained within this report was obtained from the Florida Department of Transportation Crash Analysis Reporting System (CAR). This Chapter addressed a crash report analysis and identified the major safety problems at this intersection.

3.1 Crash Report Description

Table 3-1 shows the total number of long form reported crashes by distance from the intersection. For the years 1999 through 2002, the annually reported traffic crashes at this intersection has fluctuated between 36 and 47 within a 300 feet radius from the center of the intersection.

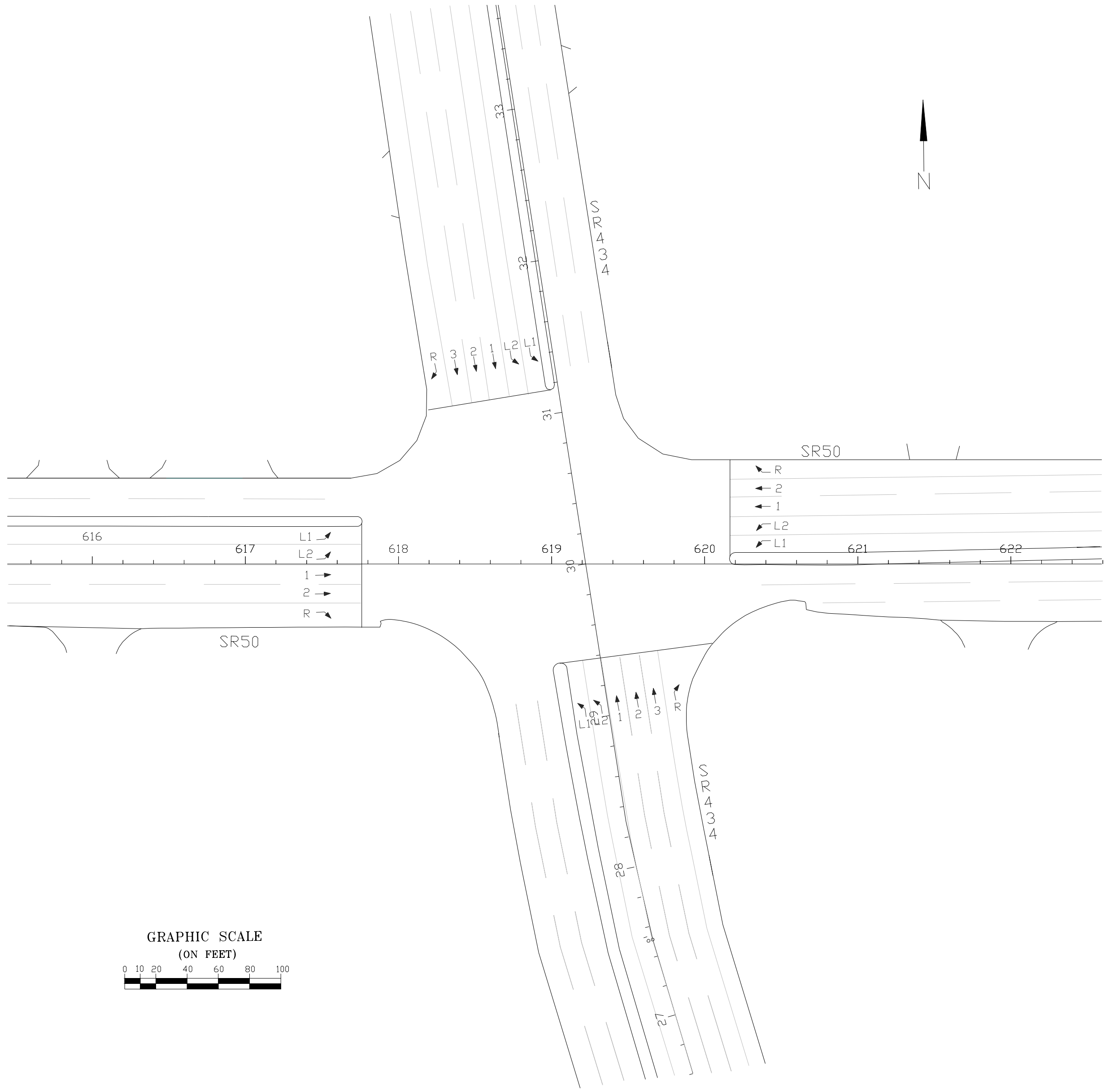


Figure 3-1: Alafaya Trail (SR434) and E. Colonial Drive (SR50) Intersection

Table 3-1: Annually Reported Crash Number to Specific Boundary of the Intersection

Year	To Dist 300ft	To Dist 250ft	To Dist 200ft	To Dist 150ft
1999	41	37	36	33
2000	47	43	42	40
2001	36	32	31	27
2002	40	38	38	34
Total	164	150	147	134

The police report initially classifies each reported crash by the first harmful event. There are 13 types of first harmful events appearing in the police reports: (1) Rear-end, (2) Angle, (3) Left Turn, (4) Sideswipe, (5) Right Turn, (6) Backed Into, (7) Collision with Pedestrian, (8) Head-on, (9) Collision with Bicycle, (10) MV Hit Utility Pole/ Light Pole, (11) MV Hit Fence, (12) Collision with Fixed Object Above Road, and (13) All Other. Tables 3-2 and 3-3 present the total number and relative frequencies of reported crashes for years 1999 through 2002. The highest type of crashes were rear-end with a frequency of 95 and a relative frequency of 57.9%. The second highest type was angle with a frequency of 24 and a relative frequency of 14.6%. Left turn, 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 are 73 PDO crashes, 90 injury crashes, and 1 fatal crash (shown in Figure 3-2). There are 138 people injured and 1 death as shown in Table 3-4.

Table 3-2: Crash Frequency for Years 1999 through 2002

First Harmful Event	1999	2000	2001	2002	Type Frequency
Rear-end	21	29	18	27	95
Angle	4	11	7	2	24
Left Turn	6	2	3	1	12
Sideswipe	4	1	3	2	10
Right Turn	3	1	3	1	8
Backed Into	3	1	0	0	4
Collision With Pedestrian	0	1	1	1	3
All Other	0	0	1	2	3
Head- on	0	1	0	0	1
Collision With Bicycle	0	0	0	1	1
MV Hit Utility Pole/ Light Pole	0	0	0	1	1
MV Hit Fence	0	0	0	1	1
Collision With Fixed Object Above Road	0	0	0	1	1
Total	41	47	36	40	164

Table 3-3: Crash Relative Frequency for Years 1999 through 2002 (%)

First Harmful Event	1999	2000	2001	2002	Total
Rear-end	51.2	61.7	50	67.5	57.9
Angle	9.8	23.4	19.4	5	14.6
Left Turn	14.6	4.3	8.3	2.5	7.3
Sideswipe	9.8	2.1	8.3	5	6.1
Right Turn	7.3	2.1	8.3	2.5	4.9
Backed Into	7.3	2.1	0	0	2.4
Collision With Pedestrian	0	2.1	2.8	2.5	1.8
All Other	0	0	2.8	5	1.8
Head- on	0	2.1	0	0	0.6
Collision With Bicycle	0	0	0	2.5	0.6
MV Hit Utility Pole/ Light Pole	0	0	0	2.5	0.6
MV Hit Fence	0	0	0	2.5	0.6
Collision With Fixed Object Above Road	0	0	0	2.5	0.6
Total	100	100	100	100	100

Table 3-4: Intersection Crash Severity Statistics for Years 1999 Through 2002

Crash Type	Number of Crashes	Number of Deaths/Injuries
PDO	73	-
Injury	90	138
Fatal	1	1
Total	164	139

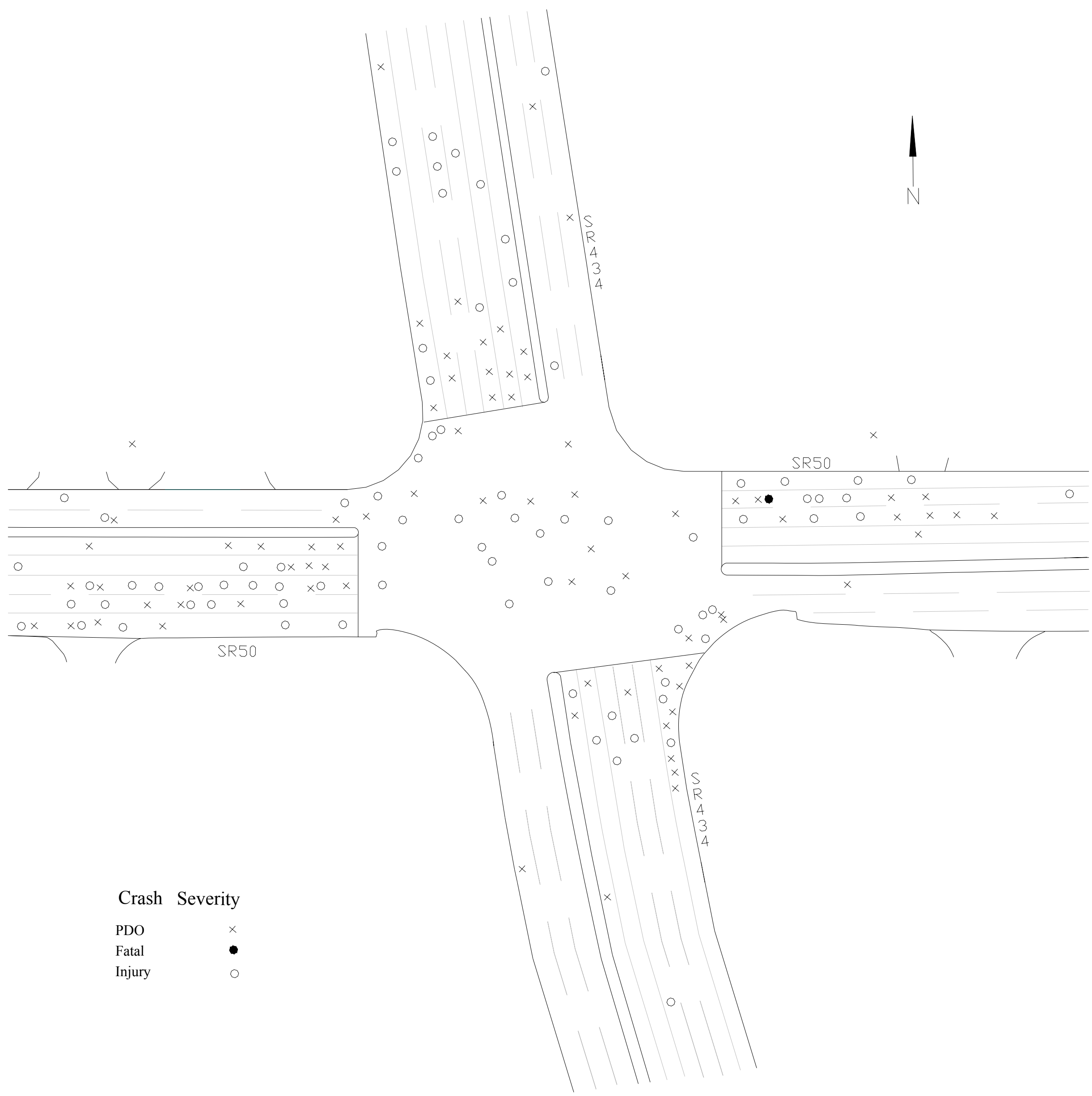


Figure 3-2: Crash Severity Diagram for Years 1999 through 2002

3.2 Crash Site Analysis

A primary function of crash reports is to identify locations with an unusually high rate of crashes and/or fatalities. Crash spot diagram can be used to identify high-risk locations. Figure 3-3 shows all the crashes of this intersection for four years. In this figure, we use different signs to indicate crash types.

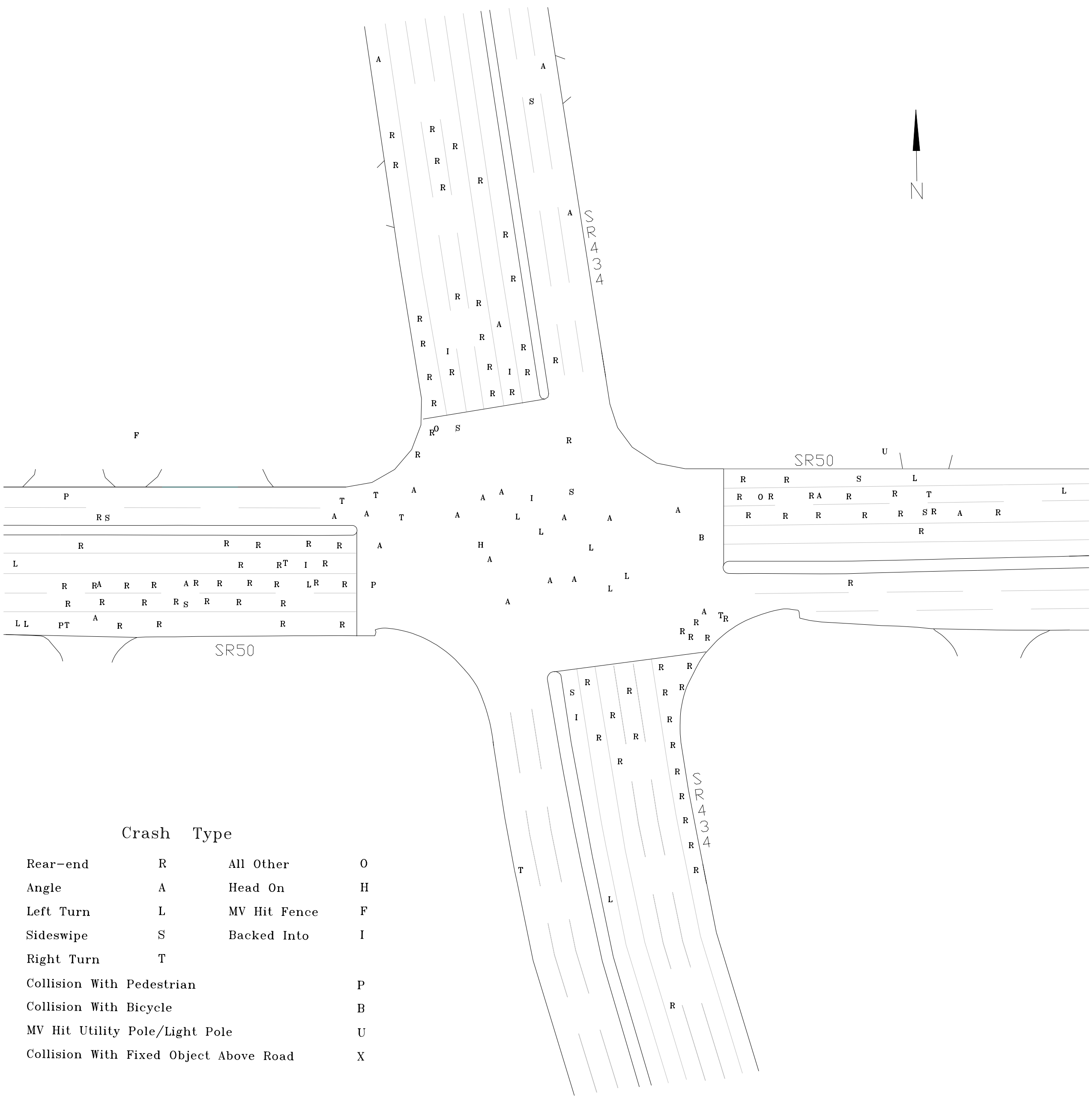


Figure 3-3: Crash Spot Diagram for Years 1999 through 2002

It is clear that this intersection has experienced primarily rear-end crashes. The total number is 95 rear-end for the four years. Figure 3-3 indicates that 91 rear-end crashes happened at the approach of this intersection, which accounts for 95.8% of total rear-end crashes. For Alafaya Trail a majority of rear-end crashes happened at its right-turn lanes. The number of the crashes is 16 for its northbound approach and 8 for its southbound approach. On the other hand, for E. Colonial Drive most of the rear-end crashes happened at its through lanes. It is 17 for its eastbound approach and 12 for its westbound approach.

From Figure 3-3, we can see that there are a number of driveways allowing access to and egress from the street at or near the intersection itself. Unexpected movements into or out of these driveways could cause some crashes to happen. Angle is the second highest type of crashes. The total number is 24 crashes for the four years. Figure 3-2 indicates 15 angle crashes happening at the intersection. Left-turn is the third type of crashes. There are 5 left-turn crashes happening at the intersection.

3.3 Alafaya Trail Right-turn Rear-end Crashes

According to the crash spot diagram (Figure 3-3), there is a total of 24 rear-end crashes happening at Alafaya Trail right-turn lanes, 8 for southbound and 16 for northbound. During the same period, E. Colonial Drive right-turn lanes have only 6 rear-end crashes. It is clear that Alafaya Trail right-turn lanes have safety problems especially compared to E. Colonial Drive. Collision diagrams for rear-end crashes for years 1999 through 2000 is shown in Figure 3-4. It can be used to determine the specific problem leading to rear-end collisions.

Summary of the environmental and physical conditions existing at Alafaya southbound and northbound right-turn lanes for rear-end crashes is shown in Tables 3-5 and 3-6. Summary of involved vehicle and driver human factors is shown in Tables 3-7 and 3-8. Also summary of contributing cause is shown in Tables 3-9 and 3-10. Most of crashes happened not at negative conditions. Most of vehicles involved in rear-end crashes are automobiles, male and female have almost same risk of involvement in rear-end crashes, and there is a high rate of middle age drivers involved in rear-end crashes. Almost all included crashes happened because the driver of striking vehicle drove carelessly.

Table 3-5: Environmental and Physical Conditions Existing at Alafaya Southbound Right-turn Lane for Rear-end Crashes

Environmental and Physical Conditions		Frequency		Relative Frequency	
Light Condition	Daylight	5	8	63%	100%
	Dark (Street Light)	3		38%	
	Dark (No Street Light)	0		0%	
Road Surface	Dry	8	8	100%	100%
	Wet	0		0%	
Weather	Clear	6	8	75%	100%
	Cloudy	2		25%	
	Rain	0		0%	

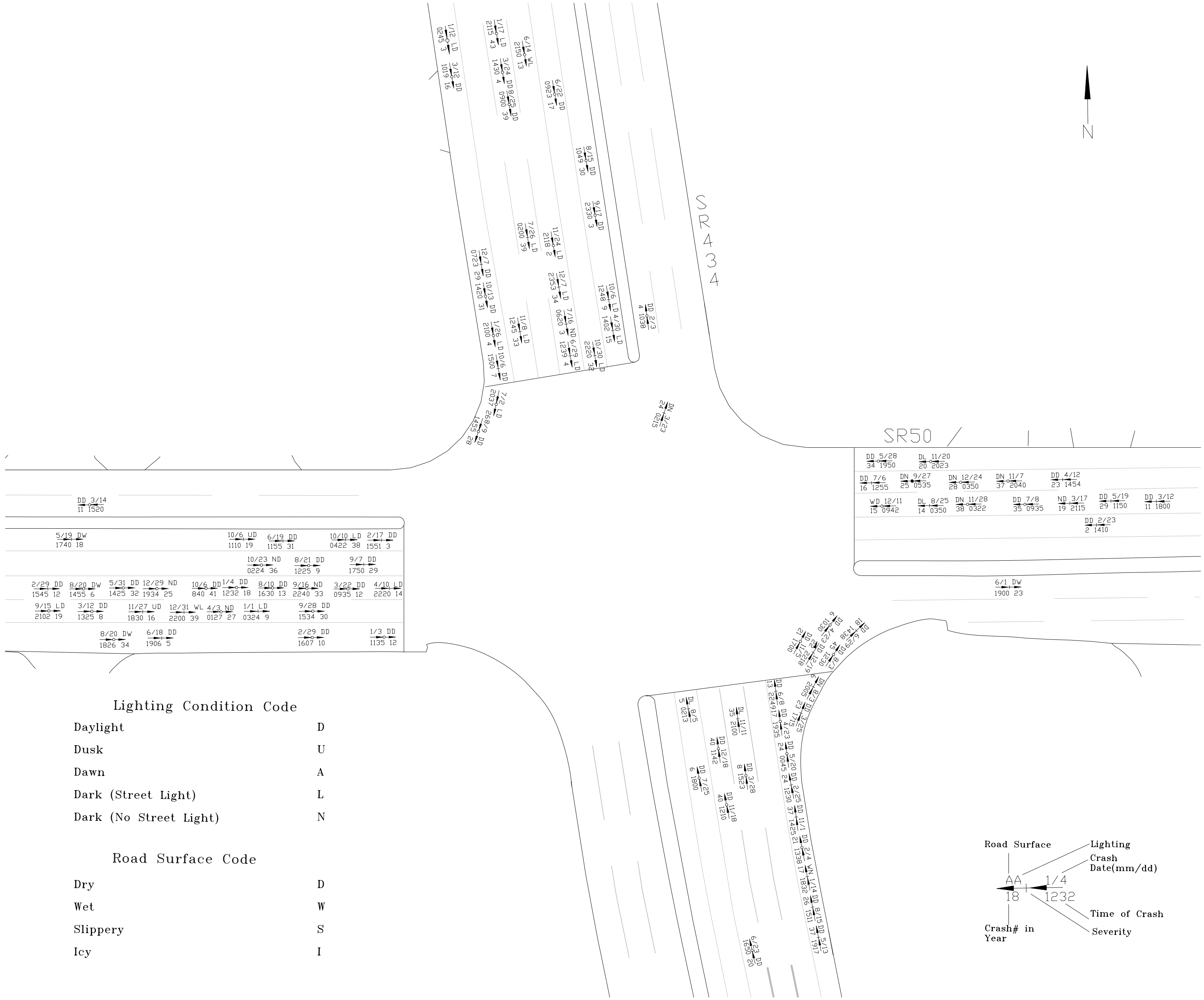


Figure 3-4: Collision diagram for rear-end accidents (1999-2002)

Table 3-6: Environmental and Physical Conditions Existing at Alafaya Northbound Right Turn Lane for Rear-end Crashes

Environmental and Physical Conditions		Frequency		Relative Frequency	
Light Condition	Daylight	14	16	87.5%	100%
	Dark (Street Light)	0		0%	
	Dark (No Street Light)	2		12.5%	
Road Surface	Dry	15	16	93.75%	100%
	Wet	1		2.25%	
Weather	Clear	5	16	31.25%	100%
	Cloudy	10		62.5%	
	Rain	1		6.25%	

Table 3-7: Vehicle and Driver Characteristic for Alafaya Southbound Right Turn Lane Rear-end Crashes

		Struck Vehicle		Striking Vehicle	
		Frequency	Relative Frequency	Frequency	Relative Frequency
Vehicle Type	Automobile	6	75%	5	62.5%
	Passenger Van	1	13%	0	0%
	Light Truck	1	13%	3	37.5%
	Sub-total	8	100%	8	100%
Gender	Male	2	25%	5	62.5%
	Female	6	75%	3	37.5%
	Sub-total	8	100%	8	100%
Age	Very Young (15-19 Year Old)	1	13%	2	25%
	Young (20-24 Year Old)	2	25%	2	25%
	Middle (25-64 Year Old)	5	63%	2	25%
	Old (65-79 Year Old)	0	0%	0	0%
	Very Old (80+)	0	0%	0	0%
	Unknown	0	0%	2	25%
	Sub-total	8	100%	8	100%

Table 3-8: Vehicle and Driver Characteristic for Alafaya Northbound Right-turn Lane Rear-end Crashes

Vehicle and Driver Characteristic		Struck Vehicle		Striking Vehicle	
		Frequency	Relative Frequenc y	Frequency	Relative Frequency
Vehicle Type	Automobile	6	37.5%	8	50.0%
	Passenger Van	3	18.8%	1	6.3%
	Light Truck	7	43.8%	4	25.0%
	Median Truck	0	0.0%	1	6.3%
	Unknown	0	0.0%	2	12.5%
	Sub-total	6	100%	16	100%
Gender	Male	8	50%	8	50%
	Female	8	50%	6	37.5%
	Unknown	0	0%	2	12.5%
	Sub-total	15	100%	16	100%
Age	Very Young (15-19 Year Old)	0	0.0%	3	18.8%
	Young (20-24 Year Old)	1	6.3%	3	18.8%
	Middle (25-64 Year Old)	13	81.3%	8	50.0%
	Old (65-79 Year Old)	0	0.0%	0	0.0%
	Very Old (80+)	0	0.0%	0	0.0%
	Unknown	2	12.5%	2	12.5%
	Sub-total	16	100%	16	100%

Table 3-9: Contributing Cause Summary for Alafaya Trail Northbound Right-turn Rear-end Crashes

Contributing Cause- Driver/ Pedestrian	Struck Vehicle	Striking Vehicle
No Improper Driving/ Action	16	1
Careless Driving	0	15
Total	16	16

Table 3-10: Contributing Cause Summary for Alafaya Trail Southbound Right-turn Rear-end Crashes

Contributing Cause- Driver/ Pedestrian	Struck Vehicle	Striking Vehicle
No Improper Driving/ Action	8	0
Careless Driving	0	8
Total	8	8

Because right-turn-on-red is permitted at this intersection, there are four cases in which Alafaya Trail right turn vehicles can perform right-turn movement. Case 1: green light period for Alafaya

Trail through traffic. Case 2: green light period for E. Colonial Drive left-turn traffic. Case 3: green light period for Colonial Drive through traffic. Case 4: green light period for Alafaya Trail left-turn traffic (Shown in Figure 3-5). There is low rear-end crash risk for Cases 1 and 2, but there is high risk of crashes for the other two cases.

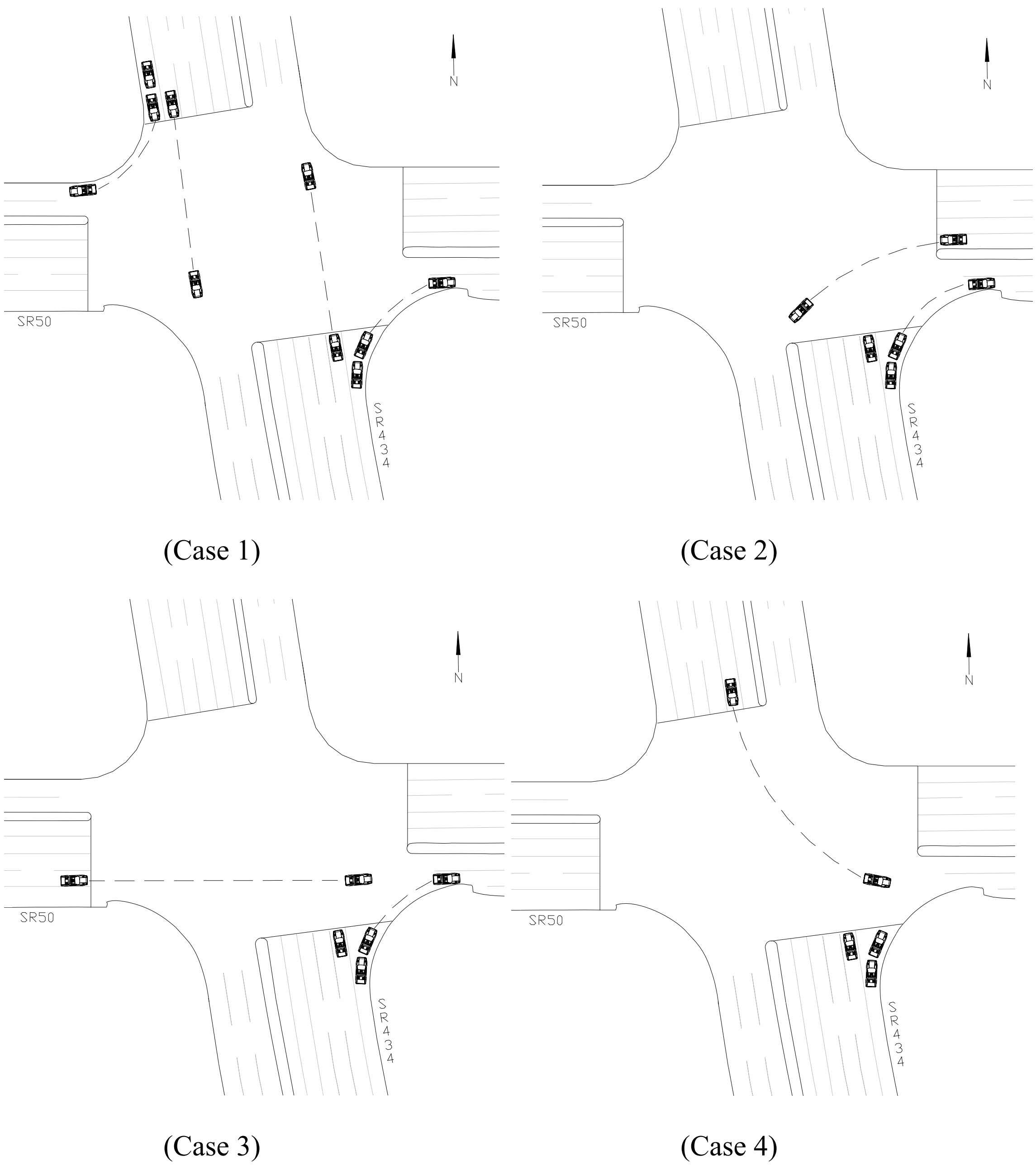


Figure 3-5: Alafaya Trail Right-turn Vehicle Right-turn Cases

From crash police report narrative, for most of Alafaya Trail right turn rear-end crashes, the struck vehicle yielded to the opposing traffic or signal and slowed to a stop. The striking vehicle failed to stop simultaneously and it proceeded to hit the rear of the front vehicle. After the investigation, we find that there are some sight distance problems with Alafaya Trail right-turn traffic. It is a skewed intersection (81°), which increases the difficulty for the driver to watch the opposing vehicle. The vehicles stopped in left side will also block the sight of the right-turn drivers especially if there are larger cars stopped. There is not enough sight distance for following driver to adjust the suitable gap, therefore not being able to adjust his/her speed accordingly. These increase the probability of a rear-end crash.

3.4 E. Colonial Drive Through Lanes Rear-end Crashes

There is a total of 46 rear-end crashes that occurred at E. Colonial Drive and 29 of them happened at its through lanes (Figures 3-3 and 3-4). Summary of the environmental and physical conditions existing at E. Colonial Drive eastbound and westbound through lane rear-end crashes is shown in Tables 3-11 and 3-12. Summary of the involved vehicle and driver human factors (sex and age) is shown in Tables 3-13 and 3-14. Also summary of the contributing cause is shown in Tables 3-15 and 3-16. Most of the crashes occurred at non-negative conditions. Most of the vehicles involved in rear-end crashes are automobiles, male and female have almost the same risk of involvement in rear-end crashes, and there is a high percentage of middle age drivers involved in rear-end crashes. Almost all included crashes happened because the driver of the striking vehicle drove carelessly.

Table 3-11: Environmental and Physical Conditions Existing at E. Colonial Drive Eastbound Through Lane for Rear-end Crashes

Environmental and Physical Conditions		Frequency		Relative Frequency	
Light Condition	Daylight	9	17	52.9%	100%
	Dusk	1		5.9%	
	Dawn	0		0.0%	
	Dark (Street Light)	4		23.5%	
	Dark (No Street Light)	3		17.6%	
Road Surface	Dry	15	17	88.2%	100%
	Wet	2		11.8%	
Weather	Clear	10	17	58.8%	100%
	Cloudy	5		29.4%	
	Rain	2		11.8%	

Table 3-12: Environmental and Physical Conditions Existing at E. Colonial Drive Westbound Through Lane for Rear-end Crashes

Environmental and Physical Conditions		Frequency		Relative Frequency	
Light Condition	Daylight	6	12	50.0%	100%
	Dusk	0		0.0%	
	Dawn	0		0.0%	
	Dark (Street Light)	1		8.3%	
	Dark (No Street Light)	5		41.7%	
Road Surface	Dry	11	12	91.7%	100%
	Wet	1		8.3%	
Weather	Clear	11	12	91.7%	100%
	Cloudy	1		8.3%	
	Rain	0		0%	

Table 3-13: Vehicle and Driver Characteristic for E. Colonial Drive Eastbound Through Lane Rear-end Crashes

		Struck Vehicle		Striking Vehicle	
		Frequency	Relative Frequency	Frequency	Relative Frequency
Vehicle Type	Automobile	10	58.8%	10	58.8%
	Passenger Van	3	17.6%	0	0%
	Light Truck	1	5.9%	7	41.2%
	Medium Truck	2	11.8%	0	0%
	Unknown	1	5.9%	0	0%
	Sub-total	17	100%	17	100%
Gender	Male	9	52.9%	9	52.9%
	Female	8	47.1%	7	41.2%
	Unknown	0	0%	1	5.9%
	Sub-total	17	100%	17	100%
Age	Very Young (15-19 Year Old)	1	5.9%	1	5.9%
	Young (20-24 Year Old)	2	11.8%	4	23.5%
	Middle (25-64 Year Old)	11	64.7%	9	52.9%
	Old (65-79 Year Old)	1	5.9%	0	0%
	Very Old (80+)	0	0.0%	0	0%
	Unknown	2	11.8%	3	17.6%
	Sub-total	17	100%	17	100%

Table 3-14: Vehicle and Driver Characteristic for E. Colonial Drive Westbound Through Lane Rear-end Crashes

		Struck Vehicle		Striking Vehicle	
		Frequency	Relative Frequency	Frequency	Relative Frequency
Vehicle Type	Automobile	10	83.3%	7	58.3%
	Passenger Van	0	0.0%	1	8.3%
	Light Truck	1	8.3%	3	25.0%
	Unknown	0	0%	1	8.3%
	Sub-total	12	100%	12	100%
Gender	Male	6	50%	3	25.0%
	Female	6	50%	3	25.0%
	Unknown	0	0%	6	50.0%
	Sub-total	12	100%	12	100%
Age	Very Young (15-19 Year Old)	1	8.3%	1	8.3%
	Young (20-24 Year Old)	1	8.3%	0	0.0%
	Middle (25-64 Year Old)	7	58.3%	4	33.3%
	Old (65-79 Year Old)	1	8.3%	1	8.3%
	Very Old (80+)	0	0.0%	0	0.0%
	Unknown	2	16.7%	6	50.0%
	Sub-total	12	100%	12	100%

Table 3-15: Contributing Cause Summary for E. Colonial Drive Eastbound Through Lane Rear-end Crashes

Contributing Cause- Driver/ Pedestrian	Struck Vehicle	Striking Vehicle
No Improper Driving/ Action	16	1
Careless Driving	1	15
Field To Yield Right-of-Way	0	1
Total	17	17

Table 3-16: Contributing Cause Summary for E. Colonial Drive Westbound Through Lane Rear-end Crashes

Contributing Cause- Driver/ Pedestrian	Struck Vehicle	Striking Vehicle
No Improper Driving/ Action	11	1
Careless Driving	1	11
Total	12	12

3.5 Angle Crashes at the Intersection

Angle crashes account for the second highest rate of crashes at this intersection. The total number of crashes is 24 in four years. Fifteen or 62.5% of the angle crashes happened at the intersection. Figure 3-6 shows the collision diagram of angle crashes at the intersection. Summary of the environmental and physical conditions existing at the intersection for angle crashes is shown in Table 3-17. Summary of the involved vehicle and driver human factors (sex and age) is shown in Table 3-18. Also summary of contributing cause is shown in Table 3-19.

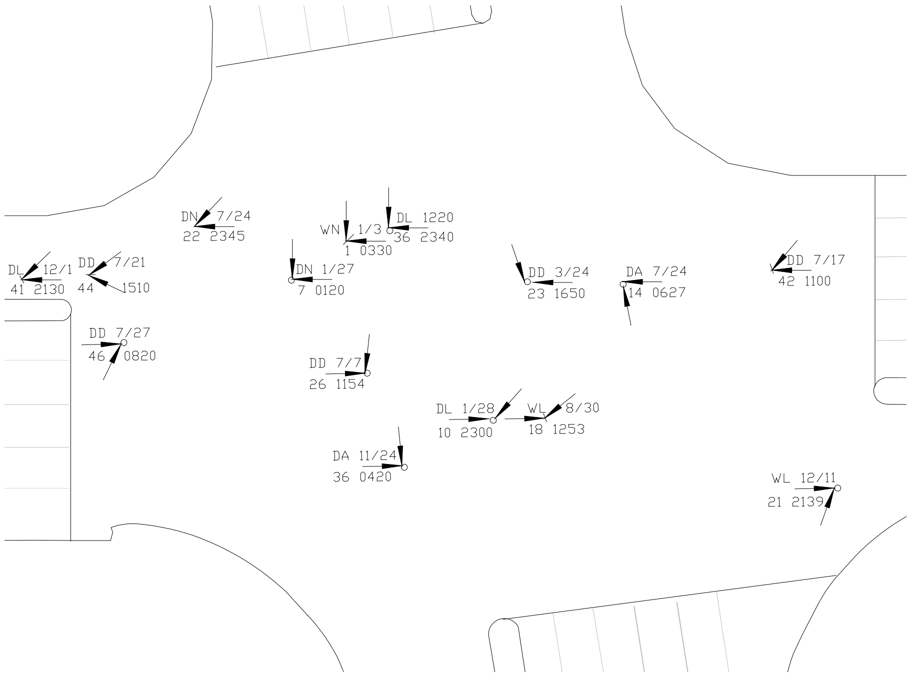


Figure 3-6: Collision Diagram for at Intersection Angle Crashes for Years 1999 through 2002

Table 3-17: Environmental and Physical Conditions Existing at Intersection for Angle Crashes

Environmental and Physical Conditions		Frequency		Relative Frequency	
Light Condition	Daylight	5	15	33.3%	100%
	Dusk	0		0.0%	
	Dawn	2		13.3%	
	Dark (Street Light)	5		33.3%	
	Dark (No Street Light)	3		20.0%	
Road Surface	Dry	12	15	80.0%	100%
	Wet	3		20.0%	
Weather	Clear	12	15	80.0%	100%
	Cloudy	3		20.0%	
	Rain	0		0	

Table 3-18: Vehicles and Driver Characteristic for at Intersection Angle Crashes

		Struck Vehicle		Striking Vehicle	
		Frequency	Relative Frequency	Frequency	Relative Frequency
Vehicle Type	Automobile	13	86.7%	9	60.0%
	Passenger Van	2	13.3%	0	0.0%
	Light Truck	0	0.0%	2	13.3%
	Medium Truck	0	0.0%	1	6.7%
	Unknown	0	0.0%	3	20.0%
	Sub-total	15	100.0%	15	100.0%
Gender	Male	6	40.0%	7	46.7%
	Female	9	60.0%	4	26.7%
	Unknown	0	0.0%	4	26.7%
	Sub-total	15	100.0%	15	100.0%
Age	Very Young (15-19 Year Old)	1	6.7%	2	13.3%
	Young (20-24 Year Old)	5	33.3%	3	20.0%
	Middle (25-64 Year Old)	8	53.3%	2	13.3%
	Old (65-79 Year Old)	1	6.7%	1	6.7%
	Very Old (80+)	0	0.0%	0	0.0%
	Unknown	0	0.0%	7	46.7%
	Sub-total	15	100.0%	15	100.0%

Table 3-19: Contributing Cause Summary for at Intersection Angle Crashes

Contributing Cause- Driver/ Pedestrian	Struck Vehicle	Striking Vehicle
No Improper Driving/ Action	13	1
Failed to Yield Right-of-Way	0	5
Improper Lane Change	0	2
Improper Turn	0	1
Disregarded Traffic Signal	1	4
All Other	1	2
Total	15	15

3.6 Conclusions

In this report, we analyze the crash police reports for Alafaya Trail and E. Colonial Drive signalized intersection for four years and found several traffic safety problems at this intersection. They are: Alafaya Trail right-turn rear-end crashes, E. Colonial Drive through lane rear-end crashes, and at-intersection angle crashes. The future experiment scenario designing for the driver simulator project will be based on testing these safety problems.

CHAPTER 4. REPLICATION OF THE ALAFAYA TRAIL AND E. COLONIAL DRIVE INTERSECTION IN DRIVING SIMULATOR

As indicated in the previous chapter, the Alafaya Trail and E. Colonial Drive intersection has been chosen because it is a major intersection (4X6) of state roads, and it has one of the highest crash frequencies in Central Florida. To validate if the UCF driving simulator can be applied to identify the safety problems and risk situations that would lead to traffic crashes, we replicated as many important features of the selected intersection in the driving simulator system as possible. Creating three-dimensional environments for real-time simulation purposes – more specifically traffic engineering simulation purposes, can be viewed both as an art form and as a methodology. Therefore, there exists a general procedure that guides a modeler from the original concept to a final graphical representation. This chapter outlines the procedure involved in developing traffic engineering databases, with attention paid to how one would create common traffic engineering objects such as large intersections. The databases are to be geospecific, meaning the objects in the graphical database represent actual real-world objects as closely as possible, with a degree of spatial and functional precision deemed sufficient by the developer. Furthermore, the discussion includes the steps required in transferring and implementing the database into the GE-ISIM simulators.

4.1 Procedure for Geo-specific Database Modeling in the ISIM Mark II Simulator

Geo-specific database modeling is the development of a virtual environment from an actual one. The process required to make a geo-specific model is laborious, and many factors have to be considered, such as the amount of detail required to properly represent the scene, the required accuracy when taking measurements, and so on. The main steps of the process are outlined below. The final result of the process will actually be two models: a graphical visual database which the one sees when one is in the simulator, and a Road motion DataBase (RDB), which is the data the physics engine uses to generate things like the motion one feels while driving, and other dynamics experienced by autonomous and non-autonomous vehicles alike. One model can be thought to lie on top of the other.

The first step required in creating a traffic engineering object such as an intersection is to obtain data about the object. To accurately model the roads and buildings, some measurements are needed. Blueprints, and AutoCAD files are preferred formats, but not usually available, so going to the site and taking measurements by hand is the common practice. Most buildings and roads in Central Florida are designed with the empirical measurement system, so it is most often used. Digital pictures and sketches of the buildings/roads/landscapes are also needed to portray essential information. The accuracy to which measurements are taken is on the inch level. The graphical modeling software has a decimal accuracy of a thousandth of an inch (0.001), so all measurements are rounded to this level. For instance, a distance measured to be 2’8” will be entered into the computer as 2.667. It should be noted that some amount of error will occur from either hand-measurements or from blueprints, as blueprints and actual building construction do not always agree. Furthermore, there must be a cut-off point for the level of detail put into a scene, as a computer can only compute so much information in the given real-time constraints. However, errors are largely insignificant as the eye cannot interpret such small discrepancies, and if the modeler is effective with the amount of detail he/she has to work with, the missing elements in the scene go unnoticed.

Once the spatial and functional data have been taken, the object may then be created in a three-dimensional modeling software design-tool. Many 3D software modeling packages exist: the two most common real-time packages being Multigen-Paradigm's Creator, and Discreet's 3D Studio Max. To create the object in graphical form, a series of polygons are drawn to represent the said object. In the case of a toll booth, only the exterior needs to be represented. All polygons in the model are then broken down into sets of triangles, as the video-card hardware only processes models in this way.

Now that the polygons have been drawn, the object is merely a shell and must be given some texture and color to improve its overall quality and to mimic the real-world object. Most modelers take pictures of the real-world object and place these pictures on the polygons instead of coloring the polygons, as a picture of a toll booth wall can provide more detail per polygon than one simple color. It is generally a good idea to take pictures of the object under diffused lighting (i.e. cloudy). The images are then processed in a software product such as Adobe's Photoshop, and are then placed on the polygons as textures. Even the roads of an intersection would contain some sort of pavement texture, and as one neared the center of an intersection, individual textures would need to be placed in the individual lanes, indicating left-turn arrows, etc. Lighting and other effects may also be applied.

Once the model has been verified to be geospecific enough for the given purpose, it is complete from a graphical point-of-view. However, it must now be ported over to a simulator for actual use. CATSS uses a GE-ISIM based simulator, and in these simulators the graphical model must first be converted into the appropriate file format. Next, the model is then loaded into the simulator. The graphical database can now be displayed in the simulator, yet this still isn't enough. Another database must be created so the driver of the simulator can interact with his/her environment, although this new database is entirely numerical, representing the roads, the road surface properties, the collision boundaries of various graphical objects, etc. A series of files must be created to outline the roads, logic for the artificial intelligent (A.I.) traffic, and collision with other objects. The creation and validation of these objects is the final step in creating a database to operate effectively in GE-ISIM simulators.

4.2 Intersection Visual Databases

This intersection visual database consists of three essential components: the two intersecting roads – extending well beyond the original goal of 1200 feet in each of the four directions, the traffic lights, and a couple of buildings. These components were chosen as they represent the three core elements required to realize the test-bed world. Further modeling is simply an extension of these core components.

The modeled road geometry is a near replica of the actual roadway network, achieved by merging roadway blueprints, autoCAD files, and hand measurements into a computer program written by a CATSS graduate student. This program does not entirely automate the creation of a road, but does aid in producing a highly accurate road model (precise to 0.001 meter). The modelers, however, must make adjustments and/or additions to the road model generated by the computer program, as limits regarding the amount of detail allowed in a scene must be considered, ensuring the simulator runs smoothly. State Road 50 extends some 500 to 600 feet in its westbound and eastbound directions respectively, whereas the northbound and southbound lanes of S.R. 434 continue to just under 300 feet. The further work extended the roads one to two miles in each direction, using a less precise, although more efficient method.

Traffic lights were created and they handle all signal cases which occur at this particular intersection. Even the “walk/don’t walk” flashing signs were built and integrated into the Traffic Control Device (TCD). The timing diagram and actuator sequencing from the actual intersection was used to create this model. Table 4-1 depicts the data used for TCD timing. Since we mainly paid attention to the isolated intersection safety problems but not road network issues in this project, the coordination plans was not considered in the simulation database.

Table 4-1: S.R. 434 and S.R. 50 Signal Timing

ORANGE COUNTY TRAFFIC SIGNAL TIMING								
Intersection: ALAFAYA TR & E. COLONIAL DR					Node: 3		Address: 3/B/09	
Equipment: EAGLE					Date: 9/4/02			
BASIC TIMING								
Phase	1	2	3	4	5	6	7	8
Direction	EBL	WB	SBL	NB	WBL	EB	NBL	SB
Min Green (sec)	5	15	5	15	5	15	5	15
Vehicle Gap (sec)	1.8	3.0	1.8	3.0	1.8	3.0	1.8	3.0
Max Green 1 (sec)	25	50	25	30	25	50	25	30
Max Green 2 (sec)	25	50	25	30	25	50	25	30
Yellow (sec)	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
All-Red (sec)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Walk (sec)		5		5		5		5
Flash Don't Walk (sec)		33		29		34		29
Recall/Memory	NL	SF/LK	LK	LK	NL	SF/LK	NL	LK
Dual Entry		Y		Y		Y		Y
Overlap								
Flash	R	R	R	R	R	R	R	R
Posted Speed (mph)	45	45	45	45	45	45	45	45
Crossing Distance (ft)	164.0	159.0	143.0	143.0	159.0	164.0	143.0	143.0
Ped Clearence (sec)	41.0	39.8	35.8	35.8	39.8	41.0	35.8	35.8
Veh Clearance (sec)	7.1	7.0	6.8	6.8	7.0	7.1	6.8	6.8

4.2.1 Polygonal Modeling

All conventional 3D models are built from triangles. Even round objects like spheres are actually made up of triangles. Triangles are the chosen basic component for many reasons, but the main rationale is computational performance. The more triangles making up a rounded object, the smoother the rounded surface appears. However, increasing the number of triangles increases the amount of work the graphics card has to do. Attention must be paid to ensure the graphics card can do all the work in the time allowed. For the CATSS/UCF driving simulator, the entire viewing screen must be calculated and drawn in 1/60 of a second, so that the system may run at 60 Hz. A 3D modeler must balance the amount of detail in a scene against the computer system's polygon budget.

Once enough data has been obtained from the data acquisition phase, the modeler can start creating the 3D object. A 3D object can be thought of as a shell, nothing inside (unless things on the inside are drawn). All 3D models begin by creating basic shapes (triangles, rectangles, cylinders) and putting them together. These shapes are then moved and modified until the 3D object is complete. At this point only a generic color is applied to the objects, and will not be presenting the final rendering. Two modeling software packages are being used on this project: Multigen's Creator, and Discreet's 3D Studio Max. All models are later converted to a .ism file format, which is proprietary to General Electric Driver Development.

Polygonal modeling takes some experience and some creativity to do well. Because the modeler only has a finite number of triangles allowed in a scene, the modeler must be creative in his/her effort to balance complexity and number of triangles. Sometimes the way in which polygons are arranged on an object will not seem straightforward. A good modeler sometimes uses peculiar polygonal arrangements to maintain object structure, yet avoid 3D problems such as t-vertices, and still allow for proper texturing.

Figures 4-1 and 4-22 depict the polygonal structure of the Papa John's on the corner of S.R. 50 & 434. Figure 4-1 shows the generic white color of the polygons as well as the wire-frame. Figure 4-2 again shows the generic white color of the polygons along with some shading effects. Both figures are snapshots taken inside the Creator modeling software.

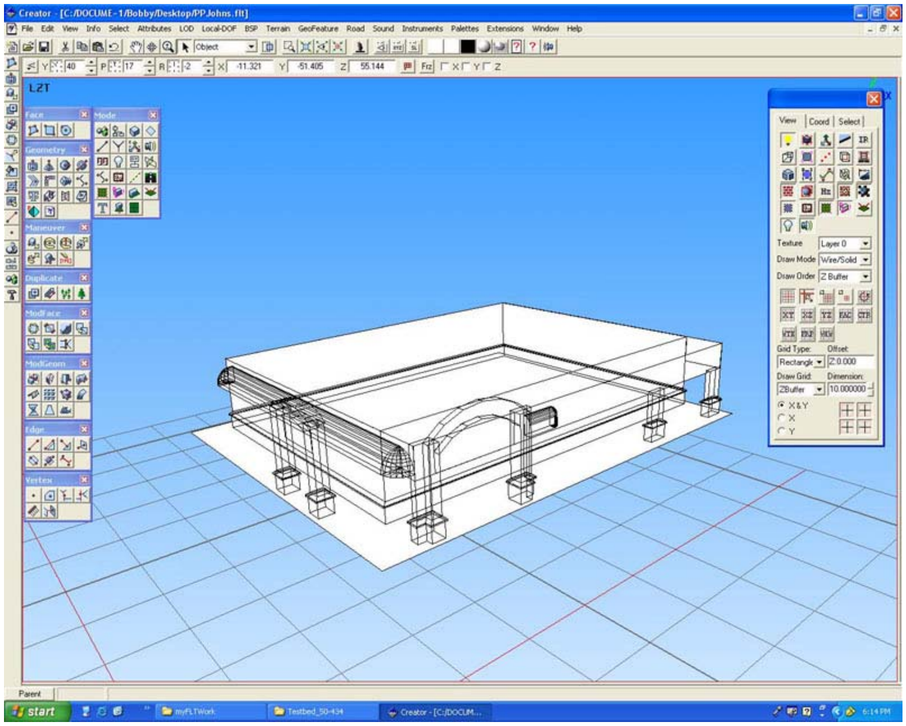


Figure 4-1: Polygon and Wireframe View of a Papa John's Pizzeria

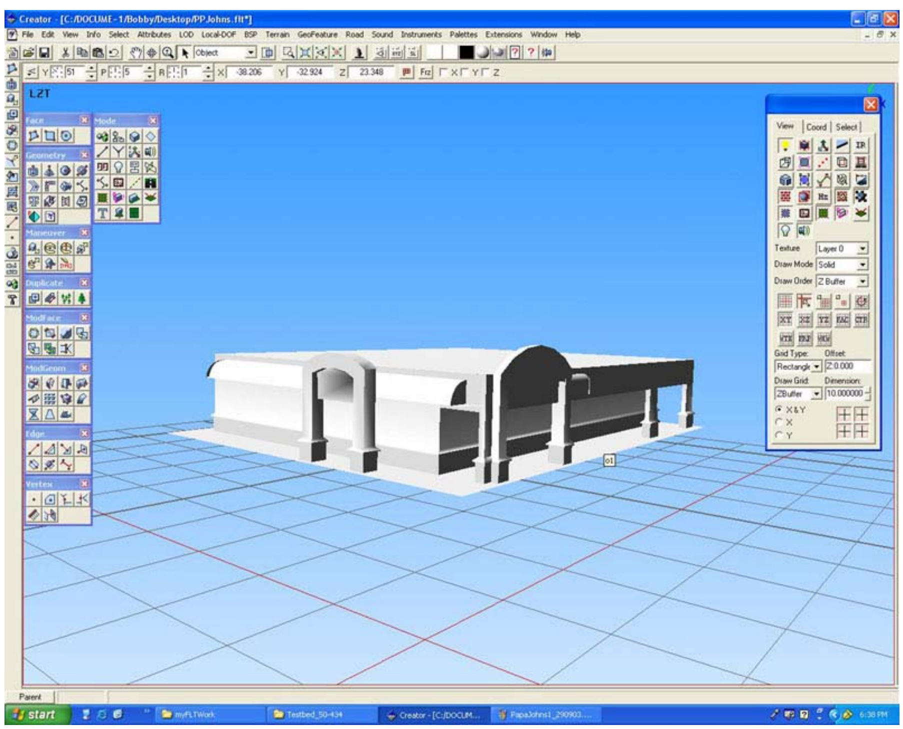


Figure 4-2 Polygon View with Shading of a Papa John's Pizzeria

4.2.2 Texturing

If the polygonal model is the shell, then texture is the paint. At this point, the 3D object only has a generic color associated with it. Textures are images taken from the actual object, or images made to replicate what an image from the object would look like. Textures are added to the surface of a polygon to give the appearance there is more detail than actually present. This is detail that a modeler either does not have the polygon budget for, the texture memory for, or simply does not deem necessary. As mentioned, there is a limit to the amount of memory textures can occupy in the graphics card. Exceed this amount, and the system will most likely not perform to specification. Textures vary greatly in size and in image complexity. They can be images of entire building walls, including bricks, windows and possible shrubbery, to just an image of a few bricks, repeated many times (tiled) around the building. Higher resolution images naturally have the potential to contain more complex information over lower resolution images.

The procedure for creating good textures starts by taking a good picture. Midday on cloudy days is the most preferable conditions to take pictures in natural, as the sun is overhead and the light itself is uniform. A digital camera is used, as it holds many images, and images can quickly be transferred to the computer. Once the image has been taken, it is then edited in an editor such as Adobe's Photoshop. Many modifications can now be done, including, cropping, perspective warping, deleting undesirable objects in the image, and lighting alterations. For real-time systems, the image should be saved with dimensions being a multiple of 2^n, where n is an integer > 0. Figure 4-3 depicts the Papa John's building with textures added. Figure 4-4 is a model of a Wendy's located across the street from Papa John's. Adding lighting to a scene drastically improves realism and will be incorporated into the final deliverable.

Figure 4-3: Papa John’s Pizzeria with Texture

Figure 4-4: Wendy’s Restaurant with Texture

4.2.3 Converting Models to GEDD Format

All 3D models require conversion from their respective formats to a .ism format that is proprietary to GEDD. The hierarchical structure in which the polygons are arranged needs to be modified in order to convert properly. A third-party software package will convert all Creator files to 3D Studio MAX. From there GEDD proprietary software will convert the models into their final form. Furthermore, all textures images require conversion to a .dds standard. This can be done through the use of plug-ins in Photoshop. Appendix A lists all objects modeled for this test-bed project and visual comparison between the snapshots in the simulator system and photo pictures in the real word.

4.3 Intersection Road Databases (RDB)

The electronic file (AUTOCAD file) of the intersection was available from the Orange County, FDOT district 5, and consultants. However, this electronic file contained much more information than what we needed. Figure 4-5 shows a snapshot of this file. This file had thirty-seven layers. Each layer contains specific information, like water, gas or road. We isolated the road layer out and cleaned it by looking into the aerial image and based on field observation. Figure 4-6 shows the cleaned road layer.

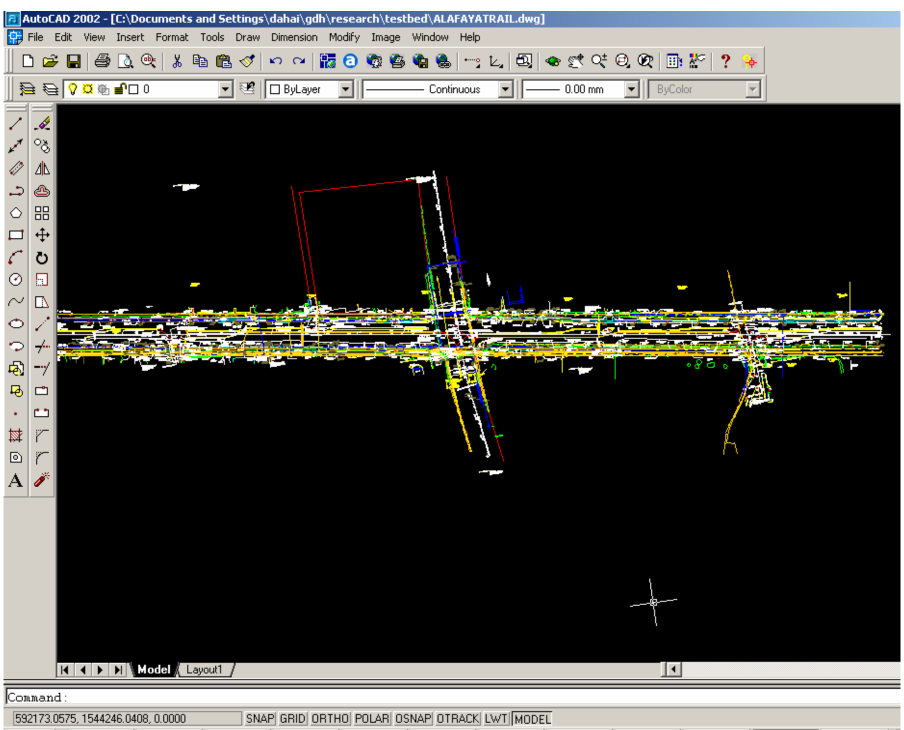


Figure 4-5: Original AUTOCAD File

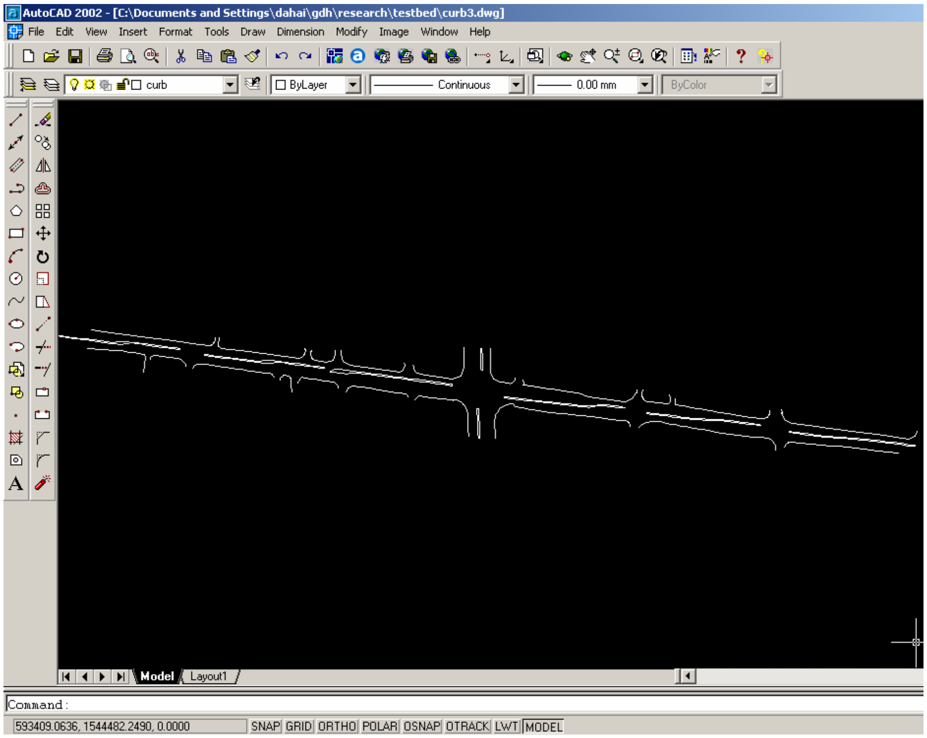


Figure 4-6: Cleaned Road Layer

4.3.1 Calculating Cross Section Top Views

After obtaining the coordinates of the road layer from AUTOCAD file, we defined the center lines of the roads. With the center lines and the lines from AUTOCAD file, it is possible to sample the center lines and calculate the top view of the cross section for each center line point. Basically, each center line is sampled at about one foot interval. At each center line point, a line perpendicular to the center line will be formed. Then this line will intersect with all the lines from AUTOCAD file. The intersections near the center line point will be preserved. In most situations, two or four intersection points are enough to define two typical top views of cross sections.

RDB requirements of UCF driving simulator are shown in Figure 4-7. A pool of cross sections should exist. Each road segment is sampled along its center line and for each center line point an entry in the cross section pool will be used to define the cross sectional view at this point. Each entry in the pool could be used more than one time, because there exist many center line points, with similar cross sectional views. For example, in Figure 4-7, the top views of cross section 1 and 2 can be defined by four points, where two are the road boundaries and two are the median boundaries. The top view of cross section 3 can be defined by only two points, since there is no median.

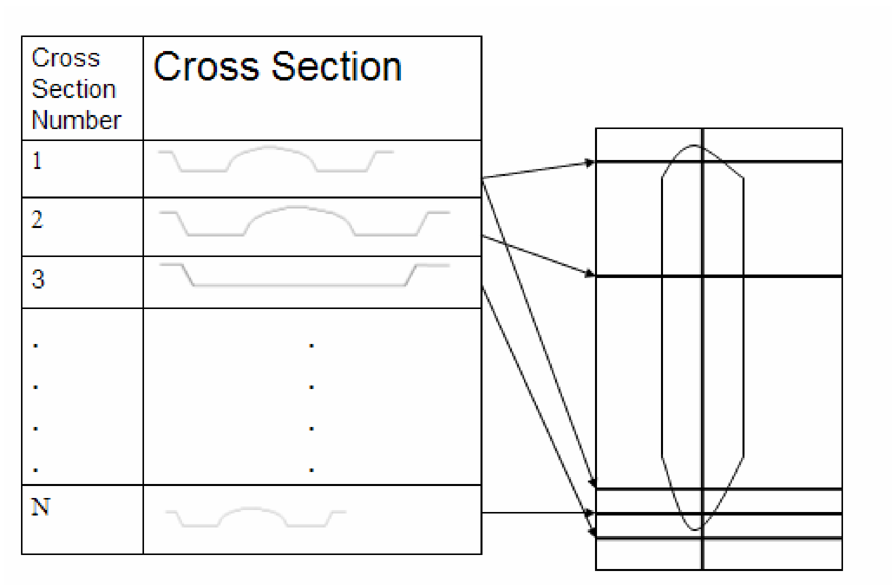


Figure 4-7: Road Databases Requirements

4.3.2 Data Conversion

Here the data conversion focuses on how to save the results of the calculation to UCF driving simulator road databases format. There are two methods. The first is to save the results to MultiGen Creator Road Tool format, and then use the converting tool in GEDD Scenario Editor to convert again to GEDD compatible format. However, this method only works well when most roads have uniform cross sections. Below is an example of road definition in MultiGen Creator Road Tool format:

- ROAD_ID: 1
- ROAD_TYPE: Straight
- PROFILE_POINT: 59.987194 0.000000
- PROFILE_POINT: 17.306002 0.000000
- PROFILE_POINT: 13.118207 0.000000
- PROFILE_POINT: -21.973700 0.000000
- WIDTH: 81.960894
- CENTER2LEFT: 21.973700
- NUM_LANES: 2
- PATHNAME: Default Road
- SPEED: 45.000
- NO_PASSING: FALSE
- STORE_HPR: TRUE
- NUM_POINTS: 2
- POINT: 315.125000 632.250000 0.000000 -262.442993 0.000000 0.000000
- POINT: 352.812500 627.250000 0.000000 -262.442993 0.000000 0.000000

In this road definition, the four profile points define only one cross section and apparently one road can only have one cross section in this definition. Using above data format, the CAD can be transferred into the RDB in the driving simulator. The visualization of the RDB information in the driving simulator software of Scenario Editor is shown in Figure 4-8. Merging the RDB database and visual database, the 3-D intersection environment can be loaded in the driving simulator system. Figure 4-9 shows the bird view of the simulated intersection.

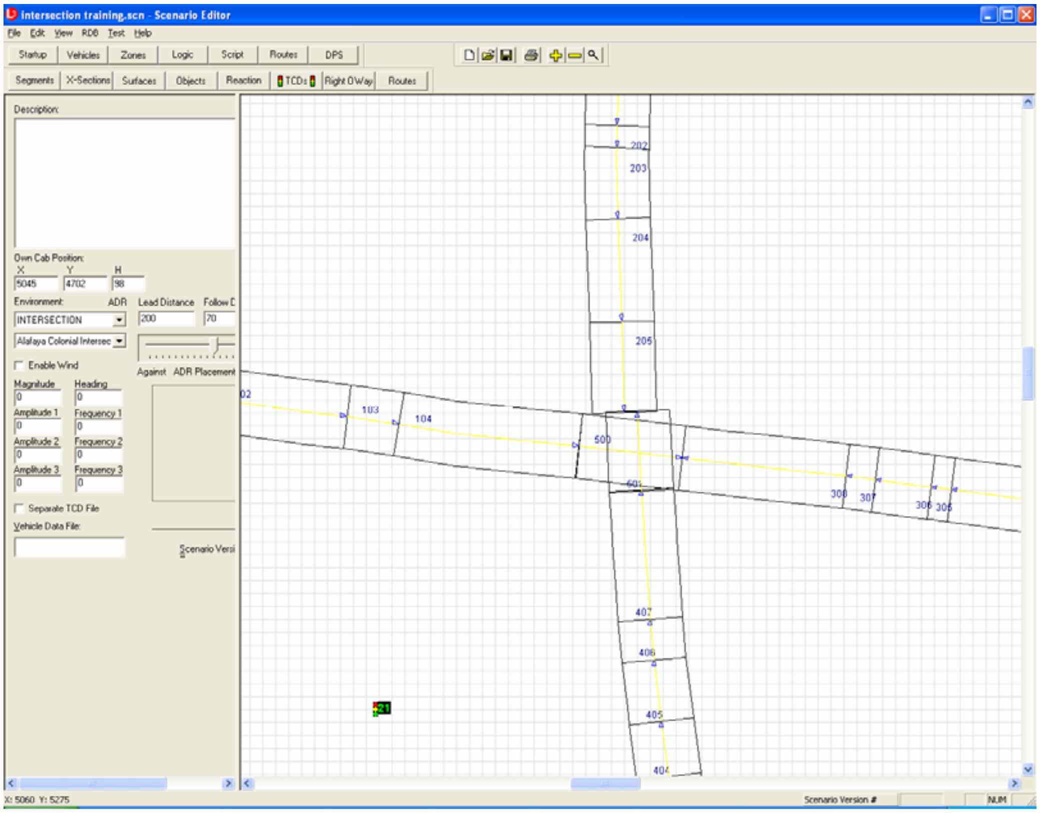


Figure 4-8: Visualization of the RDB information in Scenario Editor

Figure 4-8: Bird view of the simulated intersection

4.4 Traffic Simulation by Scenario Editor in the ISIM Mark II simulator

After the intersection database was created in the simulator system, GE Capital I-Sim's Scenario Editor Tool (ScenEdit) provides the user with the ability to create a wide range of traffic scenario types. In order to give a scenario developer more flexibility, GE Capital I-Sim has developed various vehicle types for use in scenarios. These vehicle types allow the user to create a realistic scenario with minimal effort. The following vehicle types have been developed and were used in this test-bed project:

- Fixed Object (FO): This may be any stationary object, including parked cars, signs, trees, fences, shrubs, and signs.
- Normal Vehicle Route (NVR): A library of routes enables a user to place autonomous (artificial intelligence) vehicles with the click of a button. Autonomous vehicles follow a predefined route and, by default, obey the rules of the road, including obeying traffic-control devices (TCD) and responding to a siren.
- Recorded Vehicle (REC): This vehicle type allows a scenario developer to create custom vehicle paths or make specific paths not available in the NVR library. This type also allows the user to create nonvehicle-type paths such as pedestrians, animals, planes, or other moving objects.

The Scenario Vehicle toolbar allows the operator to change specific behaviors of scenario vehicles while the simulation is running. The operator uses these functions to cause Normal Vehicle Route (NVR) and Recorded Vehicle (REC) types of scenario vehicles to disobey one or more rules of the road in order to cause traffic conflicts that interact with the driver of the OwnCab (or with other vehicles interacting with OwnCab). Especially, all NVR vehicles are programmed with an artificial intelligence that guides them to:

- Recognize each other's position and speed
- Pass on left when conditions require
- Obey general rules of the road for: - Stoplights and stop signs - Speed limits by lanes Yield right-of-way in turns
- Avoid collisions

CHAPTER 5. DRIVING SIMULATOR VALIDATION METHOD

According to Tornros (1998), 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 -- simulation and real world. 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). Absolute validity is not always achievable, since research of traffic crashes uniquely deal with matters relating to effects of various independent variables, which is very difficult to obtain those the field measurements when a crashed happened.

The main aim of this project is to validate the driving simulator in two main aspects, Speed and Safety. For the speed validation, it is expected that the speed measurement in the driving simulator environment should be statistically similar as that at the real locations, which is corresponding 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 happened in the real word, which is corresponding to the relative validity.

This chapter documents the design of the driving simulator experiment to achieve the research objective. To validate the driving simulator using Speed and Safety, a total of eight scenarios were designed in the driving simulation experiment, as listed in Table 5-1. They are classified into three categories, which are described in the following sections. Note that although scenarios AEBR and BNBR are classified into the safety validation category, they are also employed in the speed validation study since speed distributions at the through lanes of the two approaches can be collected at the moment that the green phase is terminated. Thus the speed data in these experimental scenarios will be used and compared to the field speed data collected at the real intersection.

Table 5-1: Scenario Description for Speed and Safety Validation

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

5.1 Driving Simulator Scenario Design for Speed Validation

At 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 50m downstream 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-approach speed data are also collected under free flow conditions when subjects are driving through the intersection in the scenarios AWBS, BSBS, AEBR, and BNBR, as shown in Figure 5-1. 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 comparisons between simulator experiment and field measurement are statistically similar, it means driver's speed performance in the driving simulator environment is a valid measurement for traffic studies.

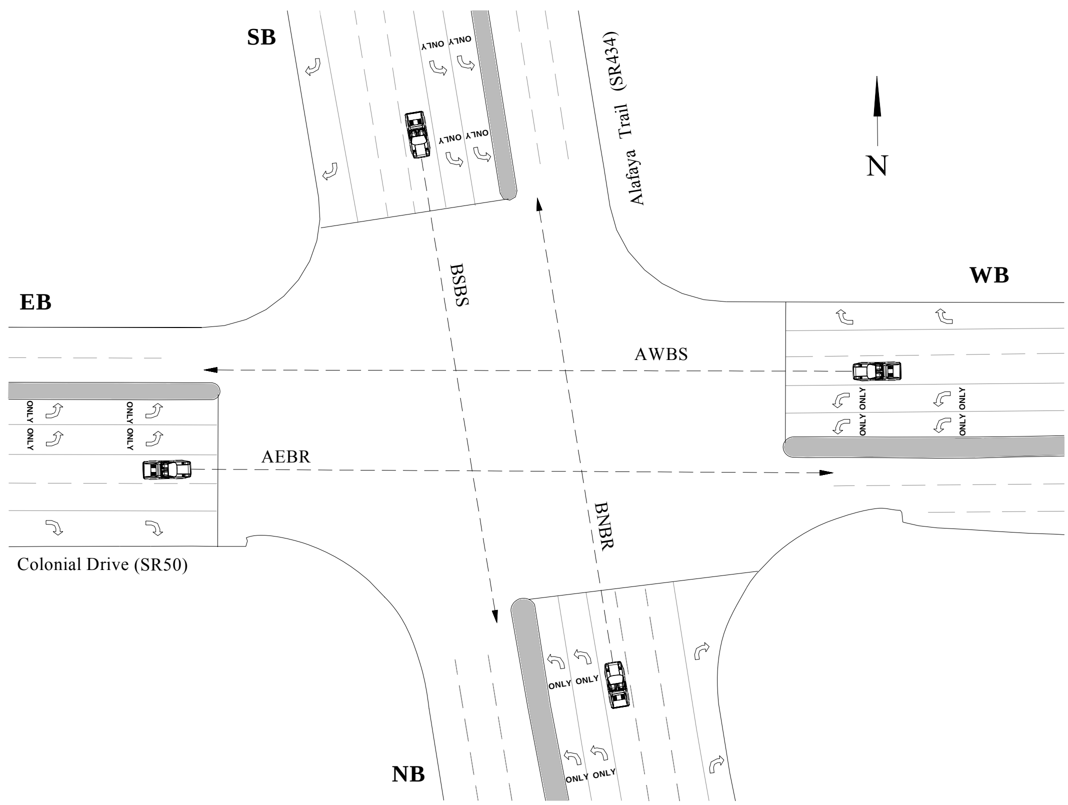


Figure 5-1: Scenarios for Speed Validation

5.2 Driving Simulator Scenario Design for Safety Validation

5.2.1 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. From the crash police report narrative, 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 urgent situations 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 a higher speed are generally associated with the rear-end crash risk.

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. If the driving simulator is a valid tool to diagnose traffic safety problems 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 at the Alafaya northbound approach are designed as test scenarios and the right-turn movements at the Colonial Drive westbound approach 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 5-2 a and b.

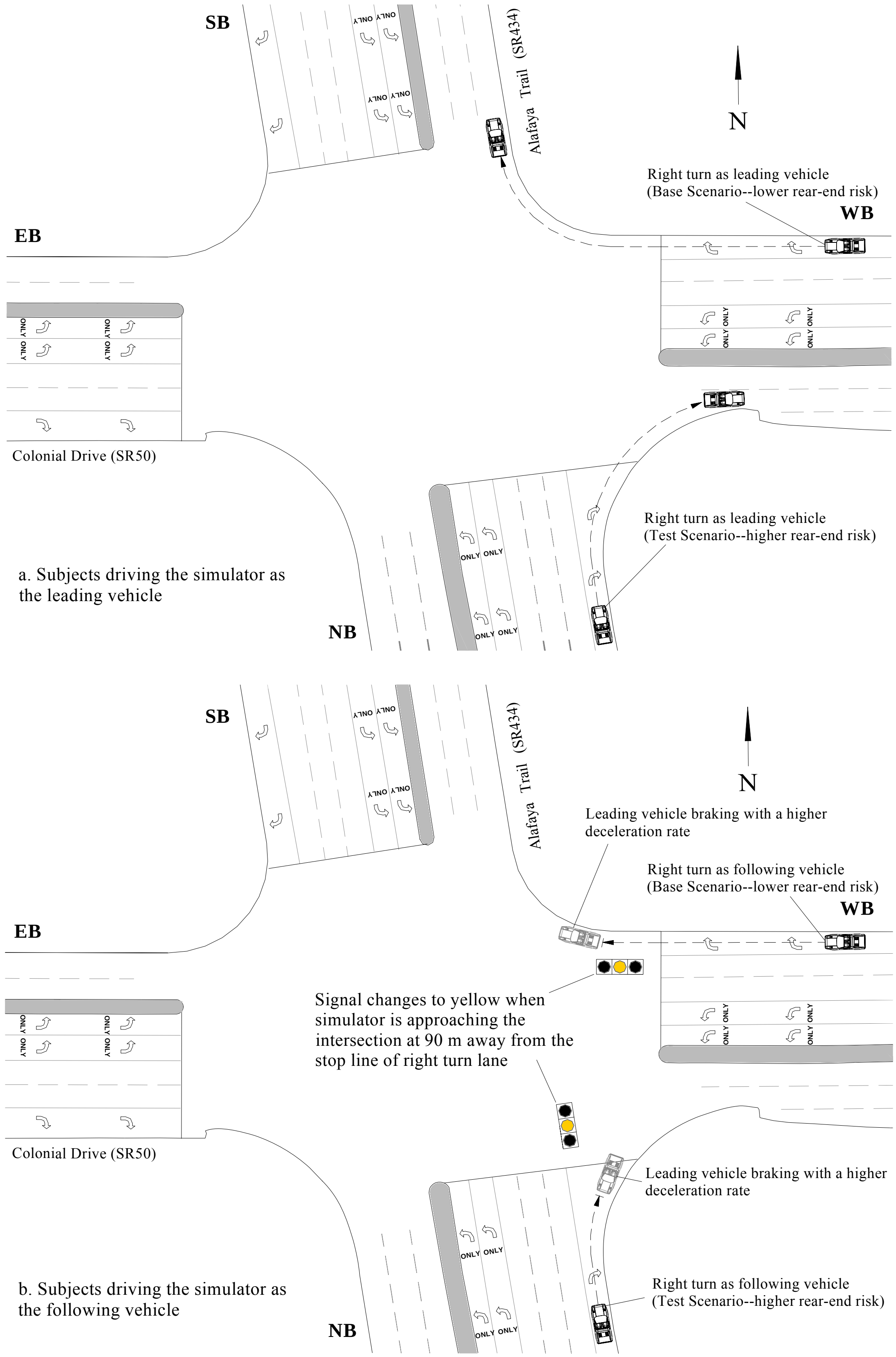


Figure 5-2: Right-turn rear-end risk test for safety validation

In scenarios BNBL and AWBL, the subject is supposed to drive the simulator as the leading vehicle, when the subject approaches the intersection at 100 m (333 ft) away from the stop line, the green phase is terminated. Since right-turn-on-red is permitted at this intersection, a legal driving maneuver 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 with higher rear-end risks at the Alafaya northbound right-turn lane compared to the Colonial Drive westbound right-turn lane (See Figure 5-2 a). For example, the vehicle's violation rate and deceleration rate at 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 other words, 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 the scenarios BNBF and AWBF that a subject is supposed to drive the simulator cab as the following vehicle, when the leading vehicle approaches the intersection at 60 m (200 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 (167 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) in the right turn lane. The driving behavior of the subject responding to the sudden stop would be measured to test the rear-end crash risk. If the driving simulator is validated, one would find that the conditional crash rate, relative driving speed, and following distance in the Alafaya northbound right-turn lane should be larger than that the Colonial Drive westbound right-turn lane (See Figure 5-2 b).

5.2.2 Safety Validation - Crash Risk Test at Through Lanes

For the through lanes at the intersection, the crash report analysis showed that the rear-end crash rate in the eastbound approach of the Colonial Drive is the highest and that in the northbound approach of the Alafaya Trail is the lowest. Moreover, the angle crash rate related to the through traffic from the eastbound approach is relatively higher but the angle crash rate related to the through traffic from the northbound approach is lowest. This trend should be considered for a 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 indication. This region of roadway is commonly referred to as the 'dilemma zone'. When vehicles are located in the dilemma zone, drivers who decide to proceed through the intersection at the onset of yellow 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 at through lanes is that subjects drive simulator to go through the intersection in the eastbound Colonial Drive and the phase will change from green to amber to red when subjects are approaching the intersection at 90 m (300 ft) away from the stop line. The base scenario BNBR used to compare with the test scenario is that subjects drive the simulator to go through the intersection in northbound Alafaya Trail and the phase will change from green to amber to red when subjects are approaching the intersection at 90 m away from the stop line as shown in Figure 5-3. 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 driving behavior associated with crash risk at through lanes of the eastbound Colonial Drive.

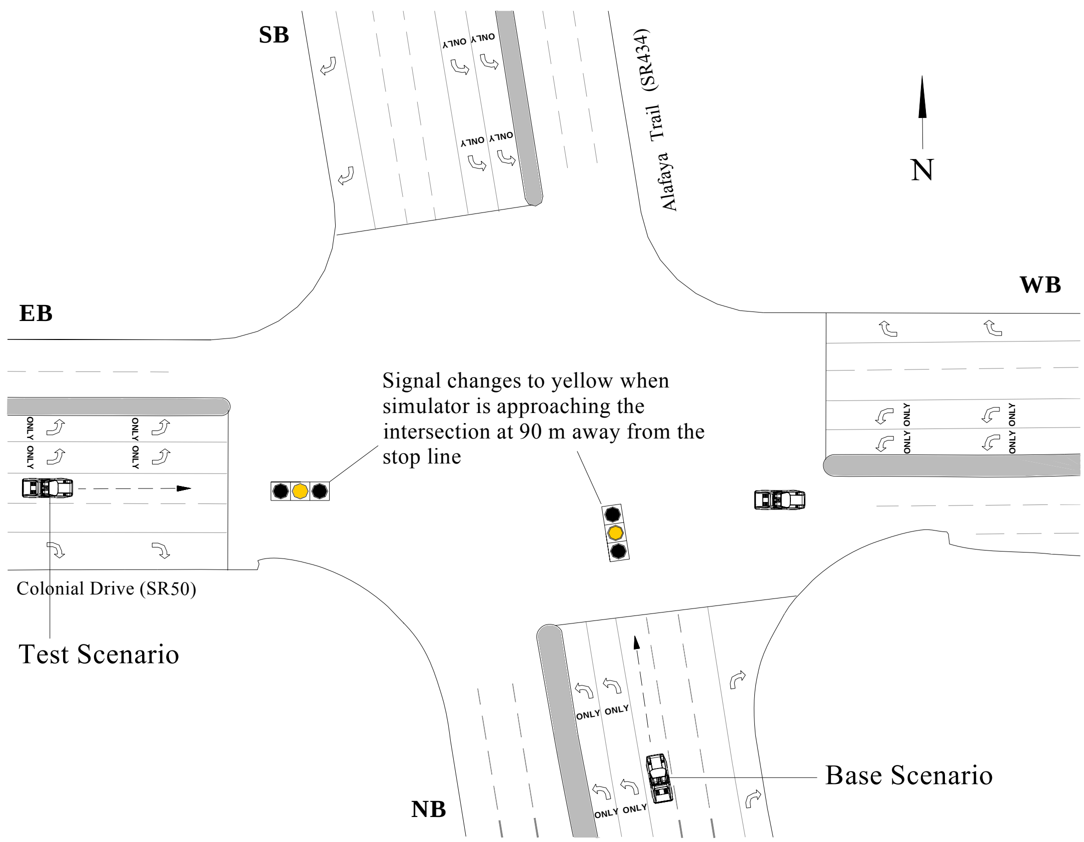


Figure 5-3: Crash risk test at through lanes for safety validation

5.3 Experimental Design

The experimental design used here is a simple within-subjects factorial design. Further, age and gender groups 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 for the old age group, it has been discarded. This classification method has been applied 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, identified using the quasi induced exposure method. Therefore, the experimental setup results in a 5 X 2 within-subjects factorial design.

5.4 Experiment Procedure

Upon arrival, the subjects were given an informational briefing about the driving simulator. Subjects were specifically advised to adhere to traffic laws, and to drive as if they were in normal everyday traffic surroundings. Then, a 5-minute practice course was programmed on the driving simulator. During this process, subjects exercised driving to become familiar with the basic simulator operation.

Next, the subjects performed the formal experiment with the 8 scenarios, which were randomly loaded for each driver so as to eliminate the time order effect and bias from subjects to the experiment results. During the course of the experiment subjects were routinely checked for simulator sickness. Whenever sickness was reported by subject in a scenario, the subject quit the experiment and the related data collected in the scenario was removed from the experiment result analysis.

Finally, when subjects completed the formal experiments, 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, 4 questions were specifically designed, which is listed in Appendix B.

CHAPTER 6. DATA COLLECTION AND EXPERIMENTAL RESULTS ANALYSES

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 the data generated from the experiments, a C program was developed to manipulate the experiment data output files. The following sections document the definitions of those independent measurements and related statistical analyses of the experimental results.

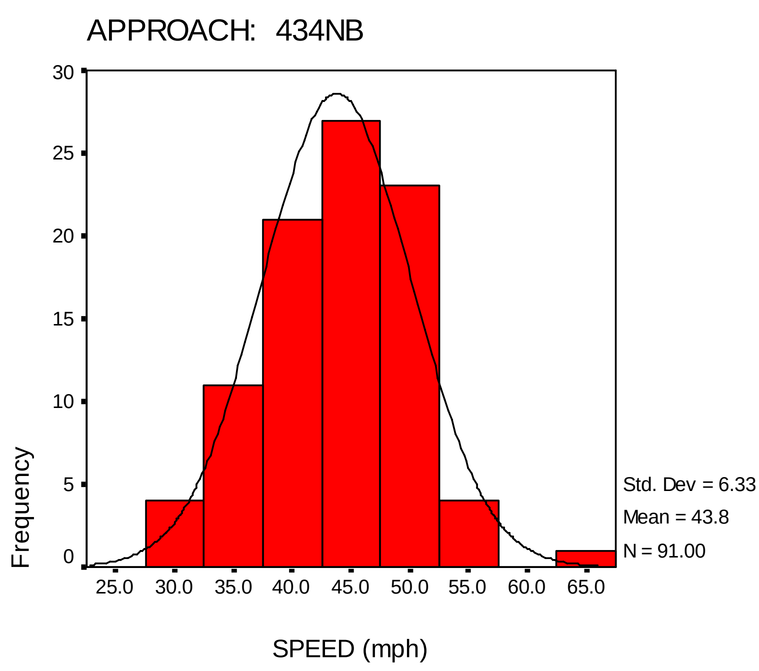
6.1 Speed validation

6.1.1 Speed Measurements at the Real 50&434 intersection

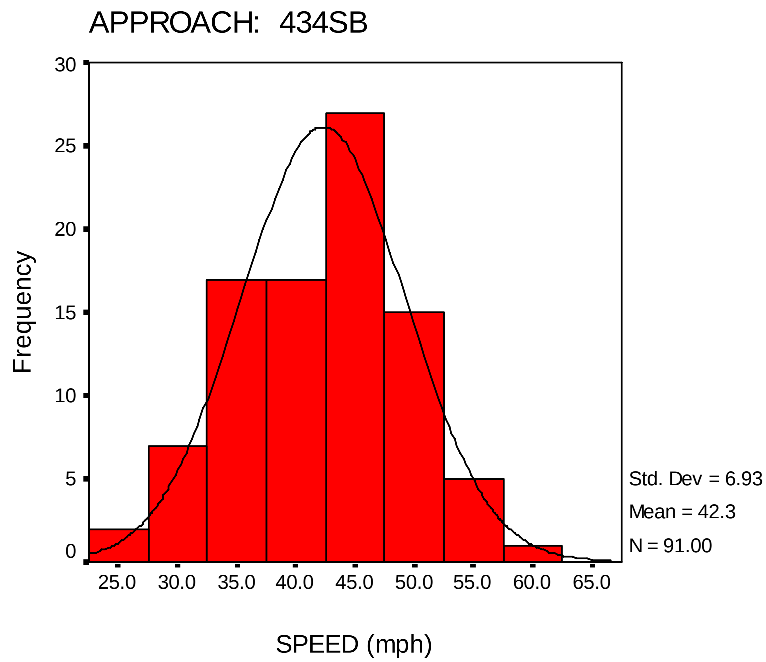
The test site considered is the Alafaya Trail (SR-434) and Colonial Drive (SR-50) intersection. Free flow speeds are recorded for vehicles entering the intersection through each approach during the green phase, using a Radar Gun. Two observers are placed around 50m down stream of the approach of which 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. Vehicles in queue are disregarded for data collection. This method is followed for all approaches; SR-434 northbound (434NB), SR-50 westbound (50WB), SR-50 east bound (50EB). For the 434SB approach, free vehicles could not be identified because there are no free flow vehicles for the current phasing design. So for this approach speeds at the upstream of the intersection are recorded. There are 134 observations for 50WB approach, 104 observations for 50EB approach and 91 observations for each of 434SB and 434NB. Table 6-1 shows the descriptive statistics of the data collected. The Figures 6-1 (a, b, c, and d) illustrate the speed distributions of the vehicles entering the intersection from all the four approaches.

Table 6-1: Descriptive Statistics of Speed Data Collected in Field.

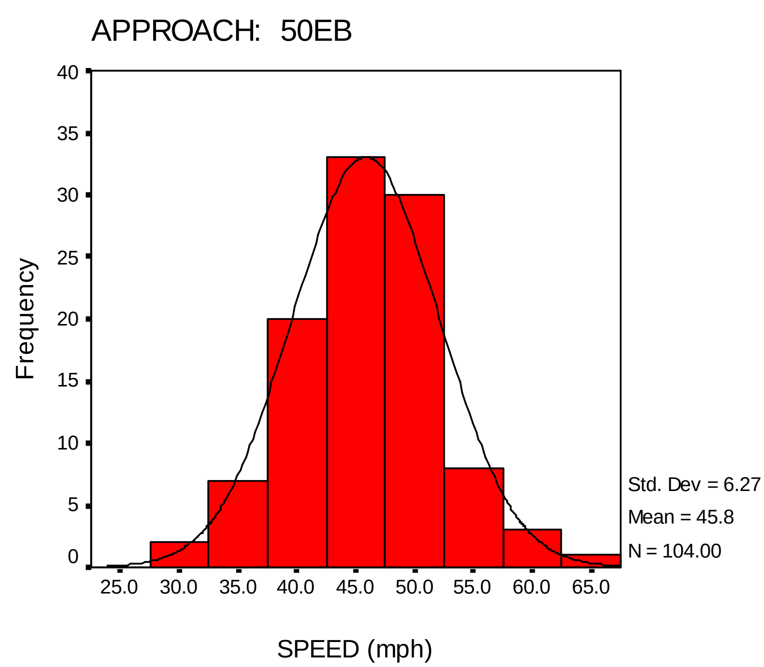
APPROACH	Mean Speed	N	Std. Deviation	Minimum	Maximum
434NB	43.7833	91	6.3348	29.8	62.79
434SB	42.2983	91	6.9296	26	60
50EB	45.8415	104	6.2663	29.8	62.79
50WB	45.0925	134	6.2919	22.35	64.91
Total	44.3889	420	6.5471	22.35	64.91



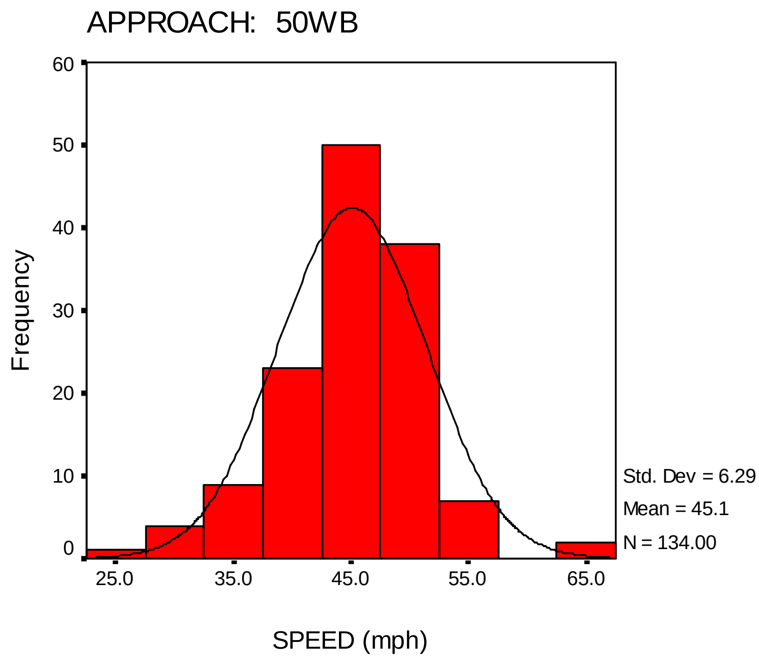
a. Histogram of speed measurements in the field at the 434NB approach



b. Histogram of speed measurements in field at the 434SB approach



c. Histogram of speed measurements in field at the 50EB approach



d. Histogram of speed measurements on field at the 50WB approach

Figure 6-1: Histogram of speed measurements in the field for each approach at the intersection

By visual inspection, the speed distributions at all the approaches follow normal distribution. This is tested statistically by Kolmogorov – Smirnov test. Kolmogorov – smirnov test of normality is used to test whether the data comes from a 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 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 6-2) 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 6-2: Kolmogorov – Smirnov Normality Test Statistics for Speeds Measured at Field

APPROACH			SPEED
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

6.1.2 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 designed far away (500 ft) from other same direction traffic. The experiment involves different subjects driving through the simulated intersection of Alafaya and Colonial. First, subjects were asked to run the training session for about three 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. 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 among male and female gender groups. Each subject was paid $10 for running the experiment. The number of subjects ranged from 58 to 62 based on the specific scenario. Table 6-3 shows the different age groups and number of subjects that participated in the experiment.

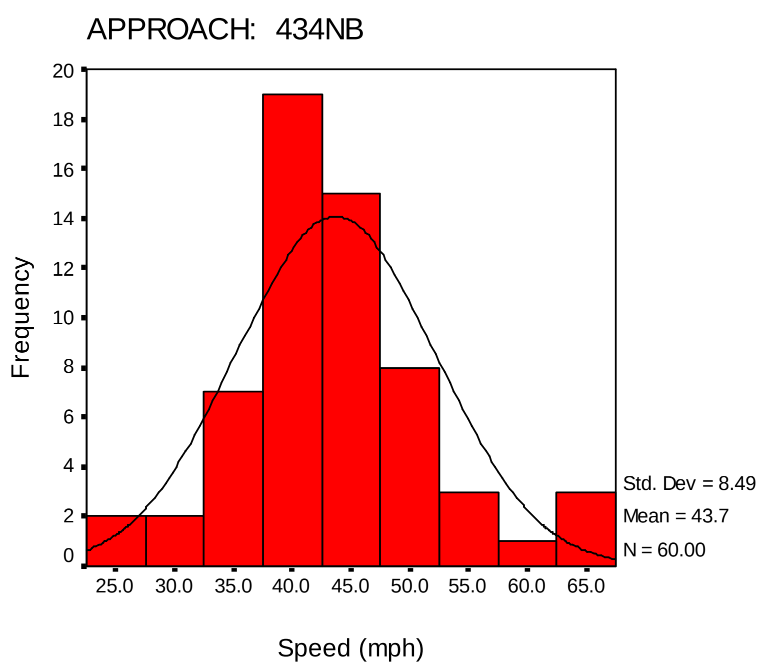
Table 6-3 Number of Subjects by scenario

	AWBS		BSBS		BNBL		AWBL		BNBF		AWBF		AEBR		BNBR	
Age group	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
16 – 19	5	8	6	7	5	8	5	8	5	6	4	6	5	6	4	6
20 – 24	6	8	6	8	7	8	6	8	6	8	7	8	8	8	7	8
25 – 34	5	9	5	8	5	8	5	8	5	9	5	9	5	9	5	9
35 – 44	5	8	5	7	5	7	5	6	4	6	4	7	4	7	4	7
45 +	1	6	1	5	1	6	1	6	2	8	2	8	2	8	2	8
Total	22	39	23	35	23	37	22	36	22	37	22	38	24	38	22	38

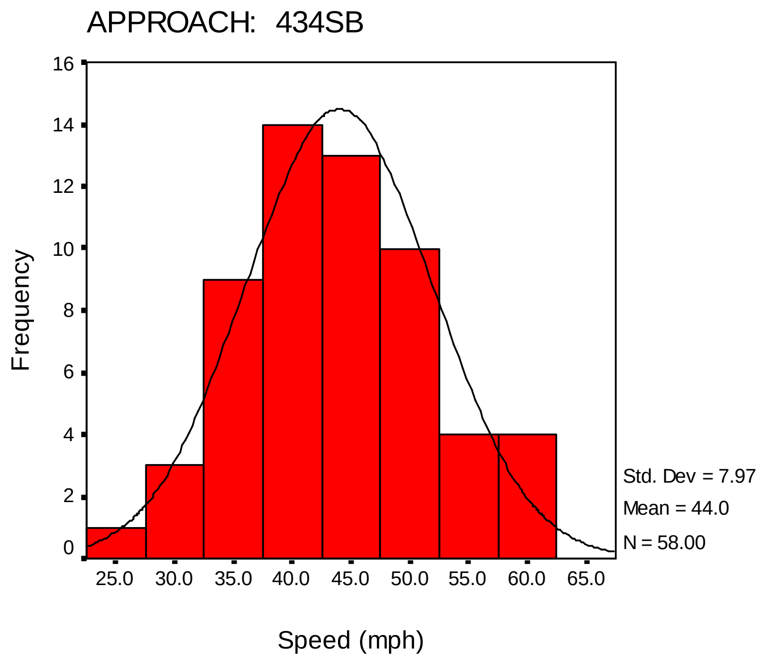
Scenarios BSBS, AWBS, BNBR, AEBR are used for speed validation. The simulator records the position and speed of the vehicle for every $1/60^{th}$ of a second. Table 6-4 shows the descriptive statistics for the speed data collected. Figures 6-2 (a, b, c, and d) illustrate the speed distributions for each approach at the intersection in the simulator.

Table 6-4: Mean Speed at Intersection Using Driving Simulator.

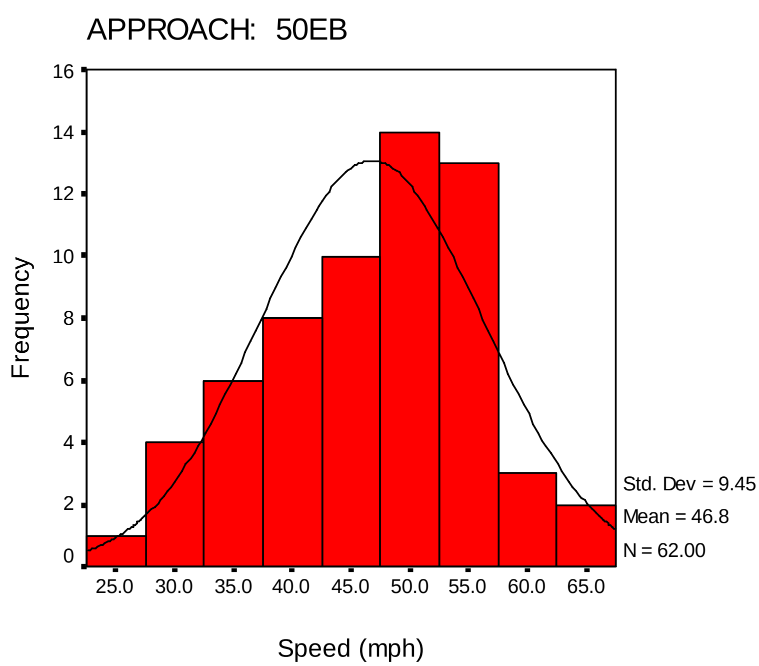
APPROACH	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
434NB	42.925	1.032	40.892	44.957
434SB	42.829	1.053	40.755	44.904
50EB	45.937	1.013	43.941	47.933
50WB	46.531	1.03	44.502	48.561



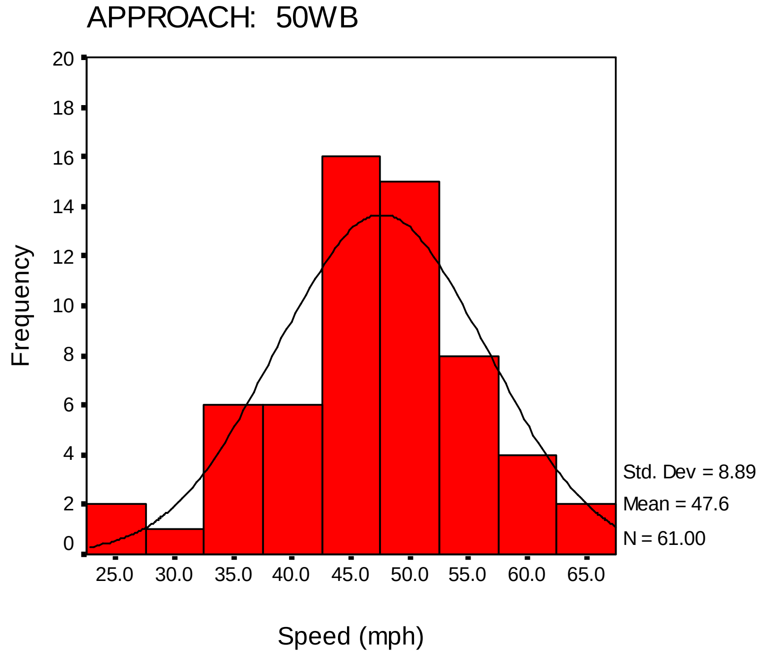
a. Histogram of speed measurements in simulator at the 434NB approach



b. Histogram of speed measurements in simulator at the 434 SB approach



c. Histogram of speed measurements in simulator at the 50 EB approach



d. Histogram of speed measurements in simulator at the 50 WB approach

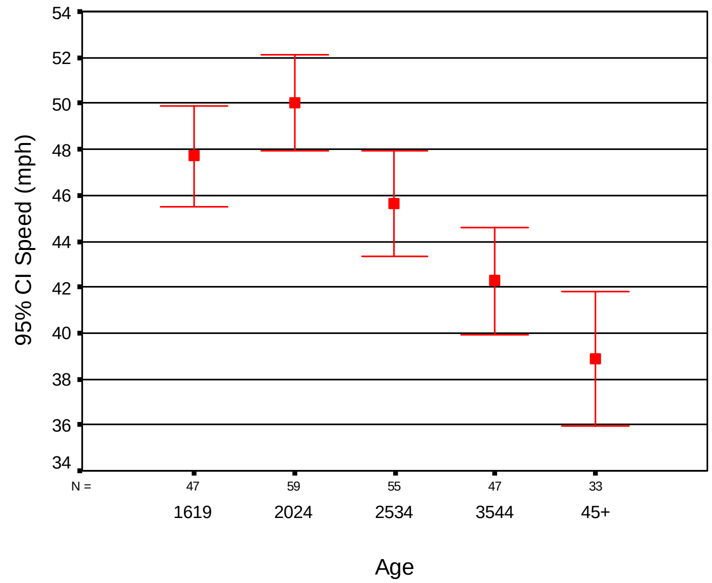
Figure 6-2: Histogram of speed measurements in simulator for each approach at the intersection

The Kolmogorov – Smirnov normality test shows that the P-value (Asymp. Sig. 2-tail as shown in Table 6-5) is greater than 0.05 for all the approaches. Therefore, the speed data in driving simulator follows normal distributions.

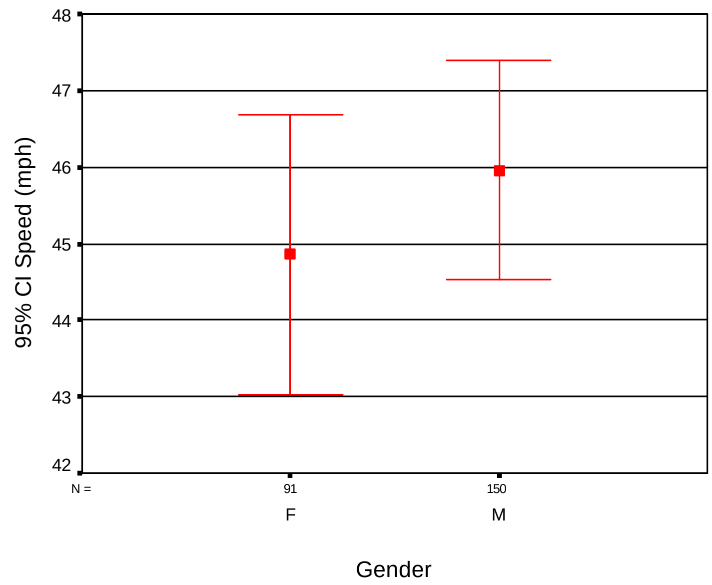
Figures 6-3a and 3b show the 95% confidence interval and mean speed across different age and gender groups. In Figure 6-3a the X-axis represents age, where, 1619 represents age between 16 and 19 years inclusive, 2024 represents age between 20years and 24 years inclusive and so on. It clearly shows the 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 6-3b. Both trends are statistically confirmed by F-test in the ANOVA analysis (see Table 6-6), 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 6-5: Kolmogorov – Smirnov Normality Test Statistics for Speed Measured in Simulator.

APPROACH			SPEED
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



a. Speed distribution by driver age



b. Speed distribution by driver gender

Figure 6-3: Driving behavior patterns of speed by driver age and gender

Table 6-6: 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 (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 significantly with age. Those driving patterns related to speed are illustrated in Figure 6-4, which shows very similar trends of speed distributions by gender and age from the simulator experiment results, as shown in Figure 6-3.

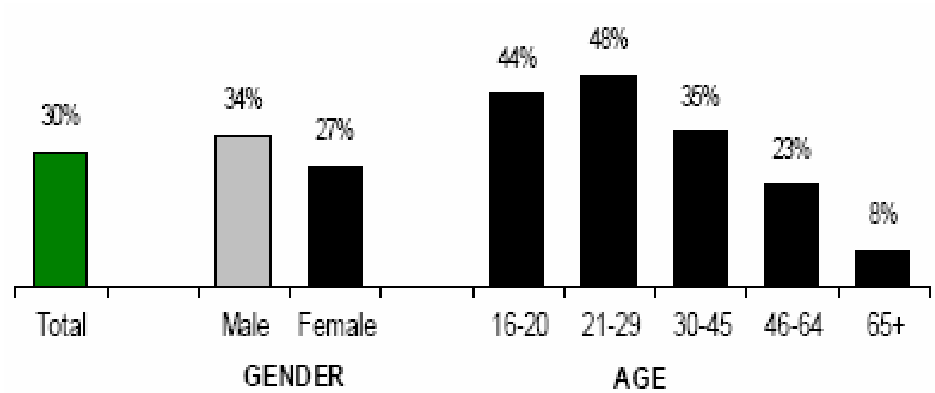


Figure 6-4: Distribution of drivers who tend to pass most other drivers by gender and age (Source: Royal, 2003)

6.1.3 Speed Validation of the Driving Simulator

For speed validation of the driving simulator, the speed distributions found out from the Driving simulator and that found from the field are compared using the Kolmogorov – Smirnov test. Table 6-7 shows the comparison of mean speeds.

Table 6-7 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 6-5 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 50WB approach.

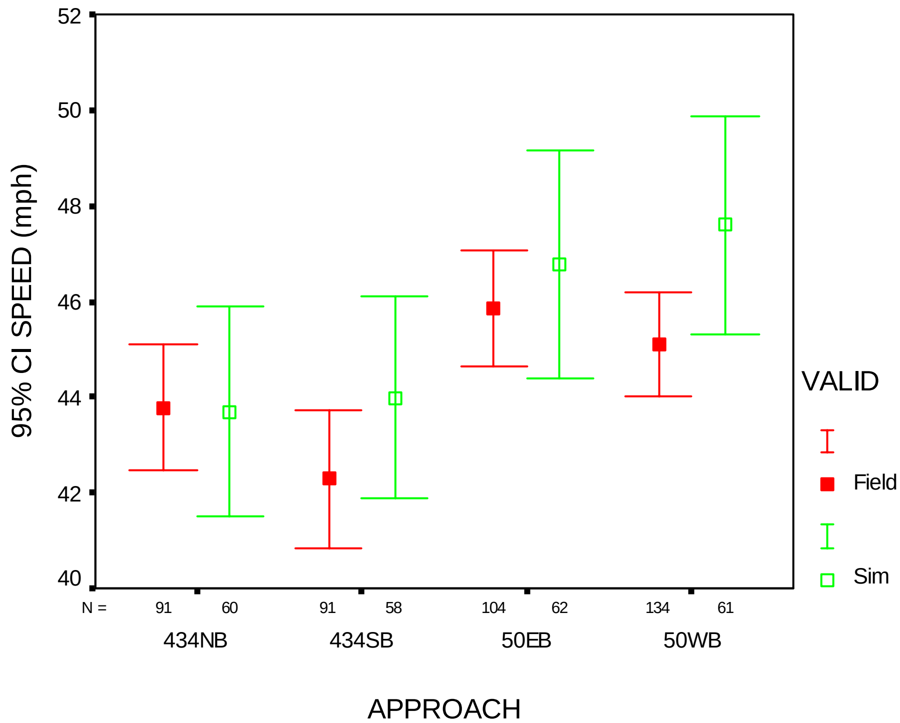


Figure 6-5: Mean speeds using simulator and from field.

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 6-8 shows the results of both F-test and t-test for variance and mean comparisons, respectively. First, 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 6-8. Based on variance type (equal or unequal) respective t–test statistic values are looked upon for validation. From the table, the significance of the P-value is greater than 0.05 for all of four approaches. Therefore null hypothesis is not rejected for the four approaches and therefore, the simulator is validated for the intersection. However, note that the speed data from the driving simulator shows a larger variability for the higher operation speeds for the approaches at the 50 highway.

Table 6-8: 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	101.285	.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	109.089	.188	-1.690	1.274	-4.215	.836
50EB	Equal Var	12.367	.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

6.1.4 Speed Validation Conclusions

From the Kolmogorov – Smirnov normality test statistics, the speed distributions observed from field and that from simulator follow normal distributions along all the 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 the 434NB and 434SB approaches, but they have unequal variances along the 50EB and 50WB approaches at a 95% confidence level. 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 the mean speeds for driver age and gender based on the simulator experiment results are very close to the distribution in previous studies.

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

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

As described in chapter three, Alafaya trial (SR-434) is more risky for right turn rear end crashes than colonial drive (SR-50). For safety validation of rear-end safety 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.

6.2.1 Driving Simulator as a Leading Vehicle

Table 6-9 shows the independent variables that are considered for safety validation in the case where the driving simulator is used as a leading vehicle.

Table 6-9: 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 away from stop line in the right turn lane	Continuous (mph)
Spd80	Simulator speed measured at 80 m away from stop line in the right turn lane	Continuous (mph)
Spd60	Simulator speed measured at 60 m away from stop line in the right turn lane	Continuous (mph)
Spd40	Simulator speed measured at 40 m away from stop line in the right turn lane	Continuous (mph)
Spd20	Simulator speed measured at 20 m 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)
Reatime	Driver’s brake response time to the signal change in the right turn lane.	Continuous (s)
Age	Driver age	Continuous
Gender	Driver gender	Categorical (M=1; F=0)

6.2.1.1 Brake deceleration rate analysis:

Table 6-10 shows the descriptive statistics of the independent variables, average deceleration and maximum deceleration. It can be observed that average deceleration rate is higher for the 434NB approach than for the 50WB approach 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 6-11 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 434NB and 50WB at a 95% confidence level. Average deceleration rate is higher for approach 434NB than 50WB. By taking average deceleration rate as surrogate measure for rear-end right turn lane crashes, it can be concluded that 434NB approach is more risky than 50WB approach with respect to rear-end right turn crashes. This result validates the driving simulator, since the same location at the intersection experiences frequent rear-end crashes. On the contrary, Table 6-12 reveals that the maximum deceleration rate is not statistically higher for approach 50WB than that for 434NB at a 0.05 significance level.

Table 6-10: Descriptive statistics of Average deceleration and Maximum Deceleration.

Approach	Variable Deceleration	N	Mean	Std Dev	Minimum	Maximum	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 6-11: Hypothesis Test - Two Sample t- test for Means of Average Deceleration Rate

Group	N	Mean of Ave_del	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 6-12: Hypothesis Test – Two Sample t- test for Means of Maximum Deceleration Rate

Group	N	Mean of Max_del	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	

6.2.1.2 Non-stop turn rate analysis:

Table 6-13 shows the frequency of subjects, driving as a leading vehicle, who stopped fully at the stop lines of 434NB right turn lane and 50EB right turn lane. The definition of 'Full-STOP' is given in the Table 6-9. From Table 6-13, 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.

Almost 81.6% of the subjects that drove along the 434NB right turn lane did not stop fully at the stop line; whereas, only 57.63% of the subjects that drove along the 50WB 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 6-14), null hypothesis that full stop behavior and intersection approaches are independent, is rejected with 95% confidence.

Table 6-13: 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 6-14: 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 the other approaches, so as to increase the risk of rear end collision with the vehicle following. Since non-stop rate is higher for 434NB (81.67%) than that for 50WB (57.63%), the 434NB right turn has more rear-end crash risk than the 50WB 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.

Considering the location of the stop line, it is located at the curve of the 434NB right turn lane and the distances between the stop line, pedestrian crossing, and the edge of the 50 highway are very short. Therefore, it requires less time to make a right turn and drivers tend to quickly watch the traffic from other approaches and then turn right quickly without stopping. In contrast, the stop line is located in the front of the curve in the case of the 50WB right turn lane and the distances between the stop line, pedestrian crossing, and the edge of the 434 highway are very long. Hence, it requires longer time to make a right turn so that drivers tend to drive very slowly or stop at this area between the stop line and the edge of the 50 highway 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-present in the 434NB right turn lane compared to the 50WB right turn lane.

6.2.1.3 Analysis of speed distribution along the right turn lane

Table 6-15 and Figure 6-6 show descriptive statistics distribution of speed measured along the right turning lane on both the approaches namely, 50-west bound and 434 north bound. The X-axis of the Figure 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 Figure 6-6, Spd100 indicates mean speed of the subjects at 100m (333 ft) upstream of the stop line; Spd80 indicates the mean speed of the subjects at 80m (266 ft) 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 that, the mean speeds are consistently higher along 50WB right turn lane than that along 434NB at locations 100m, 80m, 60m and 20m but are lower at the stop line.

Table 6-15: Descriptive Statistics of Speeds at Different Locations Upstream of the Stop Line

Approach	Location	N	Mean Speed(mph)	Std Dev	Minimum	Maximum	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

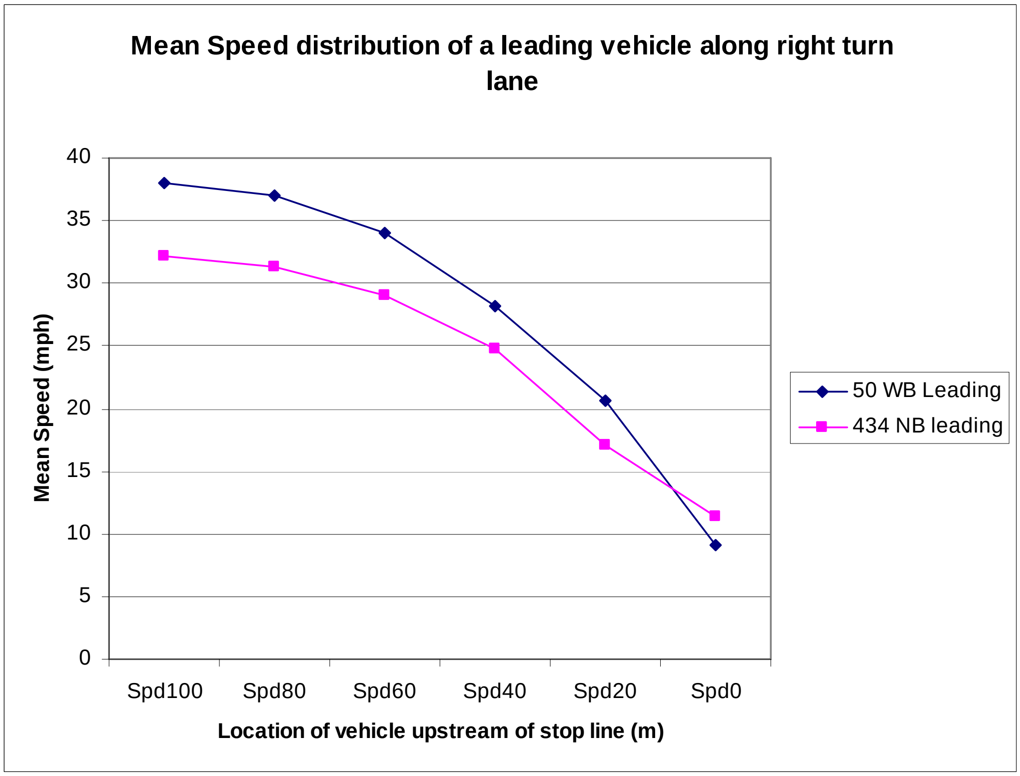


Figure 6-6: Mean speed distribution of a leading vehicle along the right turn lanes

From Table 6-16, mean speeds at the stop lines of 50WB approach and 434NB approach 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 the approach 434NB is significantly greater than that of the approach 50WB. This means that when drivers make right turns in a situation where, pedestrians crossing the intersection, it requires faster deceleration rate at the 434 approach than at the approach, to avoid collision with pedestrians. This might lead to rear end crashes. Hence, approach 434NB is found to be more risky than the 50WB approach with respect to rear end crashes. By considering speeds at stop line as surrogate measure for rear-end risk at right turn lanes, the conclusion that the 434NB approach is more risky than the 50WB approach, validates the driving simulator.

Table 6-16: 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	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	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	

6.2.2 Driving Simulator as a Following Vehicle

Table 6-17 shows the independent variables that are considered for safety validation in the case where driving simulator is used as a following vehicle. In this scenario each subject has driven the simulator cab as a vehicle following another vehicle in the right turn lane of both 434NB and 50WB approaches. When the leading vehicle approaches the intersection at 60 m (200 ft) away from the stop line, the traffic signal changes form green to yellow; when the leading vehicle approaches the intersection at 50 m (166 ft) away from the stop line with a speed of 30mph, it brakes 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 subject responding to the sudden stop would be measured to test the rear-end risk. It is expected to find that the conditional crash rate and relative driving speed, in the 434NB right-turn lane should be larger than the 50WB right-turn lane, and the following distance shorter.

Table 6-17: 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 away from stop line in the right turn lane	Continuous (mph)
Fdis50	Following distance measured when the leading vehicle is 50 m 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	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)

6.2.2.1 Rear-end crash rate analysis

Figure 6-7 shows a comparative graph of rear-end crashes that occurred in the simulator experiment between 434NB right turn lane and 50WB right turn lane. It can be observed that, the total number of rear-end crashes that occurred in the 434NB right turn lane is higher than that in the 50WB. This is tested statistically by 'Two sample test of equality of proportions'.

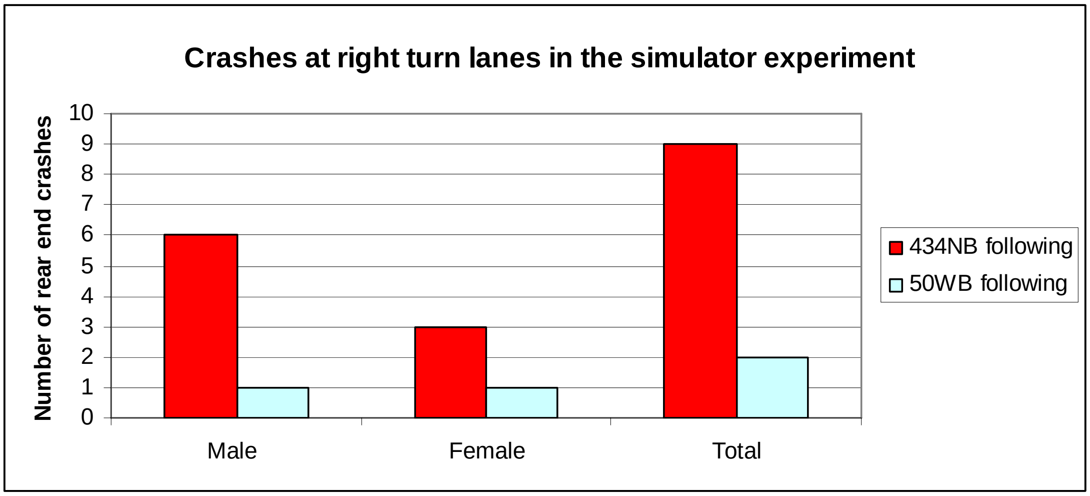


Figure 6-7: Rear-end crashes at right turn lanes in the experiment.

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 6-18), 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, the 434NB right turn lane is more risky than the 50WB right turn lane with respect to rear-end crashes. This result directly validates the driving simulator.

Table 6-18: 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

According to Table 3-8 in Chapter 3 it is found that, at the real intersection, from crash data between year 1999 to year 2002, males and females are equally involved in rear end crashes along the 434NB right turn lane. This pattern is also observed in the experiment. Assuming null hypothesis of having equal proportion of crashes along the 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 6-19) 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 6-19: 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

6.2.2.2 Following distance analysis

Table 6-20 shows the descriptive statistics of the independent variables. All the independent variables are defined in the Table 6-9. From Table 6-20 it is observed that the following distance when leading vehicle is at 50m upstream of stop line (Fdis50) is smaller for 434NB right turn lane than for 50WB right turn lane. This is tested statistically by two sample t-test. Since P-value

(0.0304) from Table 6-21 is less than 0.05, there is a significant difference in Fdis50 between 434NB right turn lane and 50WB right turn lane. Therefore, the mean of Fdis50 is significantly lesser for the 434NB approach right turn lane than that for the 50WB right turn lane with a 95% confidence level. In case of the leading vehicle decelerating faster, the following vehicle will not have enough gap to stop if the spacing is small. This could lead to a rear end crash. Since distance following is significantly lesser along the 434NB right turn lane than that along the 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 also validates the driving simulator (the 434NB right turn lane is at high rear-end crash risk than the 50WB right turn lane). Other independent factors are found not to be significantly different between the two approaches.

Table 6-20: Descriptive Statistics of Independent Variables

IN_app	N Obs	Variable	N	Mean	Std Dev	Minimum	Maximum	Range
434NB Following	59	Spd50(mph)	59	27.595	2.7259	18.745	33.11	14.365
		Fdis50(m)	59	30.191	13.43	11.071	92.515	81.444
		Ave_Del(ft/s^2)	59	14.225	7.0629	1.9885	23.792	21.803
		Max_Del(ft/s^2)	59	20.818	3.4325	8.0897	26.012	17.923
		Ye_retime(s)	58	1.7899	0.4829	1.05	3.4667	2.4167
50WB Following	60	Spd50(mph)	60	28.666	2.0801	22.922	36.411	13.489
		Fdis50(m)	60	35.582	13.409	13.211	72.287	59.076
		Ave_Del(ft/s^2)	60	13.348	6.745	2.8178	24.081	21.263
		Max_Del(ft/s^2)	60	20.429	3.7793	9.0822	26.1	17.018
		Ye_retime(s)	60	1.6744	0.5193	0.5333	2.9833	2.45

Table 6-21: Two Sample t-test for the Means of Fdis50 within IN_app

Group	N	Mean	Std. Dev.	Std. Error
434nbf	59	30.19122	1.43	1.7484
50wbf	60	35.58154	13.409	1.731
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	

6.2.3 Conclusion

The effort 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 risk happening at right turn lanes. In comparison between driving simulator experiment results and real world crash records, 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 measures of rear end safety 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 the 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 434NB right turn lane (15.25%) is significantly higher than that of 50WB (3.33%).

Based on the above findings for the right turn rear end 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 - Crash Risk Test at Through Lanes

For the through lanes at the intersection, the crash report analysis showed that the rear-end crash rate in the eastbound approach of 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 50EB through traffic is obviously higher than that related to 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 the eastbound Colonial Drive (SR-50), when signal changes from green to amber to red when vehicle is at 90m (300 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 the northbound Alafya Trail (SR-434), when signal changes from green to amber to red when vehicle is at 90m (300 ft) upstream from the stop line. This is low risk location.

If the two aforementioned 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. Table 6-22 defines all the independent variables for safety validation at intersections.

Table 6-22 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 termination of the green phase	Continuous (s)
Age	Driver age	Continuous
Gender	Driver gender	Categorical (M=1; F=0)

6.3.1 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 6-23 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 the yellow phase, drivers at the 50EB approach are more likely to cross the intersection compared to those drivers at the 434NB 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 the 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 6-23 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 6-24 shows that the mean speed at the 50EB approach is higher 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 50WB approach is 50 mph but those for the other three approaches are 45 mph. Moreover, speed limits for most segments of the 50 highway are 50 mph, which may cause drivers to not fully reduce their traveling speeds to 45 mph. It is explained that drivers at the 50EB approach are less likely to stop at the intersection during signal change. Therefore, drivers at the 50EB approach are more likely to speed. Generally, when speeding drivers encounter a yellow signal at 90 m (300 ft) away from the stop line of the intersection, they are more likely to fall into the dilemma and possibly to run a red light. Using no-stop rate as a surrogate measure for angle collisions, it can be concluded that the vehicles from the 50EB approach are more likely to run a red light so as to result in a higher angle collision rate compared to the 434NB approach. This experiment finding is consistent with the conclusion that was based on the crash report analysis. Furthermore, according to the experiment results, there are 1 red light running observation of 60 subjects at the 434NB approach and 3 observations of 62 subjects at the 434NB approach. Since red-light running is a rare event, no conclusion could directly be drawn based on the limited sample size.

Table 6-24: Mean Speed of the Simulator

Factor	Level	N	SPEED	
			Mean	Std Dev
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 measure for rear-end collisions, because within 90 m 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 50EB approach may result in more rear-end crashes compared to the 434NB approach.

6.3.2 Analysis of Stopping Behaviors at the Intersection during the Signal Change

Table 6-25 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 (AEBR) is compared for statistical significant difference with the corresponding mean of the independent variable at low risk approach, i.e. 434-North bound through (BNBR). 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 6-25: Descriptive Statistics of Independent Variables for Subjects Stopped

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

The results of the two sample t-test (Table 6-26) show that, P-value of no independent variable is less than 0.05. Therefore, this test fails to reject null hypothesis at a significant level of 0.05. Hence, there is no significant difference between mean of each independent variable between 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 vehicle is at 90m 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 similar for both approaches.

Table 6-26: Results of Two Sample t-test for Means between Approaches

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

Furthermore, the same data is looked at for significant difference of independent variables between gender groups at the high risk 50EB approach using the same two sample t-test and are compared with real world crash data from Chapter 3.

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 6-27 shows the descriptive statistics of independent variables for subjects that stopped on red at the 50EB approach. From Table 6-28, at a 0.05 significant level, there is no significant difference in speed, Treac, Decel and GAP between gender groups. Therefore, there is no significant difference in driving behavior between genders.

Table 6-27: Descriptive Statistics of Independent Variables for Subjects Stopped on Red at the 50EBApproach

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

Table 6-28: Results of Two Sample t-test for Means between Gender Groups for the 50EBApproach

Independent variable	If Variances Are	t statistic	Df	Pr > t
Speed	Equal	-0.059	89	0.9531
	Not Equal	-0.058	78.90	0.9537
Treac	Equal	2.086	76	0.0403
	Not Equal	1.889	42.57	0.0657
Decel	Equal	1.920	89	0.0581
	Not Equal	1.920	84.02	0.0582
GAP	Equal	0.435	89	0.6649
	Not Equal	0.415	65.04	0.6796

6.3.3 Conclusions

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 the Colonial Drive (50EB) has a higher crash rate for both types of the collisions than the northbound approach of 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 50EB approach are more likely to cross the intersection compared to those drivers at the 434NB 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 the traffic safety studies.

6.4 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 6-8, 6-9, and 6-10 show the results of questions 1, 3 and 4. Questions 2, 3 and 4 are valid only if the subjects recognize the intersection. Second question is "Can you say which intersection it was?" All of them, who were able to recognize the intersection, were also able to identify which intersection it was i.e. 'Colonial Drive and Alafaya Trail intersection'.

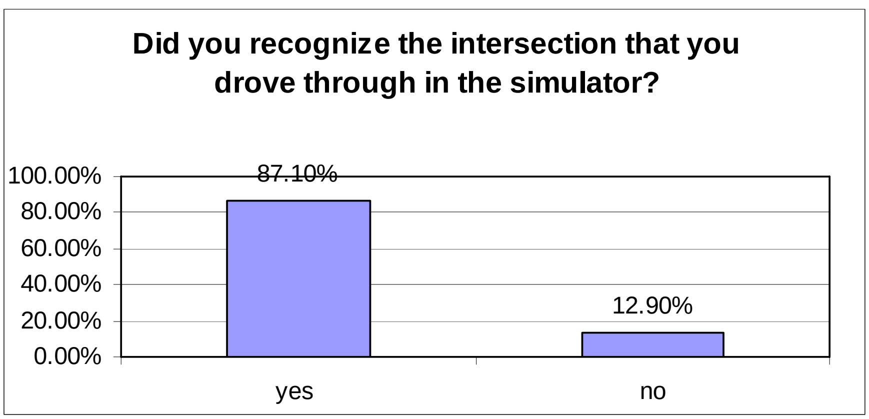


Figure 6-8: Question 1

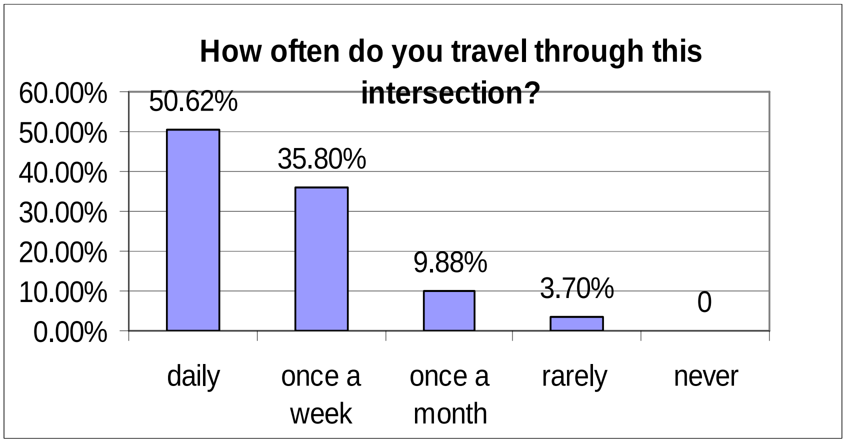


Figure 6-9: Question 3

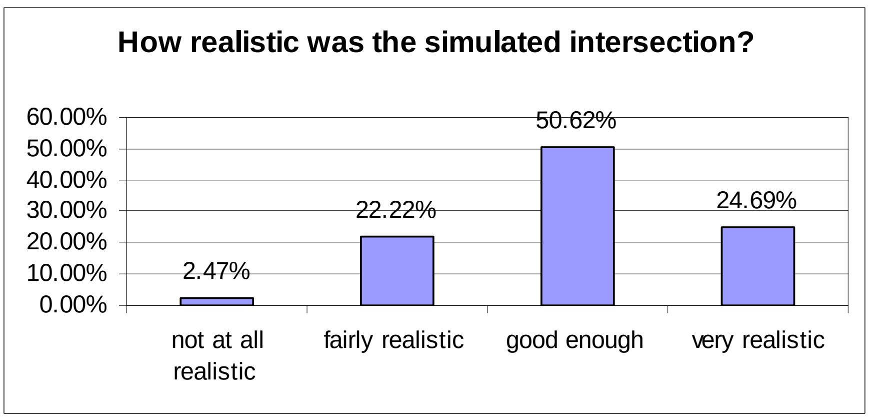


Figure 6-10: Question 4

From Figure 6-8, 87.10% of the subjects recognized the intersection. And out those who identified the intersection, from Figure 6-9, 50.62% drive daily, 35.8% drive once in a week, 9.88% drive once in a month, through the intersection. From Figure 6-10, 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.

CHAPTER 7. CONCLUSIONS AND DISCUSSIONS

7.1 Summary of the Driving simulator Validation Experiment

The UCF driving simulator has a potential to be used as a traffic safety test bed to identify potential problems of intersection design, explain interaction between drivers and roadway surrounding, and explore effective countermeasures to reduce traffic crash rates. As an initial step to develop the UCF driving simulator as a safety test bed, this project focused on validating the driving simulator from two perspectives, traffic and safety parameters (i.e., speed and crash risk). To achieve this research objective, the signalized intersection of Alafaya Trail and E. Colonial Drive that has one of the highest crash frequencies in Central Florida was replicated in the driving simulator system. To validate the driving simulator in Speed and Safety, eight scenarios were designed in a driving simulator experiment. The experimental measurements based on subjects' performances in the simulator were compared to those measured in field and police crash report analysis to investigate whether drivers have the same driving performances and traffic risk patterns.

From the perspective of speed validation, it was found that comparing speed distributions observed from the field to those from the simulator experiment, both of them follow normal distributions along all the four approaches of the intersection; they have equal variances along 434NB and 434SB approaches. Furthermore, the speed data observed from the field and that from the simulator have equal mean for each intersection approach and the distributions of mean speeds for driver age and gender based on the simulator experiment results are very close to the real distribution from previous studies. Therefore, based on the overall comparisons of speed between the simulation and real world, one can conclude that the UCF driving simulator is a valid tool for traffic studies related to driving speed behaviors.

For the safety validation, the crash report analysis showed two important risk pattern at the intersection: one is 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 has the lowest rear-end crash rate; the other is that the through traffic at the eastbound approach of Colonial Drive involved the highest rear-end crashes rate and a higher angle crash rate while the through traffic along the northbound approach of the Alafaya Trail are less likely to involve both rear-end and angle crashes.

For the right-turn rear-end risk study, it was found that considering the driving simulator as a leading right turn vehicle in the experiment, the deceleration rate at the 434NB approach is higher than that at the 50WB approach; the non-stop rate is larger 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 measures for 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 when the leading vehicle made a sudden stop in front of the subjects, the rear-end crash rate in the right turn lane of 434NB (15.25%) are significantly higher than that of 50WB (3.33%). Therefore, the drivers' performances in the simulator experiment showed the same risk pattern as that based on the police crash report analysis for the real intersection.

For the through-lane crash risk study, driver's stop/go decision can be considered as the most essential behavior at signalized intersections, which is related to both angle crashes and rear-end collisions. Using no-stop rate during the signal change as a crash surrogate measure in the driving simulator experiment, it was found that drivers at the 50EB approach are more likely to cross the intersection compared to those drivers at the 434NB approach (37.1% Vs. 13.3%) to beat the red light. The trend is attributed to that the mean speed at the 50EB was found to be larger than that at the 434NB in both the simulator experiment and field study. This finding implied that 50EB should be expected to have a higher crash rate for both angle and rear-end collisions at this intersection. This conclusion is consistent with the crash trend based on the police crash report analysis for the real intersection.

In summary, the experiment results validated that the UCF driving simulator could be a proper tool to be employed as a test bed for driving behavior research and traffic safety studies.

7.2 Challenges for this Project and Suggestions for Further Simulator Study

An important goal of this project is to investigate the feasibility of replicating real-world traffic environments into the UCF Driving Simulator. With the delays in project completion, one would question whether it is feasible to recreate real-world locations into the UCF Driving Simulator. This section discusses these feasibility issues, why the project required extension, challenges met along the way, recommendations for future projects, and the valuable lessons learned that if followed, will tremendously expedite future project development.

Replicating a real-world driving environment into a simulated virtual world is referred to as geo-specific database creation. Until this project, the UCF Driving Simulator has not used nor created a geo-specific world for the Mark II simulator, rather choosing to use/create geo-typical virtual driving environments - environments that have roadway geometry typically found in the real world, but are not specific to any real-world location.

This distinction is important; geo-typical databases are usually much easier to create, as any problems encountered during the building process can be worked around with a number of options, since the world is fictional and does not have to adhere to any one specific design. Geo-specific databases, however, are often more difficult to implement since there is only one design that can be followed: the real-world design. All obstacles have to be overcome before proceeding. The modelers and engineers working on the geo-specific database design must find a way for their simulator system to adopt all necessary aspects that the geo-specific world requires (i.e. 3D visual aspects, traffic patterns/artificial intelligence, road geometry, etc.). Since the Test-bed Intersection is a geo-specific location, we faced many technical issues in translating the real-world information into a drivable virtual environment.

The first challenge we encountered was the large learning curve required to train personnel to use the simulator development tools. There were many areas of knowledge to train individuals in, from software and artistic development tools, to simulator operation and maintenance. Development tools included learning 3D modeling software such as 3dsmax, Maya, and Multigen's Creator (such as Figure 7-1) as well as becoming proficient in programming languages such as C and C++, and development environments such as Visual Studio 6.0 and .NET. We required personnel to become familiar enough with AutoCAD and Microstation to navigate road-design files and extract data necessary to the model design. We also had to train personnel to use the simulator software, which includes the scenario editor, various conversion programs, APIs, and protocols that link the simulator to other software. Furthermore, students required training on simulator operations and maintenance (illustrated in Figure 7-2).

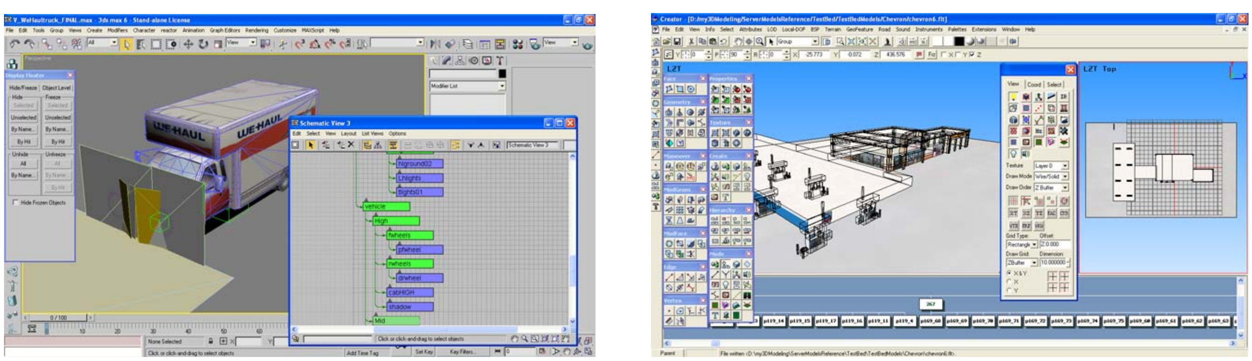


Figure 7-1: 3D Modeling Tools 3dsmax and Multigen's Creator

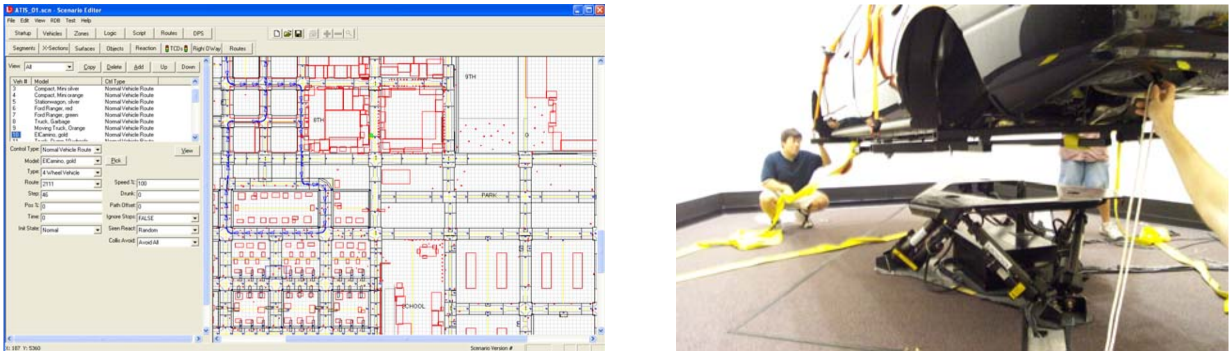


Figure 7-2: Scenario Editor Software and Simulator Maintenance

We initially started the training process on our own. However, since our core simulator hardware/software was purchased from a commercial simulator company (MPRI Ship-Analytics-STS), and given that we just went through a major hardware/software upgrade, it became apparent that we required more up-to-date knowledge to complete this project. A partnership was formed between UCF and STS in that they supplied three training sessions, each multi-day training session focusing on a different area of simulator knowledge. Moreover, STS also assisted UCF by phone and email as questions/problems arose.

Not only did employees have to learn how to use numerous tools that spanned a variety of disciplines (i.e. computer engineering, civil engineering, and 3D modeling), they also had to be proficient enough to complete tasks so the task not only fulfilled the Test-bed requirements, but also worked within the simulator's stringent system specifications. This is a daunting task, where the developer walks the line between what is specified versus what is possible to do given the current simulator functionality. Expertise was required and only gained through many hours of trial and error.

The reason for so much trial and error was due to the lack of control over some key system software. The core software of our simulator system is provided by a commercial company as a “black-box” design, and as such, we could not access the source code to make Test-bed necessary modifications. We had to use the system functionality that was provided, and if we desired any new features, we would have to find a unique method to incorporate them into the existing design. In other words, we had to invent work-arounds to solve problems, rather than use the straight-forward solution, since access to the code was not available. These work-arounds were not the ideal way to implement some of the Test-bed design, but since we did not have source-code rights, we had no other alternatives. The work-arounds were hard to realize, even harder to implement, and thus extremely time consuming. If something required adaptation later on, these methods did not lend themselves for quick modification and usually required the developer to completely redo the task instead of a quick parameter adjustment that would typically be done, for instance. This lack of control was the overwhelming reason why delays occurred on this project. Without core software access, we had little knowledge about some fundamental issues, and forced us to redo work many times over.

To compound our woes even further, issues arose where Test-bed road geometry could not be easily converted to Road DataBase (RDB) file formats. The current tools available to enter such information into the simulator system were outdated and required a large amount manual information. To solve these problems, we developed a set of software tools that improved data entry and manipulation into RDB file formats (see Figure 7-3). These tools contained a lot of graphical interface features, were intuitive to use, and although they took time to develop, it would have taken longer and have been less adaptable if we did everything by hand.

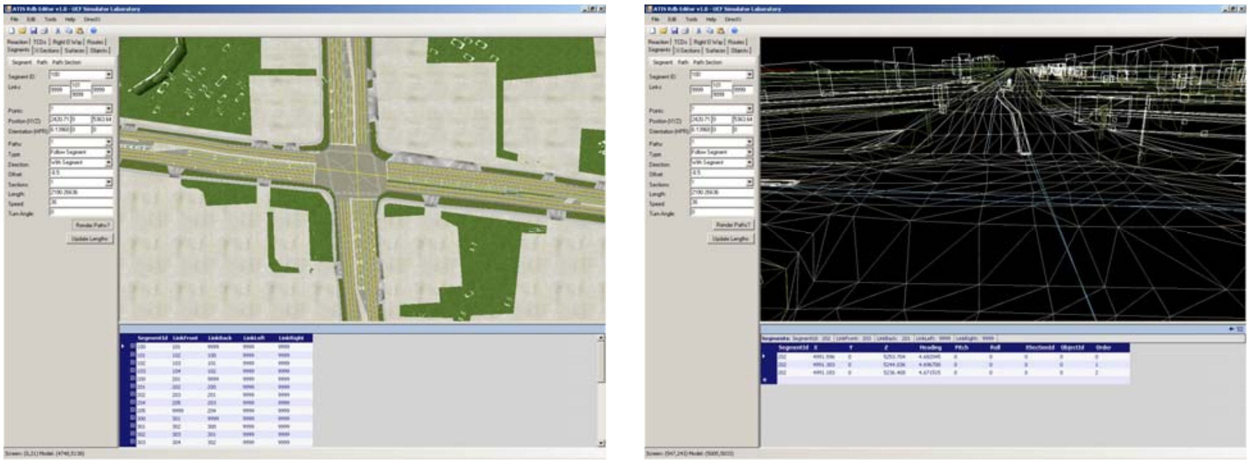


Figure 7-3: Custom Developed Tool for RDB Editing

The Test-bed project posed new and interesting challenges to the UCF Driving Simulator Lab. An extensive learning curve was required to train simulator staff in the multitude of development software. In addition, many of the existing tools were outdated or not readily adaptable to the Test-bed requirements. New tools had to be developed in-house to solve various issues, some stemming from antiquated software, others due to the fact that critical third party simulator software was formatted as a "black box" and thus not open to modification. All these factors caused delays, which summed together, required UCF to ask for time extensions.

In light of this experience, the UCF Driving Simulator Lab is left with valuable lessons learned that make it feasible to proceed with future projects similar in nature to the test bed. Provided that a comprehensive agreement is established between UCF and commercial software vendors to handle modifications to the "black box" software, many technical difficulties and delays can be avoided. Furthermore, given that UCF staff are now proficient in simulator operations, maintenance, 3D modeling, C/C++ programming, traffic operations, and design-to-simulator integration, future projects similar to the test bed will have significantly faster turnaround times with a level of quality fitting to the high standards expected from the University of Central Florida.

APPENDIX A. MODEL LIST AND VISUAL EFFECT OF INTERSECTION

Table A-1: Models Developed in the Test-bed Project for the Colonial and Alafaya Intersection

Building Name	Measurements Taken	Polygonal Structure	Pictures Taken	Images Edited	Textures Added	FX	LOD	Scaled	STS Conversion	Complete	In DB
Abandoned Gas Station											
Advance Discount Auto											
Albertsons											
Arby's											
Burger King											
Checkers											
Chevron											
Chili's											
Denny's											
Dunkin Donuts											
Florida Educator's Bank	NOT ALLOWE										
Golden Buffet											
Home Depot											
Kmart											
Midas											
Olive Garden											
Papa Johns											
Radisson Hotel											
Ramada Hotel											
Steak'n Shake											
Suntrust Bank											
Tire Kingdom											

Triple 555 Convenience											
TropiGrill											
U-Haul Facility											
Waffle House											
Wendy's											
Object Name	**Measurements Taken**	**Polygonal Structure**	**Pictures Taken**	**Images Edited**	**Textures Added**	**FX**	**LOD**		**Complete**		**In DB**
Motor Coach Vehicle											
U-Haul Midsized Truck											
EVO Car											
Benches											
Billboards											
Chainlink Fence											
Dumpster											
Fire Hydrants											
High Detail Trees											
Medium Detail Trees											
Low Detail Trees											
Bushes											
Shrubs											
Palm Trees											
Pine Trees											
Power Lines											
Public Telephones											
Small Trees											
MUTCD Street Signs											
Plus Various Objects Already part of buildings											

a. Snapshot in the UCF driving simulator

b. Snapshot at the real intersection

Figure A-1: Chevron Gas Station & Shell Service Center

a. Snapshot in the UCF driving simulator

b. Snapshot at the real intersection

Figure A-2: At the Southwest corner of the intersection

a. Snapshot in the UCF driving simulator

b. Snapshot at the real intersection

Figure A-3: Wendy's Restaurant in Albertson's Plaza

a. Snapshot in the UCF driving simulator

b. Snapshot at the real intersection

Figure A-4: Olive Garden Restaurant

a. Snapshot in the UCF driving simulator

b. Snapshot at the real intersection

Figure A-5: Tropigrill Restaurant

a. Snapshot in the UCF driving simulator

b. Snapshot at the real intersection

Figure A-6: U-Haul Rental and Storage Facility

a. Snapshot in the UCF driving simulator

b. Snapshot at the real intersection

Figure A-7: Papa John’s Pizzeria

a. Snapshot in the UCF driving simulator

b. Snapshot at the real intersection

Figure A-8: Radisson Hotel

a. Snapshot in the UCF driving simulator

b. Snapshot at the real intersection

Figure A-9: Midas Auto Service Center and Suntrust Bank

a. Snapshot in the UCF driving simulator

b. Snapshot at the real intersection

Figure A-10: Chevron gas station viewed from westbound approach of the intersection

APPENDIX B. QUESTIONAIRE OF SIMULATOR EXPERIMENT

1) Did you recognize the intersection that you drove through in the simulator?

   a) Yes
   b) No

2) If "Yes", can you say which intersection it was?

   ____

3) How often do you travel through this intersection?

   a) Daily
   b) Once a week
   c) Once a month
   d) Rarely
   e) Never

4) How realistic was the simulated intersection?

   a) Not at all realistic
   b) Fairly realistic
   c) Good enough
   d) Very realistic

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