EXAMINATION OF DRIVER LANE CHANGE BEHAVIOR AND THE POTENTIAL EFFECTIVENESS OF WARNING ONSET RULES FOR LANE CHANGE OR "SIDE" CRASH AVOIDANCE SYSTEMS

by

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(ABSTRACT)

Lane change or "Side" Crash Avoidance Systems (SCAS) technologies are becoming available to help alleviate the lane change crash problem. They detect lane change crash hazards and warn the driver of the presence of such hazards. This thesis examines driver lane change behavior and evaluates the potential effectiveness of five warning onset rules for lane change or "side" crash avoidance system (SCAS) technologies.

The ideal SCAS should warn the driver only when two conditions are met: (1) positive indication of lane change intent and (2) positive detection of a proximal vehicle in the adjacent lane of concern. Together, these two conditions create a crash hazard. The development of SCAS technologies depends largely on an understanding of driver behavior and performance during lane change maneuvers. By quantifying lane change behavior, real world crash hazard scenarios can be simulated. This provides an opportunity to evaluate potential warning onset rules or algorithms of driver intent to change lanes.

Five warning onset rules for SCAS were evaluated: turn-signal onset (TSO), minimum separation (MS), line crossing (LC), time-to-line crossing (TLC), and tolerance limit (TL). The effectiveness of each rule was measured by the maximum response time available ($t_{available}$) to avoid a crash for a particular lane change crash scenario, and by the crash outcome, crashed or crash avoided, of a particular lane change crash scenario.

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1. INTRODUCTION

Lane change or "Side" Crash Avoidance Systems (SCAS) technologies are becoming available to help alleviate the lane change crash problem. They detect lane change crash hazards and warn the driver of the presence of such hazards. The development of SCAS technologies depends largely on an understanding of driver behavior and performance during lane change maneuvers. This thesis examines driver lane change behavior and evaluates the potential effectiveness of five warning onset rules for SCAS.

The ideal SCAS should warn the driver only when two conditions are met: (1) positive indication of lane change intent and (2) positive detection of a proximal vehicle in the adjacent lane of concern. Together, these two conditions create a crash hazard. The first condition provides the most interesting challenge, requiring an understanding of driver lane change behavior. This includes quantifying various lane change performance parameters as well as human capabilities and/or limitations to perform an evasive maneuver to avoid a crash. By quantifying lane change behavior, real world crash hazard scenarios can be simulated. This provides an opportunity to evaluate potential warning onset rules or algorithms of driver intent to change lanes.

Five warning onset rules for SCAS were evaluated in this research: turn-signal onset (TSO), minimum separation (MS), line crossing (LC), time-to-line crossing (TLC), and tolerance limit (TL). The effectiveness of each rule was measured by the maximum response time available ($t_{available}$) to avoid a crash for a particular lane change crash scenario and by the crash outcome, crashed or crash avoided, of a particular lane change crash scenario.

The optimal warning onset rule should trigger a warning at the latest possible time that would allow the driver to execute an evasive maneuver in an effective and safe manner. It should be able to distinguish the more common lanekeeping case from the hazard case to minimize nuisance alarms. This provides opportunities and challenges to apply statistical pattern recognition to predict driver intent to change lanes or lane change start.

The objectives of this research include the following:

- Conduct a literature review to understand the lane change crash problem and identify potential countermeasures.
- Provide baseline data for lane change behavior.
- Evaluate the potential effectiveness of five warning onset rules for lane crash avoidance warning systems.
- Provide recommendations for the development of SCAS technologies based on the lane change behavior data and the warning onset rule evaluations.

2. BACKGROUND

2.1 Lane Change Crash Problem

In 1991, lane change crashes accounted for approximately 4% of all police reported crashes that occurred in the United States, or roughly 244,000 such crashes (Wang and Knipling, 1993). Resulting from these crashes were 224 fatalities, representing 0.5 percent of the fatalities in 1991. In addition, there were estimated to be approximately 386,000 non-police reported crashes in 1991. Alleviation of even a portion of such crashes can have substantial benefits in terms of crash-caused delays, property damage costs, and injuries.

According to a data analysis conducted by Eberhard, Luebkemann, Moffa, and Young (1994), lane change/merge accidents typically occur under "normal" driving conditions, that is daylight and clear weather. The common scenario in these types of crashes is that the driver who is unaware of the other vehicle when he or she performs a lane change/merge maneuver fails to counteract with a recovery maneuver to avoid the crash. This indicates that the proximal other vehicle was most likely in the driver's blindspot at the initiation of the maneuver. If the driver had been warned of the presence of the other vehicle, a collision might have been avoided.

Crash avoidance systems that monitor blind spots and warn when another vehicle is present could be very effective in reducing lane change/merge crashes. They could also reduce crashes that do not occur in the blind spot since the burden of monitoring such areas would be shared, distributing the driver mental workload more evenly.

2.2 Lane Change Maneuver Categories

According to Chovan, Tijerina, Alexander, and Hendricks (1994), a lane change may be defined as a deliberate and substantial shift in lateral position of a vehicle with the intention of traversing from one lane to an adjacent lane. This maneuver class includes a simple lane change, merge, exit, pass, and weave. These maneuvers are defined by the driver's intent. The driver conducts a simple lane change if he or she desires to maintain a particular route and must change lanes prior to turning or if he or she simply desires to travel in a particular lane. A merge is conducted if the driver or subject vehicle (SV) must enter a faster-moving traffic stream which implies that the SV is accelerating longitudinally. The opposite maneuver, an exit, involves a transition from a faster to a slower-moving traffic stream which implies longitudinal deceleration of the SV. A pass occurs when the driver desires to avoid a slow-moving lead vehicle. It involves two successive lane changes, one to move to the adjacent lane to pass and one to return to the original lane after passing. Finally, a weave occurs when two or more traffic streams travel in the same direction without traffic control. This may be at a point when one lane ends and merges with another or when one lane diverges into more than one lane.

2.3 Lane Change/Merge Crash Subtypes and Classifications

A lane change crash occurs when the driver attempts to change lanes and strikes or is struck by a vehicle in the adjacent lane. The two subtypes of lane change crashes include proximity and fast approach crashes. In the case of a proximity crash, there is little or no longitudinal distance between two adjacent vehicles for some time prior to the crash. Both vehicles travel at virtually the same speed. On the other hand, a fast approach crash involves two adjacent vehicles that initially have a longitudinal gap between each other. One vehicle approaches the other at a significantly higher velocity, quickly closing that gap. Although the level of severity is less, proximity crashes were found to occur considerably more often than fast approach crashes. This indicates the need for proximal crash countermeasures, namely Side Crash Avoidance System (SCAS) technologies.

Eberhard et al. identified eight classifications of lane change/merge crashes (1994). These classifications may fall in either crash subtype described above. They include: (1) angle striking, (2) angle struck, (3) drifting, (4) rearend struck, (5) leaving a parking place, (6) both changing lanes, (7) sideswipe, and (8) rearend striking. These are further divided into the manner of collision. Descriptions of these classifications are listed in Table 2-1.

Table 2-1. Description of classifications of lane change crashes.

Name	Description
LCM1	vehicle changing lanes or merging strikes another vehicle going straight; the manner of collision is "angle"
LCM2	vehicle changing lanes or merging is struck by another vehicle going straight; the manner of collision is "angle"
LCM2A	vehicle changing lanes or merging is struck by another vehicle going straight; the manner of collision is "sideswipe"
LCM3	neither vehicle intends to change lanes or merge; both vehicles are going straight but they drift together in a "sideswipe" collision
LCM3A	neither vehicle intends to change lanes or merge; both vehicles are going straight but they drift together in an "angle" collision
LCM4	vehicle changing lanes or merging and is struck in the rear by the vehicle going straight
LCM51	vehicle leaving a parked position strikes another vehicle
LCM52	vehicle leaving a parked position is struck by another vehicle
LCM53	vehicle leaving a parked position is struck by another vehicle in a rearend crash
LCM6	both vehicles are changing lanes or merging
LCM7	the vehicle changing lanes or merging strikes another vehicle going straight; the manner of collision is sideswipe
LCM8	the vehicle changing lanes or merging strikes another vehicle in the rear end

2.4 Side Crash Avoidance Systems (SCAS)

A crash avoidance system is a human-machine system equipped with sensors, signal processing, and driver displays. It is an in-vehicle warning device that warns the driver of an imminent crash situation. For such a system to be successful, the following events must occur:

- system detects proximal vehicle
- system warns driver
- driver detects warning
- driver recognizes information displayed by warning
- driver obeys the warning

The ideal lane change crash avoidance system not only detects a proximal vehicle, but it also detects driver intent to change lanes. The success of a crash avoidance system depends on the timely and safe manner with which the driver conducts a recovery maneuver in response to the warning.

Some SCAS have two different levels of warning. The first level is an SCAS "alert" which provides cautionary warning. The second level is an SCAS "warning" which provides an imminent crash avoidance warning. An alert has a lesser degree of urgency and is usually triggered when only one of the two conditions of an SCAS warning onset rule is met. When both conditions are met; that is, when there is indication of driver intent to change lanes and when there is a proximal vehicle in the adjacent lane; a warning is triggered.

2.5 Definition of False Alarms and Nuisance Alarms

A false alarm is one triggered by an inappropriate stimulus event. For example, a warning is triggered although there is no vehicle in the adjacent lane or blind spot. This may be due to rain, wind, electronic noise, parked cars, roadside appurtenances, or glare. Another false alarm scenario is that the driver may have no intention of changing lanes, but is warned of the presence of a vehicle in the adjacent lane. This violates the first SCAS condition of positive indication of driver intent.

A nuisance alarm is one triggered by an appropriate stimulus event under conditions that are not useful to the driver. This occurs in situations where the driver is already aware of a vehicle in the adjacent lane, and a warning gives redundant or unwanted information. What constitutes a nuisance alarm may differ among drivers because of their varying driving behavior. A very confident driver who conducts aggressive lane changes may consider a crash avoidance system tailored to an inexperienced driver to be a nuisance since it would warn earlier than he or she requires.

2.6 Literature Review

2.6.1 Human Factors Guidelines for Crash Avoidance Warning Systems

Vehicles often travel in a driver's blind spot without providing a threat of an imminent collision. Such a threat only occurs when the vehicles' paths converge. Lerner, Kotwal, Lyons, and Gardner-Bonneau (1996) define an imminent crash avoidance situation as when a target object is sensed in the detection zone (i.e., blind spot) and there is an indication of the vehicle's change of path that brings it into potential collision with that target. Providing unwanted or unnecessary information to the driver can cause both an annoyance and a disturbance. Therefore, to prevent numerous nuisance alarms, the imminent crash avoidance warning should only be provided when there is an indication of change of path. Lerner et al. suggest that driver intent to change lanes indicated by turn-signal activation is sufficient to define an imminent crash avoidance situation (1996).

Using turn-signal activation as the only indication of lane change intent is of particular concern, given the "probable abrupt nature of lane changes suggested by police reports" (Lerner et al., 1996). Comments provided by ITS (Intelligent Transportation Systems) professionals indicate that a need exists to quantify "abrupt" as this would aid in the evaluation of potential countermeasures. Lane change intent may not always be indicated by turn-signals, and for this reason additional defining conditions for the imminent crash situation may be useful to supplement the turn-signal criterion. Lerner et al. suggest alternatives that include directly sensing change in vehicle path through lane deviations, lateral acceleration, and/or steering actions. They also recommend a minimum separation distance of 18 inches between two proximal vehicles. Data from actual traffic regarding the speed of lane changes by non-signaling vehicles and the distribution of lateral separation between vehicles on various types of roads are recommended tools for defining the optimal imminent crash criteria.

Some comments provided by professionals in the field of ITS in response to Lerner et al. suggest that future research will show that these systems will be acceptable only if activated by turn-signal use. One additional suggestion was to modify the turn-signal to have a "two-click" operation - one click to the left for a lane change to the left (activating the blind spot sensor) and two clicks to the left for a left turn (no sensor).

Other comments state that eighteen inches seems like an extremely small distance. They suggest that there should be concern about the vehicle lateral path spacing instead of where the lane marker is since crashes can occur anywhere on the road.

Although Lerner et al. implies that some other means of device activation are needed for cases where the driver does not signal, an opposing comment was made suggesting that a crash avoidance system should be made for protecting the driver who uses the turn-signal and not for providing special or costly support for the driver who does not follow correct procedures.

One comment addressed the situation where, in congested traffic, a driver may signal to move into another lane, using the signal as a request to change lanes so that the slow moving traffic flow pauses to allow the lane change to be maneuvered. In this situation, where several lane changes may occur, there would be repeated activation of the crash avoidance warning system. This is an example of a nuisance warning that may be distracting and annoying.

2.6.2 Run-Off-Road Crash Avoidance System Using Time-to-Line Crossing Rule

Lateral run-off-road (ROR) crash avoidance systems detect when the vehicle begins to depart the travel lane, preventing ROR crashes caused primarily by the driver's inattention and wavering steering control. One such lateral system using a decision algorithm called time-to-line-crossing (TLC) was developed at Carnegie Mellon University (1995). This is a "downward-looking" system which looks down to sense the vehicle's current position within the lane. It measures the vehicle's instantaneous lateral offset from the center of the road. Based on this offset, the vehicle velocity, and the width of the road, the time-to-line crossing, or the time required to cross the lane boundary is calculated. When this time drops below a predetermined threshold, an in-vehicle warning is issued to the driver. If it drops even further without a response from the driver, automatic control is initiated by the countermeasure. This system could be applied to lane change crash avoidance systems with a few minor modifications, as TLC would be the time required to cross the lane line between two adjacent vehicles rather than the lane boundary.

2.6.3 Lane Change Maneuver and Recovery Maneuver Models

Chovan et al., (1994) present kinematic models of lane change maneuvers. As a first approximation, normal lane change maneuvers can be modeled as a sine function of time for lateral acceleration (cf. Enke 1979). That is,

$$a = Asin(wt) = \frac{2pILCD}{t_{LC}^2}\sin\left(\frac{2p}{t_{LC}}t\right),$$

where,	a	=	instantaneous lateral acceleration
	A	=	$2\pi ILCD / t^2_{LC,}$ peak acceleration
	ω	=	$2\pi / t_{LC}$, the lane change frequency
	t_{LC}	=	total time to complete the lane change
	t	=	elapsed time
	ILCD	=	intended lane change distance

Given this sine function of time for lateral acceleration, lateral velocity and lateral distance traveled during a lane change are derived by successive integration, respectively, as

$$v = \int a\,dt = \frac{A}{w}[1 - \cos(wt)] + v_0 = \frac{ILCD}{t_{LC}}\left[1 - \cos\left(\frac{2p}{t_{LC}}t\right)\right] + v_0$$

$$d = \int v\,dt = \frac{At}{w} - \frac{A}{w^2}\sin(wt) + v_0 t + d_0 = \frac{ILCD}{t_{LC}}t - \frac{ILCD}{2p}\sin\left(\frac{2p}{t_{LC}}t\right) + v_0 t + d_0$$

where,	v_0	=	initial lateral velocity (assumed equal to 0 ft/s at lane change start)

d_0	=	initial lateral distance (assumed equal to 0 ft at lane change start). d_0 is referenced to the position of the subject vehicle's centerline, at the start of the lane change, with respect to ILCD.

The evasive steering maneuver (recover maneuver) is represented by a trapezoidal recovery model shown in Figure 2-1.

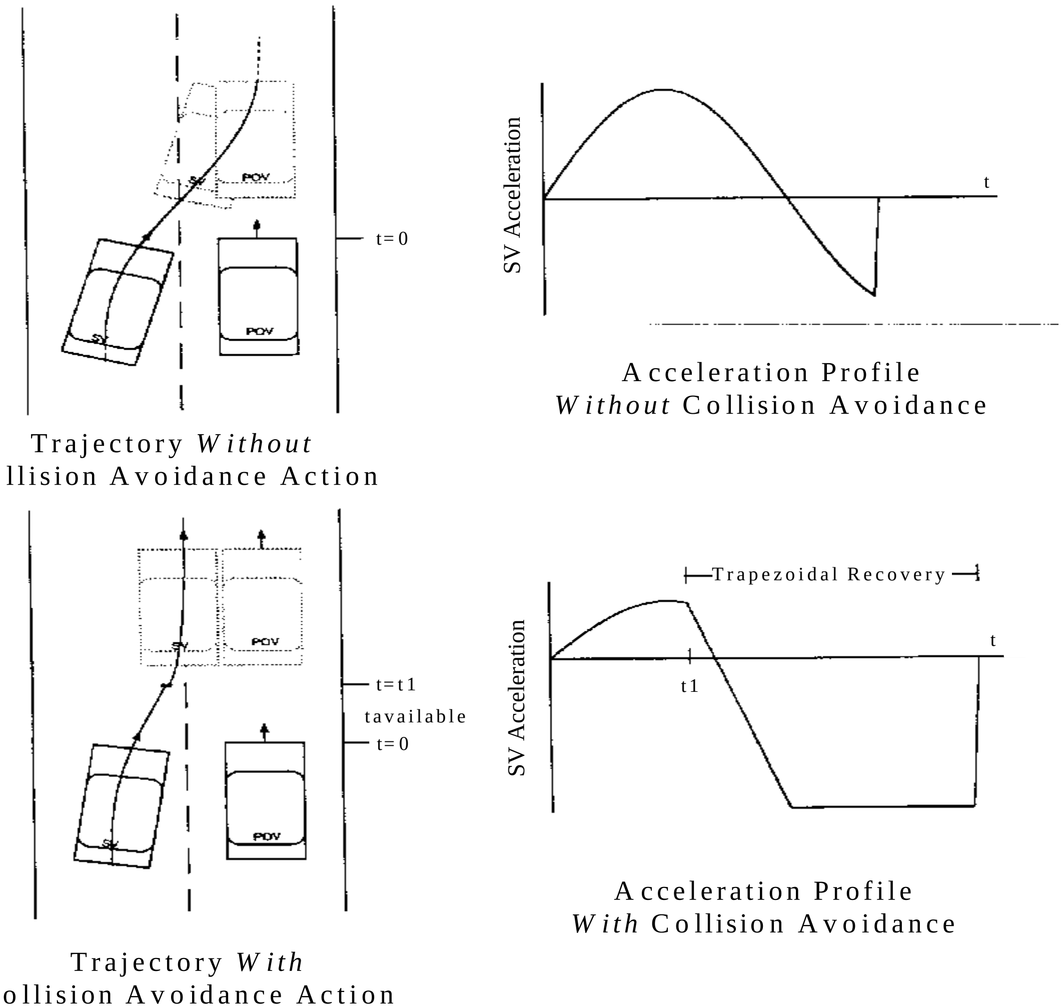


Figure 2-1. Trajectory and acceleration profile of SV with and without crash avoidance (Chovan et al., 1994)

Lateral acceleration for the recovery maneuver is given as,

$$a = \begin{cases} a_0' - kt, & a < a_r . \\ A_r , & otherwise, \end{cases}$$

By successive integrations, lateral velocity and distance are given by the following expressions, respectively:

$$v = \int a\, dt = \begin{cases} a_0' t - \dfrac{kt^2}{2} + v_0', & a < A_r. \\ A_r t + v_0'', & otherwise. \end{cases}$$

$$d = \int v\, dt = \begin{cases} \dfrac{a_0' t^2}{2} - \dfrac{kt^3}{6} + v_0' t + d_0', & a < A_r. \\ \dfrac{A_r t^2}{2} + v_0'' t + d_0'' & otherwise. \end{cases}$$

For all three equations,

a	=	instantaneous lateral acceleration
k	=	rate of change in recovery acceleration buildup in $ft/s^2/s$
A_r	=	peak recovery acceleration (away from the POV)
t	=	elapsed time
a_0'	=	lateral acceleration at the beginning of the recovery maneuver
v_0'	=	lateral velocity at the beginning of the recovery maneuver
v_0''	=	lateral velocity when maximum recovery acceleration is achieved
d_0'	=	lateral distance at the beginning of the recovery maneuver
d_0''	=	lateral distance when maximum recovery acceleration is achieved

2.6.4 Lane Change Crash Avoidance (LCAVOID) Simulation Program

Chovan et al. (1994) conducted a study that examines the maximum time available to avoid a lane change crash hazard. Different crash hazard scenarios were simulated in a program called LCAVOID which uses the lane change and recovery maneuver models to calculate the maximum response time available ($t_{available}$) for each scenario. A crash never occurs in LCAVOID; therefore, $t_{available}$ is the maximum response time available to avoid a crash. Additionally, the proportion of the population that can generate such a response time was calculated for each scenario. Lane change crash scenarios are simulated from user inputs which include:

- Resolution or number of calculation samples per second

- Maximum recovery acceleration (A_r) in g's
- Rate of change in acceleration during recovery (k) in g's per second
- Range of intervehicle gap (LATGAP) at lane change start in feet
- Range of intended lane change distances (ILCD) in feet
- Range of lane change times (t_{LC}) in seconds

The $t_{available}$ value is determined under two conditions: (1) lateral velocity, v, = 0 and (2) total lateral distance traveled, d, < LATGAP. LCAVOID assumes that the driver is warned at the start of a lane change; therefore, $t_{available}$ is the available time from the time of warning onset to the time of recovery maneuver initiation. The two components included in $t_{available}$ are the SCAS delay ($t_{SCAS\ delay}$) and driver steering reaction time ($t_{driver\ RT}$). SCAS delay is the time that accounts for the crash avoidance system to recognize a crash hazard and trigger a warning. The driver reaction time is the maximum allowable steering reaction time for the driver to recognize a warning and provide a steering input that initiates a recovery maneuver resulting in crash avoidance. The relationship of these components is illustrated in Figure 2-2.

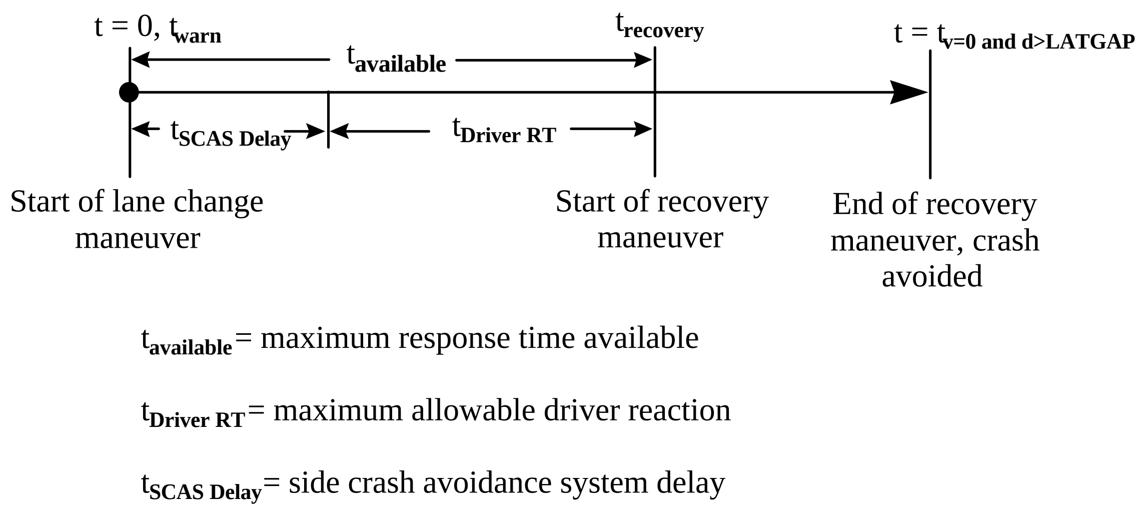


Figure 2-2. Time line of lane change crash hazard scenario for LCAVOID.

If the value of either of these two parameters is known, the proportion of drivers who can avoid a particular crash scenario can be estimated. Chovan et al. (1994) uses a log normal function of steering reaction to estimate the proportion of drivers with surprise steering reaction times less than or equal to the maximum allowable $t_{driver\ RT}$:

$$Z(t_{driver\ RT}) = \frac{\ln(t_{driver\ RT}) - (-0.240)}{0.287}$$

Given the maximum response time available and the SCAS time delay, the driver reaction time can be calculated as follows:

$$t_{driver\ RT} = t_{available} - t_{IVHS\ delay}$$

Using the same equations, an SCAS may be designed such that it fits a desired proportion of driver population, i.e. those that have less than or equal to a particular driver reaction time.

2.6.5 Study Examining Warning Onset Rules in LCAVOID

One unpublished study conducted by Tijerina and Hetrick (1996), at NHTSA's Vehicle Research and Test Center (VRTC) in Ohio, evaluated the potential effectiveness of two warning onset rules for SCAS. These are algorithms that determine when a driver should be warned of a crash hazard when conducting a lane change maneuver. The two warning onset rules evaluated are the minimum-separation rule and the turn-signal onset rule for SCAS. These rules were evaluated using LCAVOID, requiring some modifications to the program.

Chovan et al.'s version of LCAVOID assumes that an SCAS warning is triggered at the start of a lane change maneuver. LCAVOID was modified to provide a warning based on a particular onset rule which may be prior to or after the start of the lane change depending on the particular crash hazard scenario. The latest version of LCAVOID provides an opportunity to evaluate different warning onset rules rather than assuming that warning onset is at the start of the lane change (See Figure 2-3). The warning onset time (t_{warn}) is no longer assumed to be zero, representing the start of a lane change maneuver. In the modified LCAVOID, it represents the latest possible time that a driver must be warned to initiate a recovery maneuver that results in an avoided crash. In addition to calculating the maximum time available to avoid a crash, the modified LCAVOID calculates the crash avoidance potential (CAP) or sample population probability of avoiding a crash given a cumulative distribution of lane change parameters collected from a sample population.

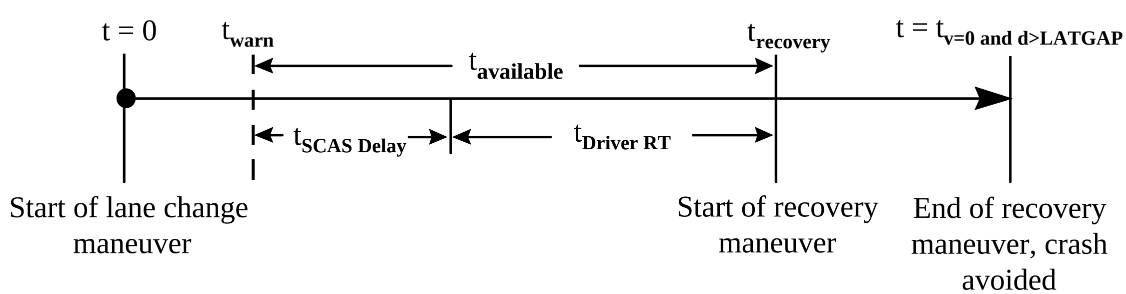


Figure 2-3. Time line of modified LCAVOID in which the time of warning is not necessarily at the start of the lane change but rather at the time that the warning onset algorithm is met.

At VRTC, a small-scale instrumented vehicle study was conducted to collect on-the-road lane change data. Empirical probability mass estimates of lane change time (t_{LC}), inter-lane change distance (ILCD), lateral gap (LATGAP), and turn-signal onset (TSO) time were used to define the conflict scenarios simulated in LCAVOID. This method uses an effectiveness estimation process. LCAVOID does not simulate each lane change individually, but rather the distribution of lane change parameters across a sample of lane changes. In each iteration, a conflict situation was simulated to determine both the maximum time available for driver surprise reaction time to the warning and the crash avoidance potential.

For the range of conditions modeled, the results of the NHTSA study indicate that the minimum separation rule is unlikely to provide substantial crash avoidance benefits without an unacceptable probability of nuisance alarms. On the other hand, the turn-signal activation rule, which has no nuisance alarms (with the exception of a scenario described earlier in Section 2.6.1), appears to hold great promise in supporting SCAS implementation for those drivers who use their turn-signals. Although turn-signal use may possibly be increased due to SCAS implementation, it is unlikely to ever reach 100% and remain there.

3. METHODOLOGY

The research method was divided into two phases: (1) on-the-road study to quantify lane change behavior and (2) simulation of lane change crash hazard scenarios to evaluate five warning onset rules in LCAVOID. These phases are illustrated in Figure 3-1. The "normal" lane change data collected in the first phase was simulated in the second phase to define parameters of crash hazard scenarios. The five warning onset rules simulated included: turn-signal onset (TSO), minimum separation (MS), line crossing (LC), tolerance limit (TL), and time-to-line crossing (TLC).

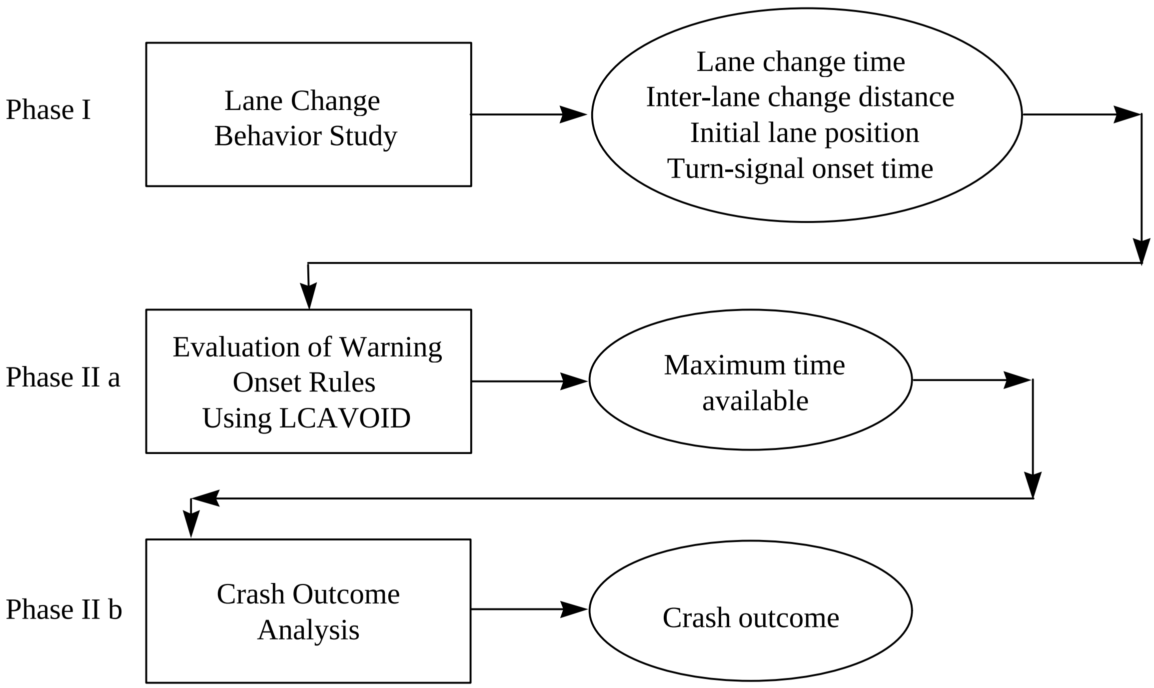


Figure 3-1. Phases of research.

3.1 On-the-Road Lane Change Behavior Study

The lane change behavior study was a field study conducted on public roadways where research participants drove an instrumented vehicle. The vehicle was equipped to collect data on lane changes performed by each participant on two different roadtypes in the Town of Blacksburg, Virginia. The first roadtype was in the business district of Blacksburg, and the second roadtype was on the 460-Bypass, an unlimited access highway in Blacksburg. For simplicity, the first roadtype will be called "city streets" and the second roadtype will be called "highway." It is important to recognize that this study was conducted on roadways of a mid-size town, which does not represent typical city streets or major highways. Each roadtype is defined by particular attributes which will be explained later in Section 3.1.6. Resulting from this study are the following lane change parameters for each lane change observed:

- Lane change time (t_{LC})
- Inter-lane change distance (ILCD)
- Lateral lane position at lane change start w.r.t. lane line (dLine)
- Turn-signal onset time (TSO)

This data provided only a baseline for lane change behavior. These results would be expected to change under conditions in which conflict scenarios were used to test actual SCAS.

3.1.1 Test Participants

Participants for this experiment were recruited through the Virginia Polytechnic Institute & State University Center for Transportation Research. A total of 16 licensed drivers participated in this experiment. Eight were within the ages of 18 and 25, and eight were within the ages of 65 and 75. Within each age group, half of the subjects were male and half were female. Each subject was required to pass a preliminary screening by telephone (See Appendix A). This ensured that their health conditions were suitable for the study and that they understood their responsibilities prior to participating in the study. Additionally, upon arriving for the study, each participant was required to complete a health, medication, and drug questionnaire to screen for immediate conditions that could suggest the participant was at a greater than normal risk. All potential subjects were determined qualified to participate in the study.

3.1.2 Apparatus

The vehicle used in this experiment was a 1995 Aurora, provided by the Virginia Tech Center for Transportation Research. It was equipped with instrumentation to record data during the experimental drive. The specific instrumentation recorded the following parameters at a rate of ten cycles per second:

- Time from start of data collection (seconds)
- Steering position (radians)
- Distance of vehicle to right lane line (meters)
- Distance of vehicle to left lane line (meters)
- Turn-signal activation
- Lane change type which served as event markers to indicate the start and end of a lane change maneuver in a data stream (instructed left and right and non-instructed, left and right)
- Visual allocation to mirrors: video with time stamp
- Driving scene ahead: video with time stamp
- Lane position with respect to right lane line: video with time stamp

3.1.3 Experimental Conditions

The lane change crash type is one that typically occurs under "ideal" circumstances. For this reason, as well as for safety considerations, all data were collected under conditions of dry pavement and daylight. The same ride-along observer rode in the passenger's seat in the instrumented vehicle for all subjects. The observer's duties were to operate test equipment, look out for hazardous conditions, and direct the driver on the predetermined route. The observer's primary role was to serve as an accompanying passenger providing directions to a particular destination, rather than an experimenter, in order to provide a more natural environment.

3.1.4 Preliminary Experimental Tasks

Upon arrival, the participant was asked to show a valid driver's license. The participant read and signed the informed consent form (See Appendix B). The participant was then issued a brief health, medication, and drug questionnaire to screen for immediate conditions that could suggest the participant was at a greater than normal risk (See Appendix B). If the participant met the screening requirements, the experimenter proceeded to provide instructions about the experimental drive.

3.1.5 Test Instructions

Before beginning the experimental drive, the subject was given a vehicle briefing as well as instructions concerning the first part of the drive (See Appendix C). The experimenter informed the participant that the purpose of the research was to collect data on normal driving behavior. The participant was unaware that lane change data in particular was collected. The driver was instructed to drive in a normal manner, conducting lane changes when it was appropriate and safe. Since the participant was told to listen for the observer's directions on the predetermined route, talking was prohibited. He or she was instructed to make turns cautiously, remaining in the appropriate lane through the turn. After the oral instructions were administered, the test participant proceeded to begin the drive on the city streets. Upon completion of the city street data collection, the subject was provided with instructions concerning the highway data collection (See Appendix C). Again, the subject was instructed to conduct turns conservatively because he or she would be asked to turn off the highway so that the computer could be reconfigured. The participant was instructed to drive in the right lane unless otherwise told to do so or unless he or she desired to pass a slower moving lead vehicle.

3.1.6 Experimental Drive

The procedure involved observation and collection of data from lane change maneuvers performed by each test participant while driving the instrumented vehicle. Each participant drove along a predetermined route in which all lane changes would be conducted only on straight-aways. The predetermined route prompted each subject to perform approximately 24 lane changes: six left and six right, on city streets; and six left and six right, on the highway. City streets included streets in the Blacksburg, VA business district on RT-460, traveling westbound. The highway included the RT-460 bypass in Blacksburg. City streets were undivided with speed limits between 35 and 45 mph, and the highway was divided with a speed limit of 55 mph. Total driving time was approximately one-and-a-half hours.

During the city street data collection, lane changes were prompted by instructions to turn off Main Street (RT-460), as if accompanied by a passenger providing directions to a particular destination. For example, if the driver was in the right lane and was instructed to turn left, a left lane change maneuver was required to perform that task. The route was laid out so that a certain number of left and right lane changes were performed by each test participant. At the beginning of the experiment the driver was instructed to remain in the appropriate lane through turns to maximize safety. However, this was actually so that particular lane changes would be prompted. After the driver turned left, he or she was instructed to turn right, prompting a right lane change. If the driver made a wide turn, from the left lane, onto the next road in the right lane, a right lane change would be missed. Most participants adhered to the instructions; however, due to habit or preoccupation, some did not, which resulted in missing data.

During the highway data collection, the same procedure of prompting lane changes by instructions to turn off the highway was used. The driver was told that this was required to "reconfigure the computer" to reduce any inquiries since unlike the city streets, they had to turn off the highway and then turn around to return to the highway. Another way of prompting lane changes, right lane changes in particular, was when the driver turned left onto the highway, he or she was required to change lanes to adhere to the initial instructions of remaining in the left lane through a turn as well as instruction to drive in the right lane except when passing. Some lane changes were performed at the discretion of the driver such as when passing. At random times throughout the highway session, the presence of slower moving lead vehicles prompted the driver to pass, requiring both left and right lane changes.

The lane change scenarios on both city streets and the highway were created by indirect prompts by the ride-along observer. The driver was never directly instructed to change lanes; rather, the various methods mentioned above were used to prompt lane changes. These methods concealed the fact that lane change behavior, in particular, was being observed.

3.1.7 Data Reduction

After the lane change data were collected, they were reduced into a form that was suitable for manipulation in LCAVOID. The raw data were data points collected every ten seconds during each experimental drive. The first task was to determine the start and end of each lane change performed by each subject. This required using a plotting program called DXQPlot which plotted all data points for specified parameters in a continuous graph. Five parameters were plotted: lane change type, steering position, distance to left lane line, distance to right lane line, and time from start of data collection. All parameters were plotted on the y-axis, except for time, which was plotted on the x-axis. The lane change event markers were easily detected while panning through the graph. Upon reaching an event marker, the graph was more closely examined to determine the start and end of a lane change using steering position, distance to left lane line, and distance to right lane line. This required certain pattern recognition such as changes in slope of the lines representing distance to left and right lane lines which were accompanied by steering inputs. The lane change parameters for the start and end of each lane change were used to calculate lane change time (t_{LC}), inter-lane change distance (ILCD), turn-signal onset (TSO), and warning distance (dWarn) values for LCAVOID input.

3.2 Simulation of Lane Change Data and Warning Onset Rules in LCAVOID

Using the lane change data collected from the experimental drive, five warning onset rules were simulated: minimum separation (MS), line-crossing (LC), tolerance-limit (TL), turn-signal onset (TSO) and time-to-line crossing (TLC). A description of each rule is listed in Table 3-1. This study involved integrating real world data into a simulation that models driver behavior during a lane change crash avoidance maneuver. Such behavior would be expected to change under conditions in which actual conflict scenarios are created. Since it is unsafe to create real world crash hazards, these hazards were simulated in LCAVOID, an analytical model developed by Chovan, Tijerina, Alexander, and Hendrick (1994) and modified by Tijerina in 1996.

Previously, warning onset rules were evaluated at NHTSA using the modified LCAVOID. Empirical mass probability estimates were used to generate crash hazard scenarios for a sample population. The same version of LCAVOID was used to evaluate the five potentially effective warning onset rules for SCAS. Because each warning rule was simulated with each lane change, probability estimates were not used. Rather, lane change time (t_{LC}), inter-lane change distance (ILCD), and turn-signal onset (TSO) time for each lane change defined crash hazards. The crash avoidance potential was not used since it was calculated using probability estimates.

Table 3-1. Alternate SCAS Warning Onset Rules.

SCAS Warning Rule Name	Warning Rules	Data Needs	Comments
Turn Signal Onset (TSO)	If turn signal activated and obstacle present, then warn; otherwise, no warning	SCAS sensor of obstacle, turn signal state	Potentially effective but will not work when turn signal not used (non-use, drift, POV encroaching)
Minimum Separation (MS)	If SV-POV separation less than x feet, then warn; otherwise, no warning	Range between SV and POV	Unlikely to be effective without excessive or nuisance alarms; may help with slow drift
Line-Crossing (LC)	If SV touches or exceeds lane line, warn if obstacle is present; otherwise, no warning	SCAS sensor to detect lane line, obstacle presence detection	Does not take into account SV-POV separation, SV lateral velocity, but may have some benefit
Time-to-Line-Crossing (TLC)	If TLC < t seconds, and obstacle present, then warn; otherwise, no warning	Lane position, lateral velocity sensors, obstacle presence capability	Has had some impact on evaluation in Europe; holds promise, may be difficult to implement practically
Tolerance Limit (TL)	If current lane position falls outside of tolerance limit, and obstacle present, then warn; otherwise, no warning	SCAS obstacle detection, lane position sensing only	Does not take into account SV-POV separation, SV lateral velocity, but may have some benefit

3.2.1 Minimum Separation Rule

The minimum separation (MS) rule triggers a driver warning whenever the Subject Vehicle (SV) and Principal Other Vehicle (POV) come within a predetermined minimum separation distance (dMS). Because the modified version of LCAVOID does not warn at the start of a lane change, it requires a value or rule that determines when a warning will be triggered. For the minimum separation rule, warning distance (dWarn) is this value. It is the minimum allowable distance between the Subject Vehicle (SV) and the Principal Other Vehicle (POV) at which a warning would be triggered. By definition, dWarn is equal to dMS. When evaluating onset rules based on distance parameters, only the initial SV position with respect to the POV, LATGAP, and the lateral distance that the SV moved at the time of warning, dTraveled, define the crash hazard scenario. Lane lines do not exist in LCAVOID. Therefore, dWarn is always calculated as follows:

$$dWarn = LATGAP - dTraveled$$

For the MS rule, the lane positions of the SV and the POV are irrelevant; only the distance between the two vehicles is of concern as illustrated in Figure 3-2. For example, in a crash hazard defined by a LATGAP of 4 feet and a dWarn or MS rule of 3 feet, the SV is warned 1 foot into the lane change maneuver.

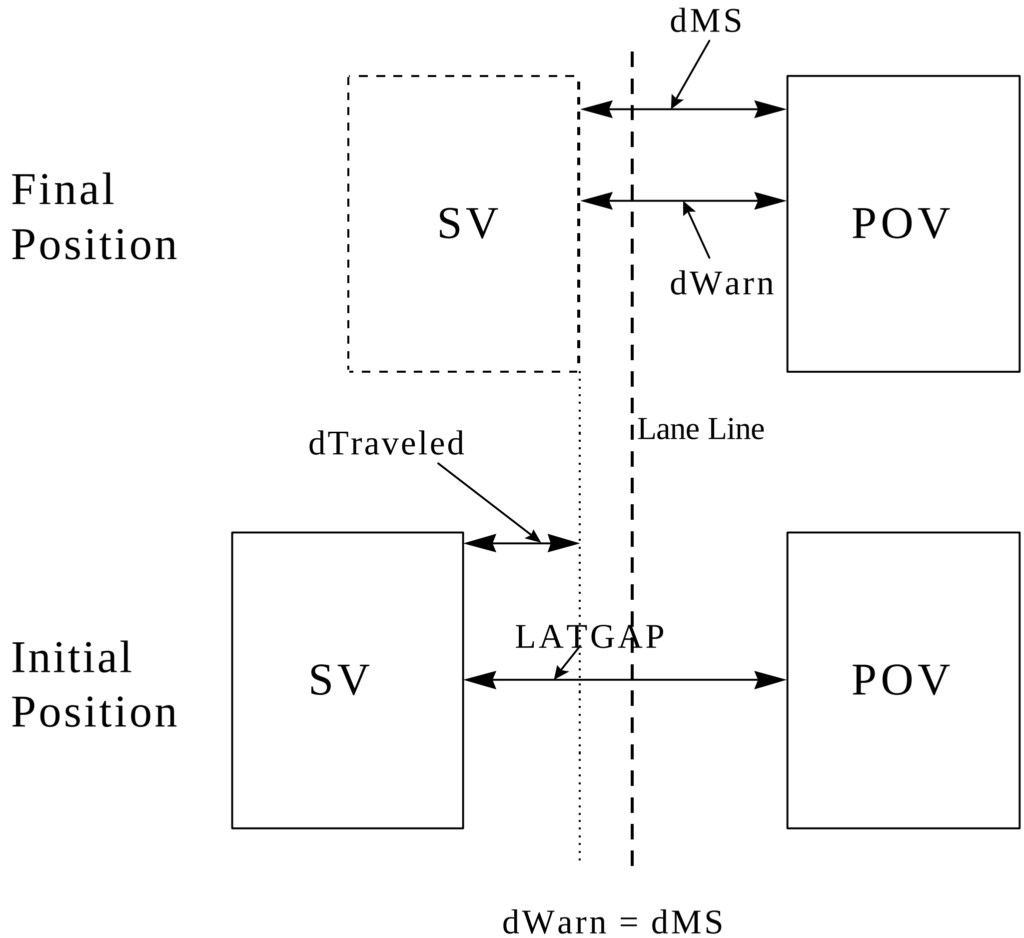


Figure 3-2. LCAVOID crash hazard scenario using minimum separation rule.

3.2.2 Turn-Signal Onset Rule

The turn-signal onset (TSO) rule triggers a driver warning when the driver activates the turn-signal indicator and there is a vehicle in the blind spot. The turn-signal onset rule does not use dWarn in LCAVOID since it is a rule based on time rather than distance. Turn-signal onset is the time of turn-signal activation with respect to the lane change start time of zero seconds. Consequently, a negative onset value indicates turn-signal activation prior to lane change start, while a positive value indicates turn-signal activation after lane change start.

3.2.3 Line-Crossing

The line crossing (LC) rule triggers a driver warning whenever the vehicle's tire touches the lane line given the presence of a vehicle in the blind spot. According to the Worrall and Bullen distribution of lane position in Figure 3-3 , lane change executions typically begin much earlier. Therefore, the line crossing rule may provide a less than timely warning; i.e., the driver may be too far into the maneuver to effectively and safely counteract a crash hazard.

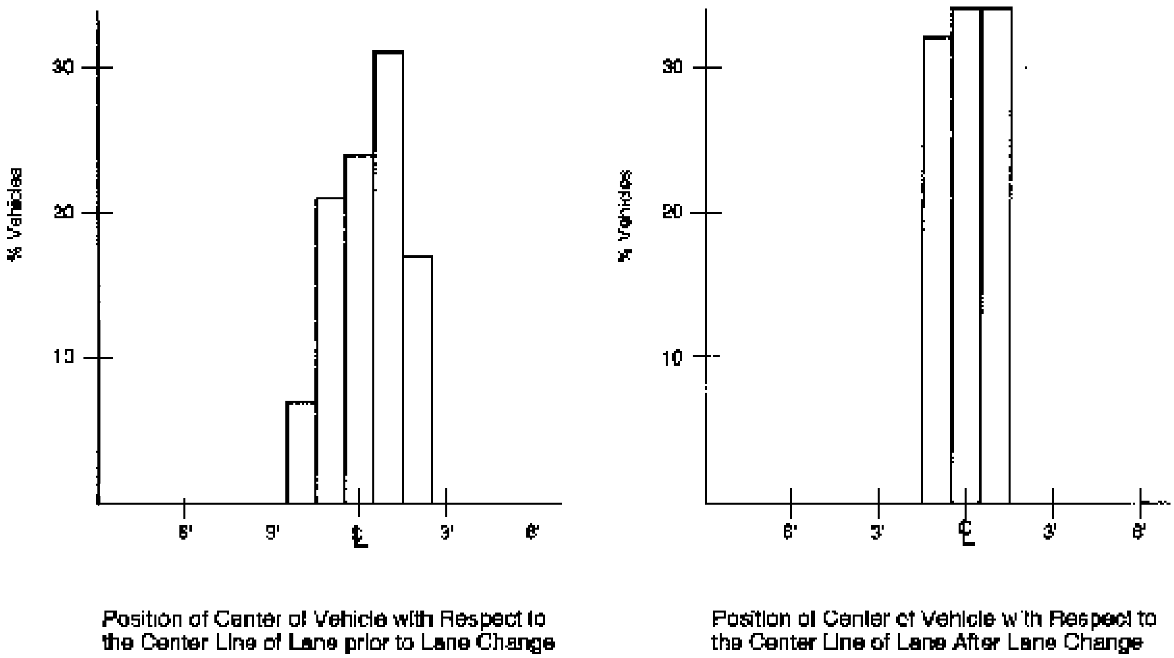
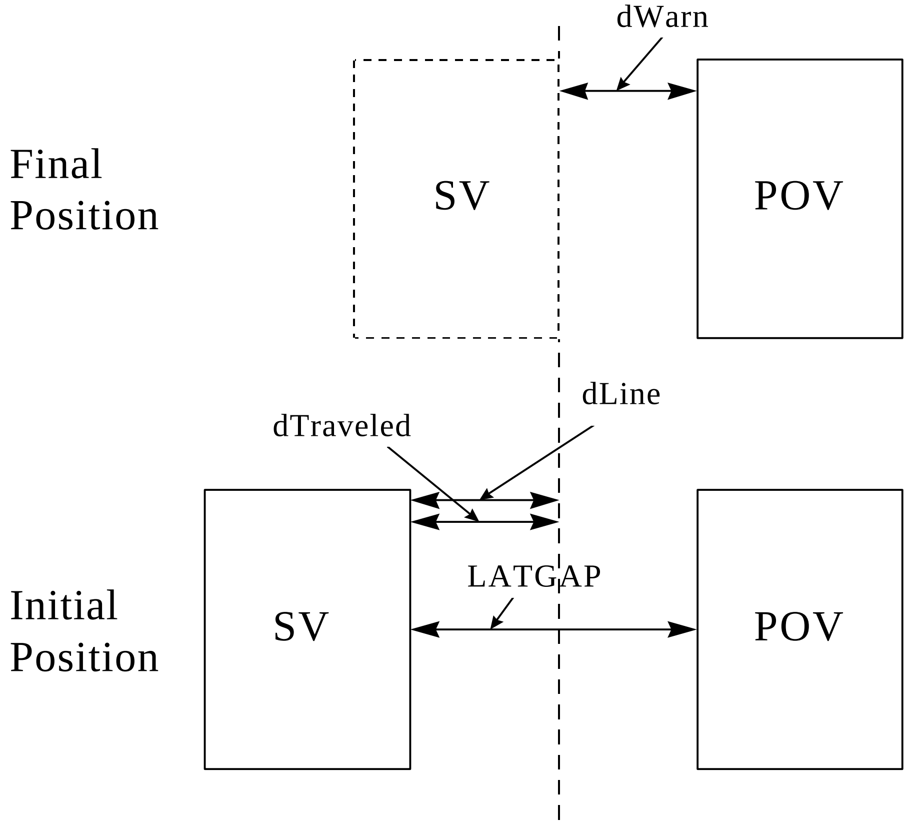


Figure 3-3. Distribution of lane positions at start and end of lane change maneuver (Worrall and Bullen, 1970). These histograms were interpreted to indicate lane position such that being closer to the y-axis meant a vehicle was closer to the centerline separating the SV and POV.

Without further modifications, the latest version of LCAVOID may also be used to assess the line crossing. Like the minimum separation rule, this rule is based on distance; however, unlike the minimum separation rule, lane position of the SV is important when using the line crossing rule. Since LCAVOID only considers the distance between SV and POV and not lane position, the dWarn value must be set at the distance between the POV and the lane line, given the SV is at the lane line (See Figure 3-4).



dWarn = LATGAP - dLine

Figure 3-4. LCAVOID crash hazard scenario using line crossing rule.

3.2.4 Tolerance-Limit Rule

A tolerance-limit (TL) rule triggers a driver warning based on lateral position with respect to lane center. When the current lane position deviates or falls outside of a given tolerance limit (99%) and there is a vehicle in the blind spot, a SCAS warning is triggered. The tolerance-limit rule is based on the idea that lanekeeping occurs at lane center and any deviation from lane center by a predetermined amount constitutes lane change intent. Consequently, it does not account for personal driving style which may increase nuisance alarms for those who do not lanekeep along the center of the lane. Not only might the tolerance limit rule be helpful in driver warning for lane change crashes, but it may also detect drifting which is almost never indicated by activation of turn-signals. However, it would only warn for drifting if there is a vehicle in the proximal adjacent lane; otherwise, it would cease to be a SCAS and would become solely a drift detector.

The tolerance-limit (TL) rule of 99% is calculated using the following equation:

$$x = \mu \pm Z\sigma$$

where μ = mean lane position = 0 ft wrt lane center
σ = standard deviation of lane position = 1 ft
$\alpha = 0.01$

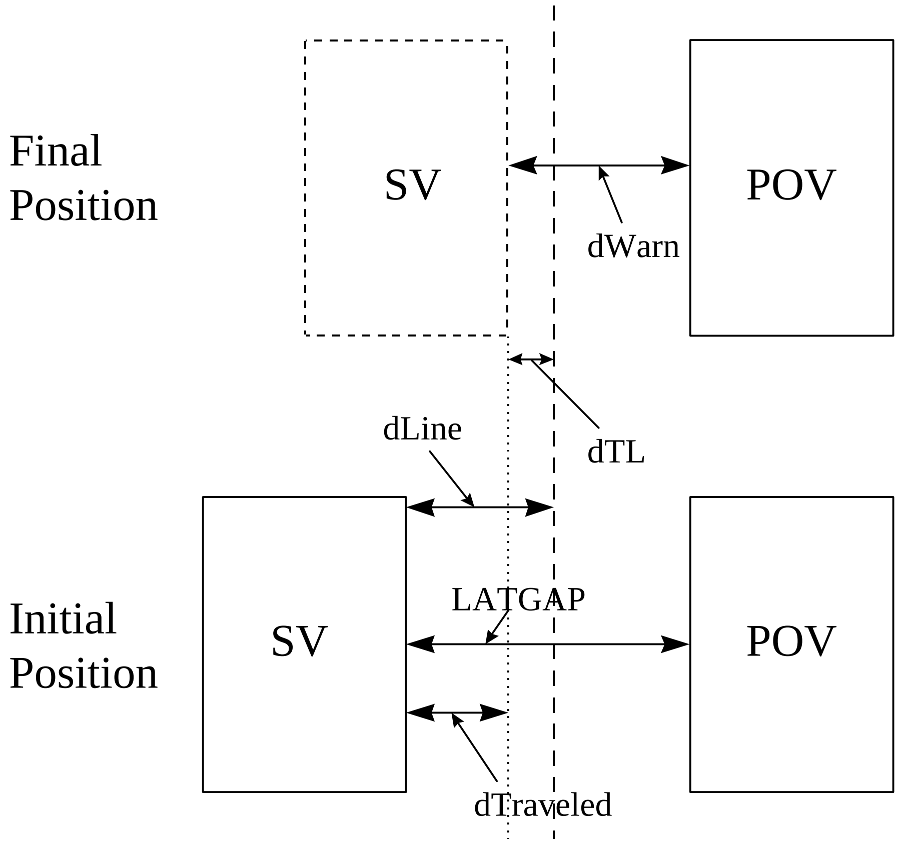
$P(x - z_{\alpha/2} < Z < x + z_{\alpha/2}) = 1 - \alpha$

$1 - \alpha/2 = 1 - 0.01/2 = 0.995$

$P(-2.575 < Z < 2.575) = 0.99$

$Z = 2.575$

Therefore, the lane position of the vehicle may vary about lane center 2.575 feet to the left and right, i.e., a warning is triggered when the vehicle falls outside of tolerance limits. Given the mean lane position is at lane center, standard lane width of twelve feet, and vehicle width of six feet, the tolerance limit (dTL) is calculated as follows: (12-6)/2 - 2.575 = 0.425 ft, about five inches from the lane line. Defining the tolerance limit rule in LCAVOID works in a way that is similar to the line crossing rule. Since LCAVOID does not consider lane position, the dWarn value must be set at the distance between the POV and the tolerance limit boundary, given the SV is at the tolerance limit boundary (See Figure 3-5).



dWarn = LATGAP - (dLine - dTL)

Figure 3-5. LCAVOID crash hazard scenario using tolerance limit rule.

3.2.5 Time-to-Line Crossing Rule

The time-to-line crossing (TLC) rule is different from the other warning onset rules since the lateral dynamic motion of the vehicle is continuously measured. TLC is based on both lateral distance to the lane line (d_{line}) and lateral velocity:

$$TLC = \frac{d_{line}}{v_y}$$

As the vehicle moves toward the lane line, the distance to the lane line decreases, while velocity increases due to lateral buildup; thus, TLC decreases . The warning threshold is the minimum allowable time-to-line crossing or time it takes to touch the lane line. When TLC decreases or drops to the warning threshold (TLC=threshold), a warning is triggered if a vehicle is in the adjacent lane. By definition, the TLC rule warns earlier than the LC rule since the LC rule is equivalent to TLC=0 sec.

The lane change behavior data was used to determine the TLC warning threshold. It was based on the cross times (t_{line}) or time at line crossing of all the lane changes, which was calculated on a spreadsheet using the lane change model equations mentioned in Section 2.6.3. The lowest 1% or fastest cross times determined this threshold. Subtracting this threshold from the cross time of each lane change provided the time at which a warning would be triggered or when TLC = threshold. Using the lane change model spreadsheet, the distance traveled, which corresponds to the TLC (dTLC) of each lane change, was calculated. An illustration of the application of this rule is shown in Figure 3-6.

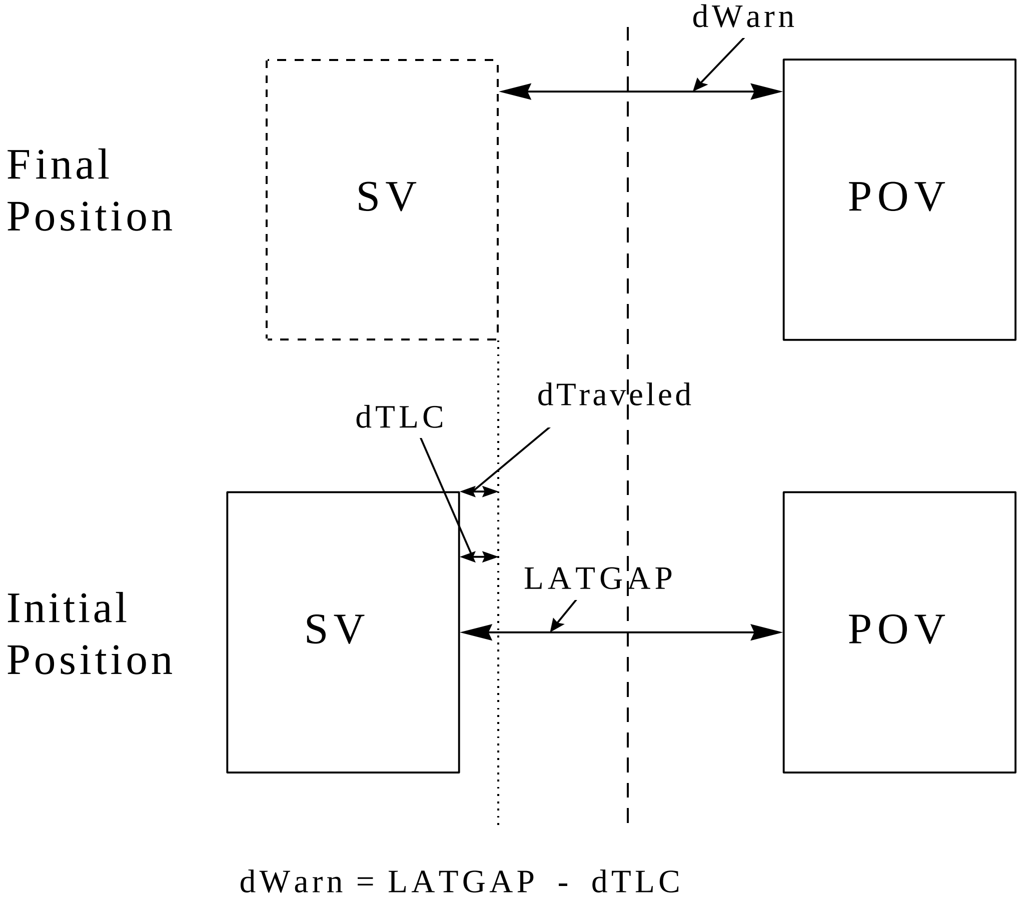


Figure 3-6. LCAVOID crash hazard scenario using time-to-line crossing rule.

4. DATA ANALYSIS

There are two parts to the data analysis. The first part involved evaluation of the on-the-road lane change behavior data. The second part involved feeding the lane change behavior data into a simulation program called LCAVOID to evaluate five warning onset rules for SCAS.

4.1 Analysis of Lane Change Behavior

Common in any field study with a limited amount of control, the number of lane changes performed varied according to traffic and test participant. Furthermore, the data collected on city streets was insufficient for evaluation since the lane lines were difficult to track. This was a problem particular to city streets and not highways, since their lane lines are not well painted or are more heavily traveled given the higher volume of traffic. On the city streets, there are also sections where a lane line does not exist because of parking lots or adjoining streets. Although there was insufficient city street data to include in a general linear model, city street data is included in overall distributions of lane change parameters as well as percentage of crash avoidance for evaluating the warning onset rules. The distribution of lane changes for different conditions is shown below:

	City	**Highway**	**Unplanned**	**Total**
No. of Lane Changes	28	164	90	**282**

Unplanned lane changes are those that subjects performed without indirect prompting from the experimenter. No lane changes were performed by direct instructions to do so.

This experiment did not include any on-the-road conflict situations or SCAS instrumentation; therefore, the results of this study provide only a baseline for lane change behavior. The results would be expected to change in actual tests of an SCAS. In studies that include conflict situations and an SCAS system, one might expect driver behavior to change. In addition to providing baseline data, the lane change behavior data served as input into a simulation program to evaluate the five warning onset rules for SCAS: turn-signal onset (TSO), minimum separation (MS), line crossing (LC), tolerance limit (TL), and time-to-line crossing (TLC).

4.1.1 Experimental Design for Evaluating Lane Change Behavior

The design configuration is a three-factor, mixed experimental design:

Factor	Description	Levels
A	Age of driver	2; young, old
D	Direction of lane change	2; left, right
C	Lane change order	6; 1, 2, 3, 4, 5, 6

Structural Model:

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \delta_k + \gamma_{l(i)} + \alpha\beta_{ij} + \alpha\delta_{ik} + \beta\delta_{jk} + \alpha\beta\delta_{ijk} + \beta\gamma_{jl(i)} + \delta\gamma_{kl(i)} + \beta\delta\gamma_{jkl(i)} + \varepsilon_{m(ijkl)}$$

Independent Variables:

- Age of driver
- Direction of lane change
- Lane change order

Dependent Variables:

- Lane change time (t_{LC})
- Inter-lane change distance (ILCD)
- Lateral lane position at lane change start w.r.t. lane line (dLine)
- Turn-signal onset time (TSO)

General linear models (GLM) were used to generate analysis of variance (ANOVA) tables for each of the dependent variables. ANOVAs were used to test for significant main effects and interactions (See Section 5.1).

4.2 Analysis of Five Warning Onset Rules

Using the methods outlined in Section 3.2, five warning onset rules were simulated at seven different levels of initial LATGAP, 3 feet through 9 feet. Each condition was simulated as the lane change crash hazard scenario for each lane change performed in the lane change behavior study. Since the lane change behavior study was not conducted under conditions for actual SCAS testing, the results of this analysis would be expected to change otherwise.

4.2.1 Modeling Parameters in LCAVOID

Crash hazard scenarios were defined in LCAVOID using lane change behavior parameters from the on-the-road study as well as parameters determined by other studies. Rice and Dell'Amico (1974) found mean peak lateral acceleration values during an evasive steering maneuver to range from 0.4 g to 0.6 g for average drivers. Chovan et al. (1994) used maximum recovery accelerations of 0.4 g, 0.55 g, and 0.7 g to represent mild, moderate, and aggressive steering maneuvers, respectively. They suggest that a maximum recovery acceleration of 0.4 g with an associated rate of recovery deceleration of 0.4 g/s represents an aggressive driver response, but is mild with regard to emergency maneuvers. Only one value of maximum recovery acceleration and one value of rate of recovery deceleration were used in this study to generate a response to the five warning onset rules. To account for the less aggressive drivers, values of 0.4 g and 0.4 g/s were chosen. In the study conducted by Tijerina and Hetrick (1996), resolution samples of rates of 1, 2, 5, 10, and 20 were manipulated. The differences between 10 and 20 samples per second were substantially less than between 10 samples per second and 5 samples per second. Frequent updates less than10 samples per second are likely to degrade performance. SCAS warning delay was chosen to be 0.1 second, and a sample rate of 20 samples per second was chosen. These modeling parameters and their corresponding values simulated in LCAVOID are listed in Table 2-1.

Table 4-1. Summary of modeling parameters for LCAVOID simulation of crash hazard scenarios.

Parameter	Value
Lateral Gap (LATGAP) in feet	3 to 9
Inter-Lane Change Distance (ILCD) in feet	Lane change behavior data
Lane Change Time (t_{LC}) in seconds	Lane change behavior data
Warning Distance (dWarn) in feet *	Lane change behavior data
Turn Signal Onset Time (TSO) in seconds *	Lane change behavior data
Resolution in cycles per second	20
SCAS delay in seconds	0.1
Maximum Recovery Acceleration (A_r)	0.4 g
Rate of Recovery Deceleration (k)	0.4 g/s

*Note: dWarn was calculated using equations outlined in the Methodology Section.
** Note: TSO was used only for evaluating the TSO rule. Negative values indicated TSO prior to lane change start, and positive values indicated TSO after lane change start.

4.2.2 Experimental Design for Evaluation of Five Warning Onset Rules

The design configuration is a two-factor within-subjects experimental design:

Factor	Description	Levels
W	Warning onset rule	5; turn-signal onset, minimum separation, line crossing, tolerance limit, time-to-line crossing
L	Lateral gap (LATGAP)	7; 3, 4, 5, 6, 7, 8, 9 ft

Independent Variables:
- Warning onset rule
- LATGAP

Dependent Variables:
- maximum time available for recovery maneuver (max $t_{available}$)

Structural Model:
$Y_{ijklmn} = \mu + \alpha_i + \beta_j + \gamma_k + \alpha\beta_{ij} + \alpha\gamma_{ik} + \beta\gamma_{jk} + \alpha\beta\gamma_{ijk} + \varepsilon_{l(ijk)}$

General linear models (GLMs) were used to generate analysis of variance (ANOVA) tables for maximum time available (See Section 5.2). The first GLM contained two different minimum separation rules of 3 feet and 4 feet in addition to the four other warning rules. The second GLM contained the five warning onset rules, using only the significantly better of the two minimum separation rules (MS=4) as evaluated in a Student-Newman-Keuls (SNK) test to represent the MS rule. ANOVAs were used to test for significant main effects and interactions. SNK tests were used to test for significant differences among factor level means of maximum time available for warning onset rule and LATGAP.

4.2.3 Analysis of Crash Outcome for Evaluation of Five Warning Onset Rules

In addition to evaluating the warning onset rules using maximum time available as the measure of merit, the dichotomous crash outcome of a particular crash hazard scenario was used as a measure of merit. When simulating a crash hazard scenario in LCAVOID, a crash never occurs. The output is always maximum time available to avoid the crash. To assess the crash outcome, a particular reaction time was assigned to each lane change, i.e. a certain proportion of the population was represented in the study. The driver reaction time is no longer the maximum allowable reaction time since crash outcome is being evaluated. Driver reaction times that represent fast, moderate, and slow surprise steering reaction times, respectively, are the 5th, 50th, and 95th percentile driver population reaction times. They can be calculated using the following log normal model given by Chovan et al.(1994):

$$Z(t_{driver\ RT}) = \frac{\ln(t_{driver\ RT}) - (-0.240)}{0.287}$$

$$t_{driver\ RT} = t_{available} - t_{SCAS\ delay}$$

Using the log normal model above results in the following values for 5th, 50th, and 95th percentile $t_{driver\ RT}$ with Z-values of -1.645, 0.000, and 1.645, respectively:

$$t_{driver\ RT} = 0.4908 \text{ s at 5th percentile}$$
$$t_{driver\ RT} = 0.7866 \text{ s at 50th percentile}$$
$$t_{driver\ RT} = 1.2613 \text{ s at 95th percentile}$$

Using the maximum response time available ($t_{available}$) generated from LCAVOID for each lane change crash hazard scenario, the driver reaction time, and the SCAS delay (0.1 seconds), the crash outcome for each scenario was calculated as follows:

$$\text{if } t_{available} - t_{SCAS\ delay} - t_{driver\ RT} \geq 0\text{, crash is avoided}$$

Because certain proportions of the driving population were represented, the experiment changes to a between-subjects design configuration. The rationale is that each subject represents a certain proportion of the population; thus, he or she cannot represent different proportions simultaneously. Driver reaction time is a factor nested in subjects. Additionally, a crash outcome is a terminal situation, i.e. a crash occurs or a crash is avoided. The same subject cannot be used to evaluate each lane change crash hazard scenario since subjects do not have "nine lives."

Independent Variables:

- Warning onset rule
- LATGAP
- Age
- Direction

Dependent Variables:

- Crash outcome (crash occurrence or crash avoidance)

To test for significant effects on crash outcome, a Chi-Square test was conducted for each factor.

5. RESULTS

5.1 Results of Lane Change Behavior Study

The ANOVA tables generated from the general linear models for each dependent variable indicate that there were no significant main effects at an α level of 0.05 (See Table 5-1 through Table 5-4). Thus, age of driver, lane change order, and direction of lane change maneuver are not significant factors of lane change time, inter-lane change distance, initial lane position, and turn-signal onset time. The only significant interaction was lane change order crossed with driver age when ILCD was the dependent variable. This shows that there may have been learning effects between younger and older drivers. After more lane changes had been performed, older drivers who tended to overshoot (See Section 5.1.1) may have learned how to control the vehicle better when changing lanes as time progressed.

Table 5-1. ANOVA table of lane change behavior data with dependent variable : t_{LC} in seconds. Significant effects are denoted by an asterisk (*), α=0.05.

Source of Variation	df	SS	MS	F	p
<u>Between</u>					
Age (A)	1	7.477	7.477	0.89	0.3618
S/A	14	117.763	8.412		
<u>Within</u>					
Direction of lane change (D)	1	0.005	0.005	0.00	0.9735
D x A	1	3.685	3.685	0.87	0.3669
D x S/A	14	59.342	4.239		
Lane change order (C)	5	24.117	4.823	2.15	0.0706
C x A	5	2.879	0.576	0.26	0.935
C x S/A	65	145.901	2.245		
D x C	5	23.686	4.737	2.14	0.0765
D x C x A	5	25.670	5.134	2.32	0.0576
D x C x S/A	47	103.841	2.209		

Table 5-2. ANOVA table of lane change behavior data with dependent variable: ILCD in feet. Significant effects are denoted by an asterisk (*), α=0.05.

Source of Variation	df	SS	MS	F	p
Between					
Age (A)	1	1.207	1.207	0.19	0.6728
S/A	14	90.814	6.487		
Within					
Direction of lane change (D)	1	0.458	0.458	0.30	0.5923
D x A	1	0.089	0.089	0.06	0.8124
D x S/A	14	21.331	1.524		
Lane change order (C)	5	4.096	0.819	0.96	0.4468
C x A	5	12.080	2.416	2.84*	0.0221
C x S/A	65	55.264	0.850		
D x C	5	6.683	1.337	1.77	0.1381
D x C x A	5	4.177	0.835	1.10	0.3708
D x C x S/A	47	35.553	0.756		

Table 5-3. ANOVA table of lane change behavior data with dependent variable: dLine in feet. Significant effects are denoted by an asterisk (*), α=0.05.

Source of Variation	df	SS	MS	F	p
Between					
Age (A)	1	0.010	0.010	0.00	0.9486
S/A	14	32.844	2.346		
Within					
Direction of lane change (D)	1	2.696	2.696	1.69	0.2143
D x A	1	0.556	0.556	0.35	0.5641
D x S/A	14	22.306	1.593		
Lane change order (C)	5	2.321	0.464	0.99	0.4292
C x A	5	4.633	0.927	1.98	0.0931
C x S/A	65	30.401	0.468		
D x C	5	2.285	0.457	1.12	0.3635
D x C x A	5	1.717	0.343	0.84	0.5280
D x C x S/A	47	19.203	0.409		

Table 5-4. ANOVA table of lane change behavior data with dependent variable: TSO in seconds. Significant effects are denoted by an asterisk (*), α=0.05.

Source of Variation	df	SS	MS	F	p
Between					
Age (A)	1	1.469	1.469	1.25	0.2821
S/A	14	16.434	1.174		
Within					
Direction of lane change (D)	1	1.605	1.605	1.01	0.3309
D x A	1	4.879	4.879	3.08	0.1009
D x S/A	14	22.149	1.582		
Lane change order (C)	5	5.518	1.104	1.54	0.1920
C x A	5	1.013	0.203	0.28	0.9213
C x S/A	61	43.828	0.718		
D x C	5	2.048	0.410	0.40	0.8433
D x C x A	5	2.871	0.574	0.57	0.7258
D x C x S/A	38	38.585	1.015		

5.1.1 Distribution of Lane Change Parameters

The distribution of vehicle lane position at the start of a lane change maneuver shown in Figure 5-1 is consistent with Worrall and Bullen’s lane position data in Figure 3-3. Most of the lane changes observed began with a vehicle position at lane center, 0 feet, or at one foot from lane center opposite the direction of lane change intent. One might think that most drivers would begin closer to the lane line, but the discrepancy may be due to a general desire to begin further rather than closer to other vehicles traveling in the adjacent lane. No drivers began the lane change maneuver at the lane line, but some were found to be within a foot of the lane line.

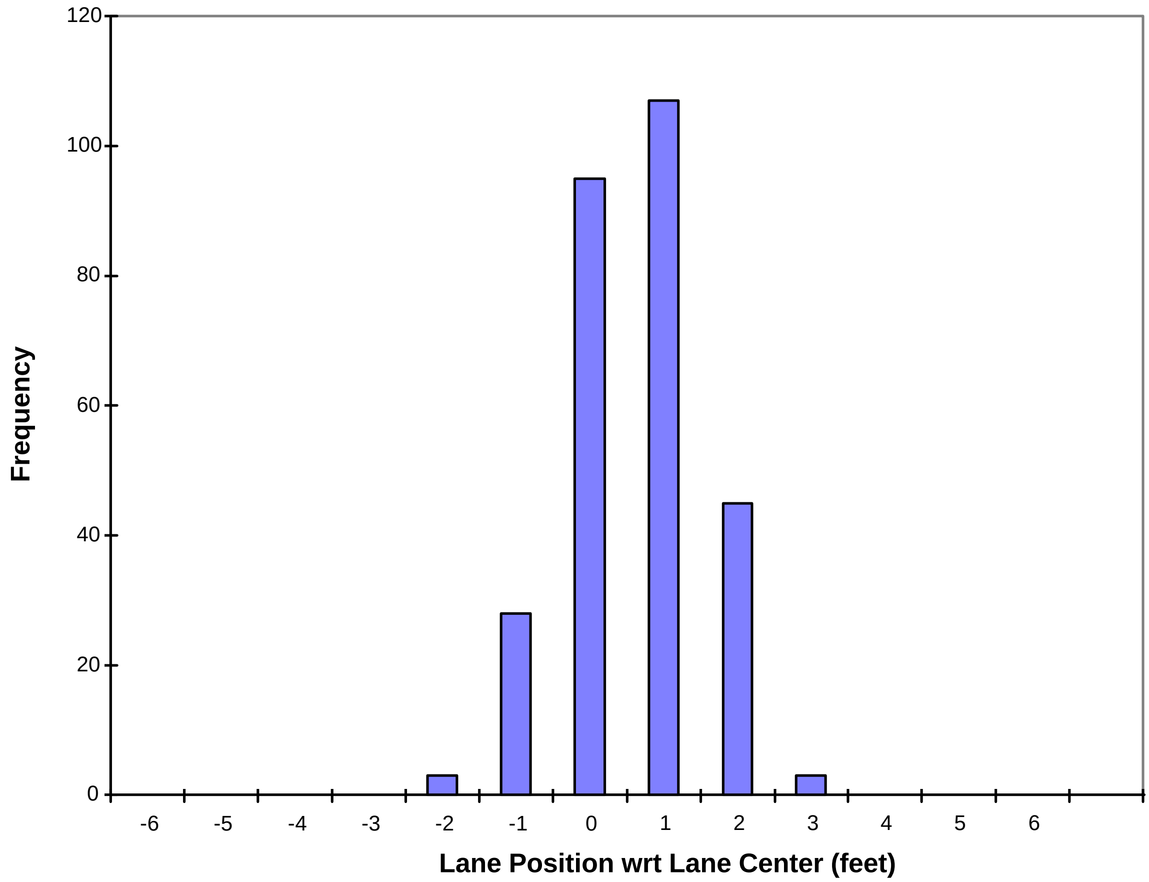


Figure 5-1. Distribution of 282 vehicle lane positions at lane change start with respect to lane center at 0 feet . Y-axis represents centerline separating the SV and POV.

The distribution of lane change times ranged from 3.41 to 13.62 seconds (See Figure 5-2). Younger drivers accounted for the majority of lane change times ranging from 3.41 to 6.60 seconds, while older drivers accounted for the majority of lane change times of 12.98 to 13.62 seconds. This could be expected since younger drivers tend to be more aggressive in changing lanes. A larger data set might show age to be a significant main effect of lane change time; however, this particular data set shows no significant effects for lane change time. The complete range of lane change times is not as wide as the range of 2 to 16 seconds, which was used in the study conducted by Chovan et al. (1994); however, it is consistent with the range found from Tijerina and Hetrick (1996) of 2 to 14 seconds. The lane change time of 6 seconds was observed most frequently, which also agrees with Tijerina et al.'s distribution of lane change time.

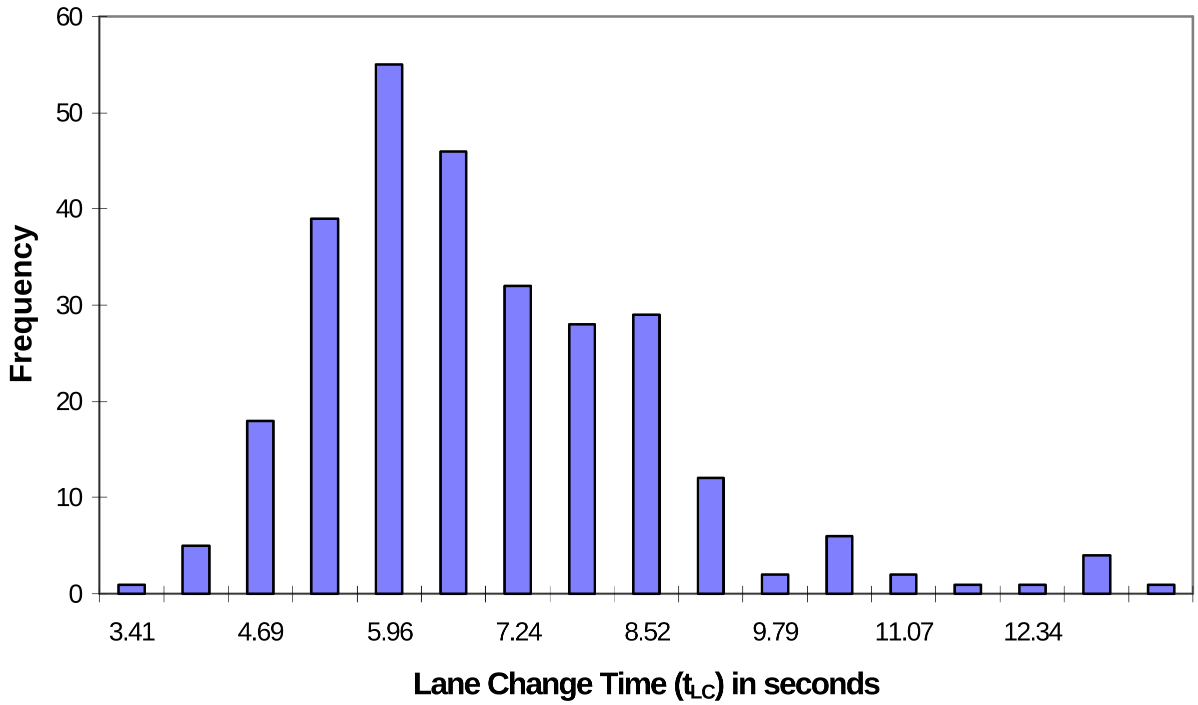


Figure 5-2. Distribution of lane change time in seconds of 282 lane changes.

As indicated in Figure 5-3, the distribution of inter-lane change distance ranged from 8.84 to 15.19 feet, with 12 feet being the most frequently observed. This is probably due to the fact that lane width is generally 12 feet; thus, to travel from lane center of one lane to lane center of the adjacent lane, the driver must travel 12 feet. The distribution of ILCD between older and younger drivers was as expected: older drivers accounted for a majority of the ILCD's ranging from 13.2 to 14.79 feet, and younger drivers accounted for a majority of the ILCD's ranging from 10.83 to 12.81. This shows that older drivers tend to overshoot when changing lanes, possibly due to difficulty with hitting an unmarked target, the center of the lane or a large target between the lane lines. A larger data set might show age to be a significant effect of ILCD. As mentioned earlier, the interaction of age with order of lane change was found to be a signifcant interaction for ILCD. Compared with Tijerina et al's distribution of ILCD, this study has very similar results (not considering age).

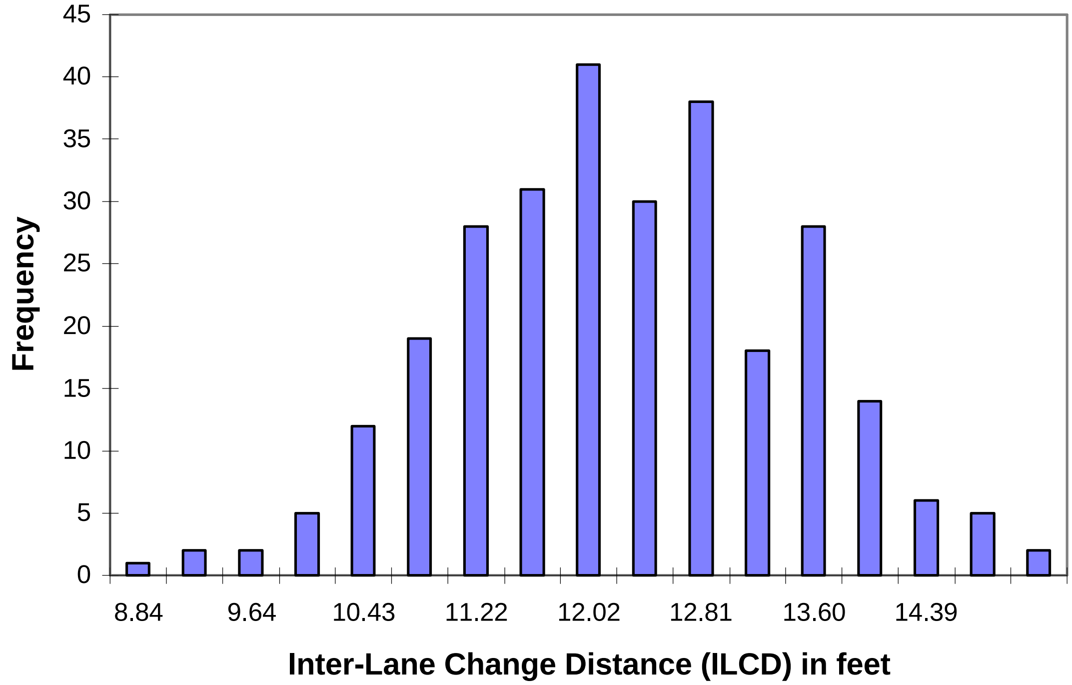


Figure 5-3. Distribution of inter-lane change distance (ILCD) in feet.

Drivers generally indicate lane change intent by activating their turn-signal. This tells other drivers to take caution of their intention to change lanes or “asks permission” from other drivers to change lanes. Turn-signal activation is a good habit formed early in a person’s driving career. However, some drivers do not use their turn-signals for a number of reasons. One common and legitimate reason is simply because there are no other proximal vehicles to alert of their intention. Probably the most common, but less acceptable reason is due to bad habit. People usually do not think about turning their turn-signals on, rather they perform this task by habit. Thus, turn-signal activation may be driver behavior specific. In this experiment, 92 percent of the lane changes conducted were indicated by a turn-signal. This percentage was taken from the total number of lane changes performed in the experiment, 282 lane changes. The remaining 22 lane changes without turn-signal activation were performed by six drivers. One driver accounted for more than half of such lane changes, performing 15 lane changes without turn-signal use. Two other subjects each did not use their turn-signal for two lane changes, while the three remaining drivers did not use their turn-signal for one lane change. The experimental setting may also have promoted more turn signal use than might ordinarily occur. If the turn-signal onset rule were applied, this rule would be ineffective for approximately eight percent of the lane changes performed in this study. This eight percent would require the application of a different warning onset rule for the SCAS to be effective.

The turn-signal onset time, or time of turn-signal activation with respect to lane change start at 0 seconds, ranged from as early as -4.28 seconds to as late as 7.04 seconds. These two onset times were considered outliers since the normal distribution ranged from -2.42 to 3.62 seconds. Most turn-signal onsets occurred close to lane change start which shows that it is a good indicator of lane change intent. However, over half the turn-signal activations observed in this study occurred some time after lane change start. This suggests that a turn-signal onset rule may not be completely effective. These results are shown in Figure 5-4.

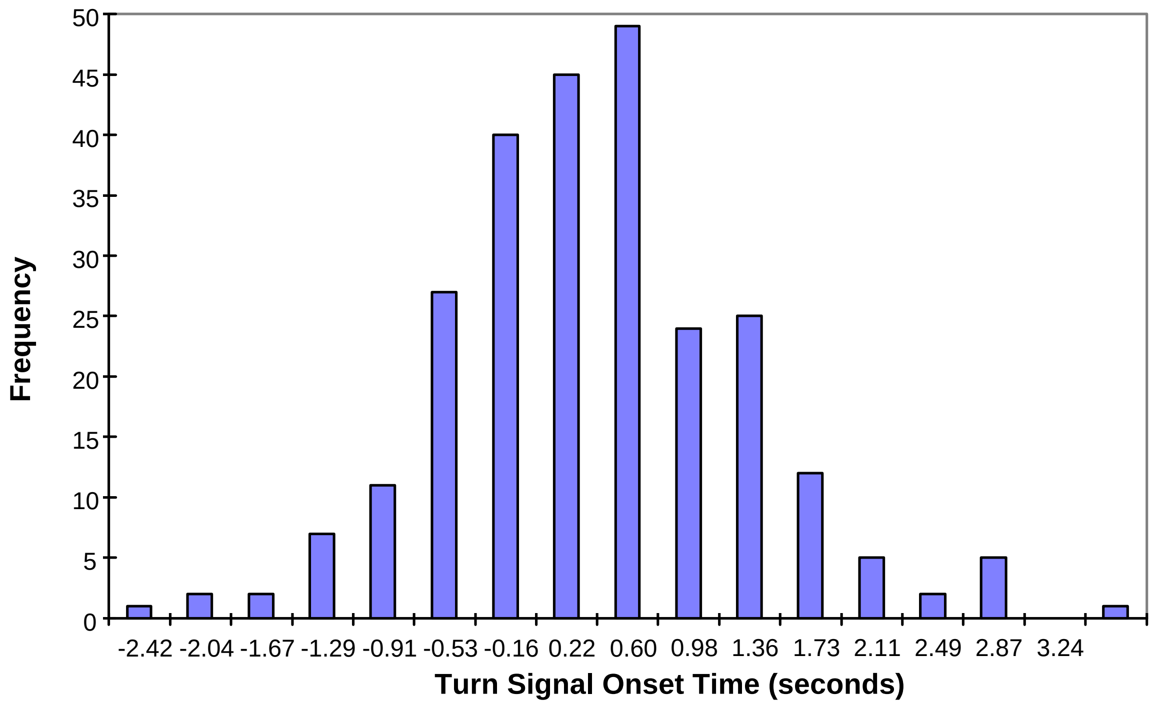


Figure 5-4. Distribution of 260 turn-signal onset times with respect to lane change start at 0.00 seconds. Negative onset time indicates onset before start, and positive onset time indicates onset after start.

5.1.2 Deriving the TLC Warning Threshold

Using the lane change behavior data, the warning threshold for the TLC rule was derived. Because LCAVOID may be checked with a spreadsheet, the distance traveled at a given point in time was easy to calculate. Distance was evaluated at 0.05 increments, or a resolution of 20 increments per second. Using the spread sheet the cross time or time which corresponded with the distance to the lane line was found for each lane change. A distribution of these cross times is shown in Figure 5-5. Given a cumulative distribution of these cross times, the lower 1% was chosen to find the TLC threshold value of 1.25 seconds. Consequently, 99% of the lane changes performed would receive the TLC warning where 1% would not. The 1% represents the three fastest cross times out of the 282 lane changes. Using the lowest 1% as opposed to the lowest 5% is more advantageous since it warns earlier and since 99% rather than 95% of the lane changes performed would receive a warning.

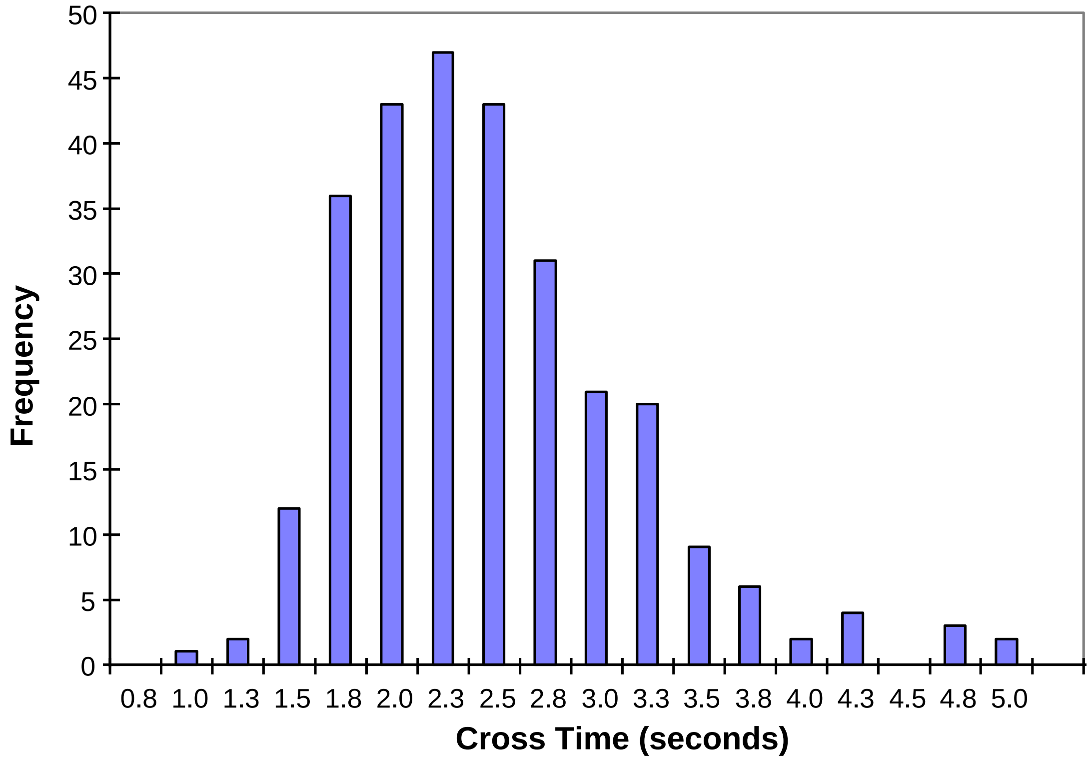


Figure 5-5. Distribution of cross times in seconds. The fastest one percent are indicated at the left end of the chart at 1.3 seconds.

5.2 Results of Warning Onset Rule Evaluation

Two ANOVA tables were generated from two different general linear models (GLMs). The first GLM included six warning rules using two different minimum separation rules at 3 feet and 4 feet in addition to turn-signal onset, line crossing, tolerance limit, and time-to-line crossing. The ANOVA table shown in Table 5-5, which was generated using the first GLM, indicates that warning onset rule, LATGAP, and the interaction of these two variables were significant effects of maximum response time available. A Student-Newman-Keuls (SNK) test was used to test for significant differences in $t_{available}$ means of the six onset rules. The SNK test indicates that the warning rules with the three longest $t_{available}$ means, turn-signal onset (TSO), time-to-line crossing (TLC), and minimum separation of 4 ft (MS4), respectively, had means that were significantly different from each other as well as the remaining rules with shorter maximum time available. The three remaining warning rules were not significantly different from each other according to the SNK test shown in Table 5-6.

Table 5-5. ANOVA table of LCAVOID data with dependent variable: $t_{available}$ in seconds. Minimum separation rules of both 3 ft and 4ft were included. Significant effects are denoted by an asterisk (*), α=0.05.

Source of Variation	df	SS	MS	F	p
Between					
S	15	533.769	35.585		
Within					
Warning onset rule (W)	5	2709.114	541.823	206.23	0.0001*
W x S	75	197.050	2.627		
LATGAP (L)	6	408.301	68.050	174.89	0.0001*
L x S	90	35.019	0.389		
W x L	30	1605.677	53.523	463.76	0.0001*
W x L x S	450	51.935	0.115		

Table 5-6. Student-Newman-Keuls test for dependent variable: $t_{available}$ in seconds (MS3 and MS4 included). Due to unequal sample sizes, the harmonic mean of cell sizes was used to calculate the critical difference values.

SNK Grouping	Mean	N	Warning Rule
A	2.43678	1057	TSO
B	1.59690	1134	TLC
C	1.04549	1148	MS4
D	0.64645	1148	TL
D	0.56932	1148	MS3
D	0.52494	1148	LC

Note: Means with the same letter are not significantly different.

Since the minimum separation rule of 4 feet was significantly better than the MS rule of 3 feet and since there was no significant difference between the MS rule of 3 feet and the two other slower rules, the MS rule of 3 feet was eliminated from further evaluations of warning onset rules. Four feet was the value used to represent the minimum separation rule for the remaining evaluations.

The second GLM, which did not include the MS 3 feet rule, was used to generate a new ANOVA table. The new ANOVA shown in Table 5-7 indicated results similar to the first ANOVA table. Thus, the main effects, warning onset rule and LATGAP, and the interaction of these two factors were significant effects of maximum response time available. A SNK test was used to test for significantly different means between the five warning rules. The same three warning rules with the longest means were found to be significantly different from each other and significantly different from the remaining two rules as shown in Table 5-8.

An SNK test was also used to test for significantly different $t_{available}$ means of the seven levels of LATGAP (See Table 5-9). All means were found to be significantly different except for means of LATGAPs of 4 feet and 6 feet. The LATGAP with the longest $t_{available}$ mean was at 9 feet. As LATGAP decreased, the $t_{available}$ mean significantly decreased. However, when LATGAP decreased to 6 feet, an irregularity occurred since the next highest mean was at 4 feet, not 5 feet. This irregularity is due to the interaction of LATGAP with the minimum separation rule of 4 feet (See Figure 5-9 through Figure 5-11). The maximum time available for this rule has a parabolic behavior such that it is longest at a LATGAP of 3 feet and 4 feet, then drastically reduces at a LATGAP of 5 feet. From there, it gradually decreases until it reaches a LATGAP of 8 feet, where it begins to increase. The reason for this is that at a LATGAP of 3 feet or 4 feet and a MS of 4 feet, a warning is triggered at the start of the lane change. At the start of a lane change maneuver, there is barely any lateral buildup or the lateral velocity is close to 0 ft/sec, as illustrated in Figure 5-8. At a LATGAP of 5 feet and a MS of 4 feet, the vehicle has already moved one foot towards the adjacent lane when the driver is warned, thus lateral velocity increases, decreasing the maximum time available to avoid a crash. The lateral velocity reaches its peak in the middle of a maneuver, then begins to decrease back to 0 ft/sec at the end of the maneuver since the vehicle stops moving laterally. At a LATGAP of 9 feet and a MS of 4 feet, the vehicle will have moved 5 feet. By that time, the lateral velocity has already begun to decrease since it reaches its peak in the middle of the maneuver, 4.5 feet into the maneuver. This decrease in lateral velocity causes the maximum time available to increase. Because this rule has an almost opposite effect on maximum time available as the other rules, an irregularity in the data was found. The drastic reduction at a LATGAP of 5 feet may be what caused the mean maximum time available at 5 feet to be less than at 4 feet.

Table 5-7. ANOVA table of LCAVOID data with dependent variable: $t_{available}$ in seconds. Minimum separation rule of 4ft was only MS rule included. Significant effects are denoted by an asterisk (*), α=0.05.

Source of Variation	df	SS	MS	F	p
<u>Between</u>					
S	15	499.968	33.331		
<u>Within</u>					
Warning onset rule (W)	4	2331.949	582.987	191.13	0.0001*
W x S	60	183.013	3.050		
LATGAP (L)	6	611.159	101.860	211.58	0.0001*
L x S	90	43.329	0.481		
W x L	24	1075.457	44.811	461.73	0.0001*
W x L x S	360	34.938	0.097		

Table 5-8. Student-Newman-Keuls test of significantly different means of warning onset rules for dependent variable: $t_{available}$. Due to unequal sample sizes, the harmonic mean of cells sizes was used to calculate the critical difference values.

SNK Grouping	Mean	N	Warning Rule
A	2.43678	1057	TSO
B	1.59690	1134	TLC
C	1.04549	1148	MS4
D	0.64645	1148	TL
D	0.52494	1148	LC

Note: Means with the same letter are not significantly different.

Table 5-9. Student-Newman-Keuls test for LATGAPs of significantly different means of dependent variable: $t_{available}$.

SNK Grouping	Mean	N	LATGAP
A	1.86543	805	9
B	1.54166	805	8
C	1.28923	805	7
D	1.07913	805	6
D	1.04902	805	4
E	0.92925	805	5
F	0.85689	805	3

Note: Means with the same letter are not significantly different.

5.3 Results of Crash Outcome Analysis

Reaction times representing the 5th, 50th, and 95th percentile driving population were used to produce the outcome of each simulated crash hazard scenario. Those drivers with reaction times less than the given maximum response time available plus SCAS warning delay for a particular crash hazard scenario were considered to be unable to avoid the crash. The proportion of crashes avoided increased for faster reaction times, or as proportion of the population represented decreased.

The Chi-Square tests of independence at an α level of 0.05 indicate that crash outcome was independent of age and direction when representing 50% of the driving population. Crash outcome was also independent of direction when representing 95% of the driving population. Crash outcome, however, was not independent of warning onset rule and LATGAP for all populations represented. These results shown in

Table 5-10 are consistent with the results of the ANOVA tests of significance with maximum time available as the dependent variable. The turn-signal onset rule resulted in the largest proportion of crashes avoided, as the time-to-line crossing rule shortly followed. For all populations represented, these two rules resulted in more crashes avoided than crashes occurred. Of the remaining warning rules, only the minimum separation rule resulted in more crashes avoided than crashes occurred when representing 5% of the driving population. All other rules resulted in more crashes than crashes avoided for all populations represented. These results are shown in Figure 5-6.

Table 5-10. Chi-square test of independence of crash outcome. Crash outcome is not independent of effects denoted by an asterisk (*), α=0.05.

Factor	5th Percentile RT			50th Percentile RT			95th Percentile RT		
	DF	χ^2	p	DF	χ^2	p	DF	χ^2	p
Warning Rule	4	1568.698	0.001*	4	1655.268	0.001*	4	1692.437	0.001*
LATGAP	6	304.656	0.001*	6	254.579	0.001*	6	243.589	0.001*
Age	1	5.406	0.02*	1	2.776	0.096	1	5.502	0.019*
Direction	1	5.850	0.016*	1	6.073	0.140	1	2.151	0.143

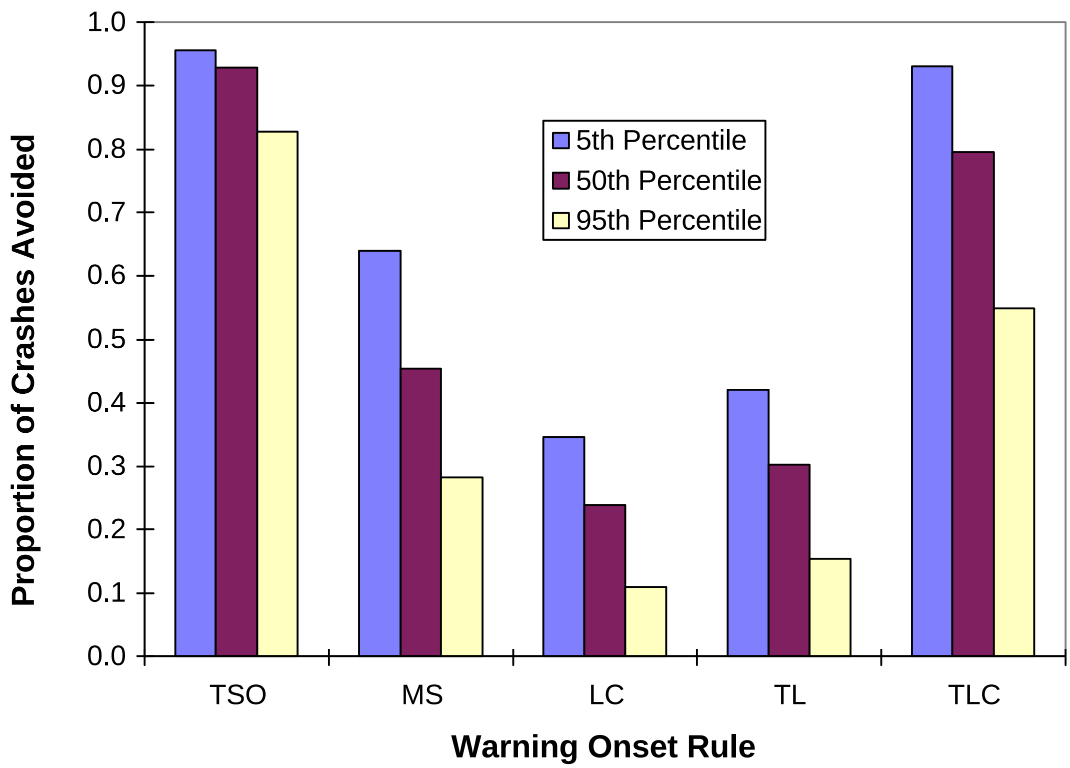


Figure 5-6. Proportion of crashes avoided by the 5th, 50th, and 95th percentile driver population for five warning onset rules.

The results of the effect of LATGAP are shown in Figure 5-7. From a LATGAP of 3 feet to a LATGAP of 5 feet, the proportion of crashes avoided is at its lowest then increases then decreases. At a LATGAP of 5 feet, a trend becomes evident since the proportion of crashes avoided increases as LATGAP increases to 9 feet for all populations represented. The irregularity in the first three LATGAPs may be due to the fact that the SV begins the lane change maneuver when it is relatively close to the POV. The same reasoning can be used in this analysis as described before in analyzing the effects of LATGAP on maximum time available. Consequently, when a warning is triggered, the SV is closer to the POV, yet little time has passed to produce lateral buildup which may be evident in Figure 5-8. At a LATGAP of 5 feet, however, more time has passed from the beginning of the lane change maneuver to when a warning is triggered. Consequently, the lateral buildup may be such that there is a decrease in the proportion of crashes avoided. Additionally, for the minimum separation rule of 4 feet and a LATGAP of 3 feet, the driver did not receive a warning at the 4-foot separation since he began the maneuver at a distance to the POV closer than the MS rule. Therefore, the driver would receive the warning at the beginning of the maneuver. This may be why the proportion of crashes avoided is higher at 3 feet than 5 feet for the 95th percentile population.

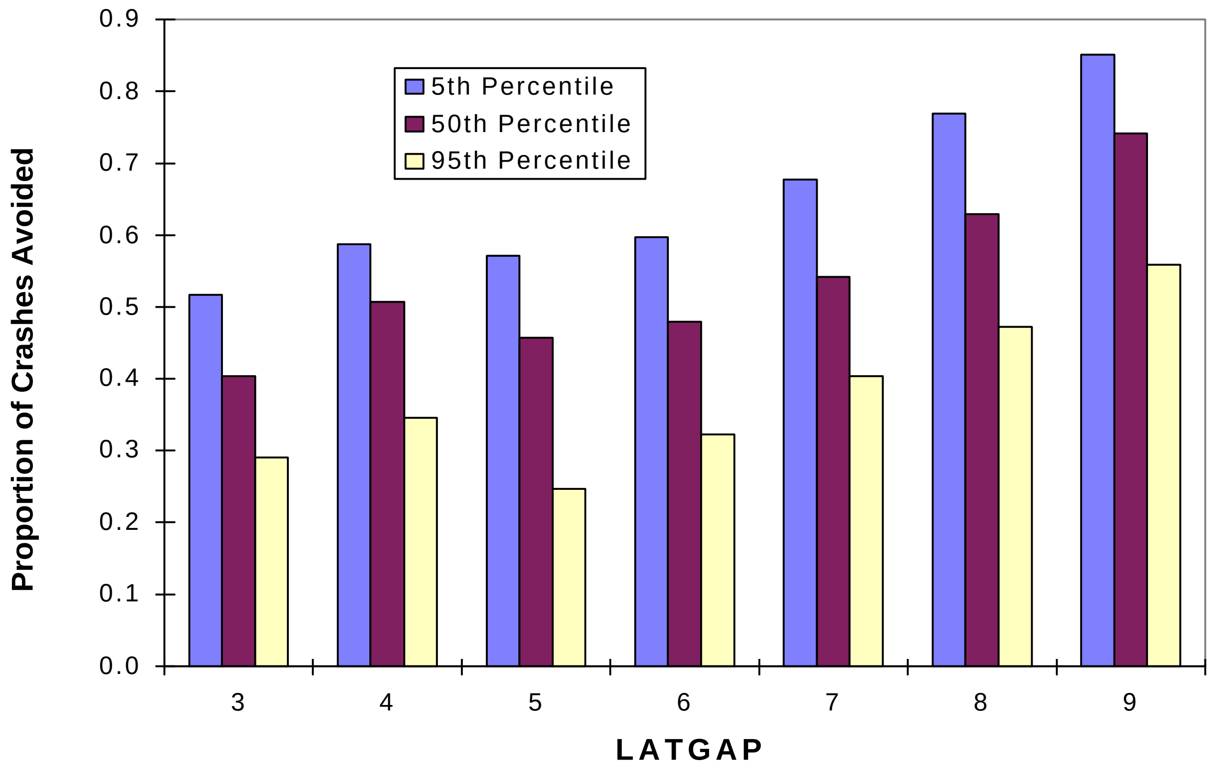


Figure 5-7. Proportion of crashes avoided by the 5th, 50th, and 95th percentile driver population for seven levels of LATGAP.

Examining combinations of different warning onset rules and different levels of LATGAPs results in less obvious trends. As mentioned earlier, the ANOVA tables generated from the GLMs, indicated significant interactions between warning onset rule and LATGAP. The most obvious effects are seen at a LATGAP of 3 feet, where the MS rule percentage of crash avoidance is higher than any other rule (See Figure 5-9 through Figure 5-11). This percentage and all other percentages involving LATGAP-warning rule interactions, were found using all lane changes performed. As LATGAP increases, the MS percentage of crash avoidance sharply decreases then gradually increases at 8 feet. This may due to the parabolic nature of lateral velocity shown in Figure 5-8.

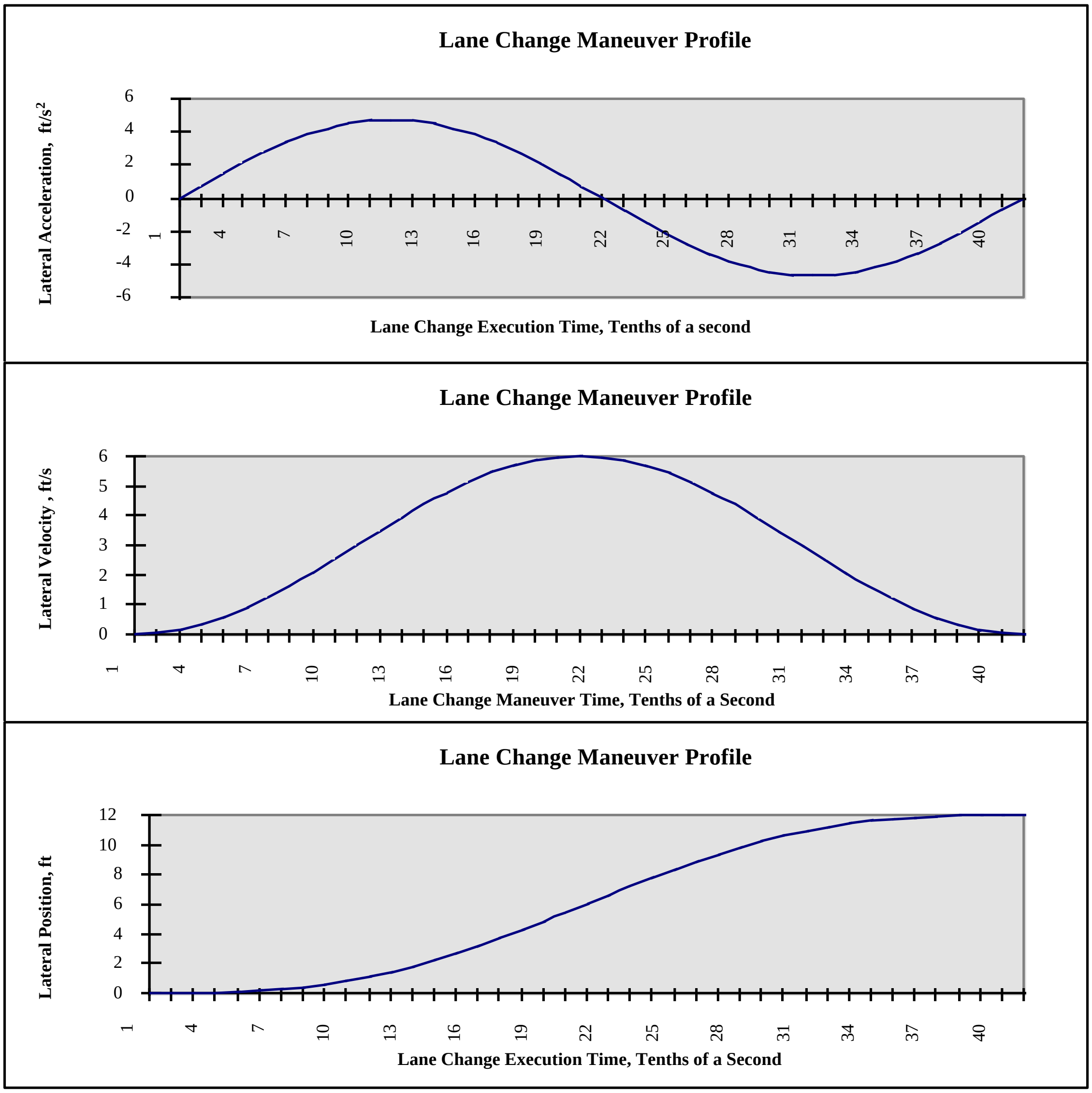


Figure 5-8. Lane change maneuver profiles for lateral acceleration, lateral velocity, and lateral position as a function of time (Tijerina et al., 1996).

In addition to the interesting trend of the minimum separation rule, a notable decrease in the percentage of crash avoidance for the time-to-line crossing rule occurs from the 5th percentile reaction time to 50th percentile reaction time (See Figure 5-9 through Figure 5-11). This may be due to the fact that this rule is based on both distance and velocity, or time to reach a particular point. Subtracting more $t_{driver\ RT}$ and $t_{SCAS\ delay}$ from $t_{available}$ causes a substantial decrease in time-to-line crossing since lateral velocity increases faster than distance as time increases. TLC, however, is consistently higher than the other rules as LATGAP increases.

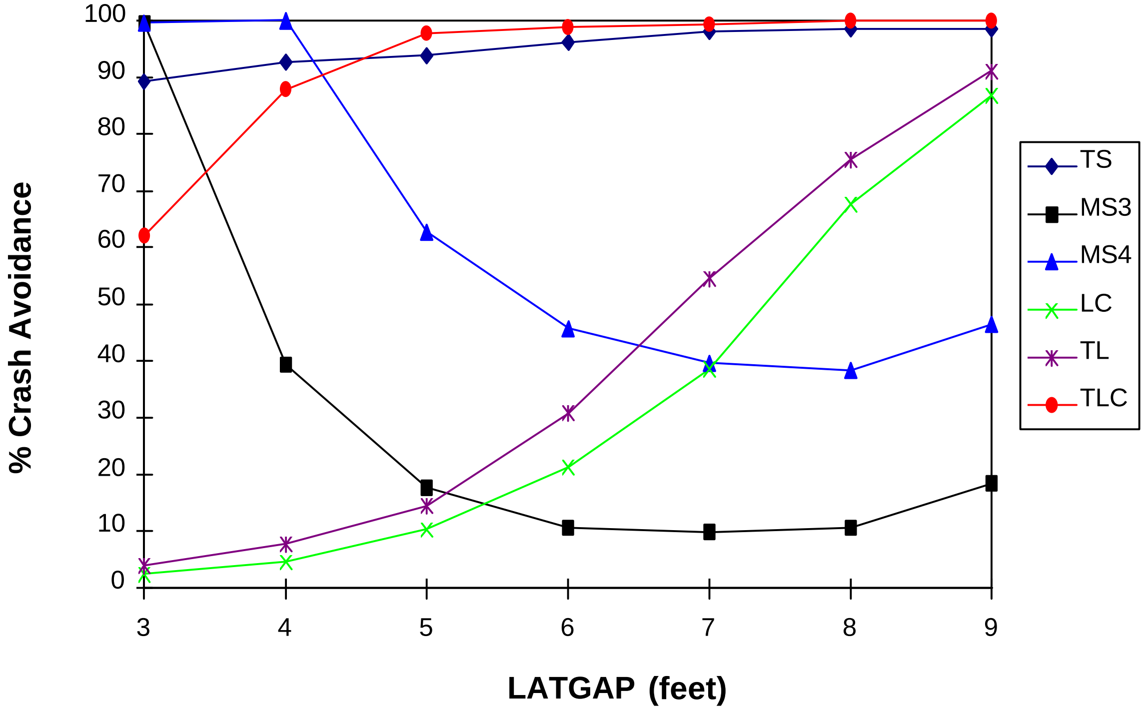


Figure 5-9. LATGAP vs. percentage crash avoidance for each warning rule, given the 5th percentile driver reaction time of 0.4906 seconds. These percentages represent all lane changes performed.

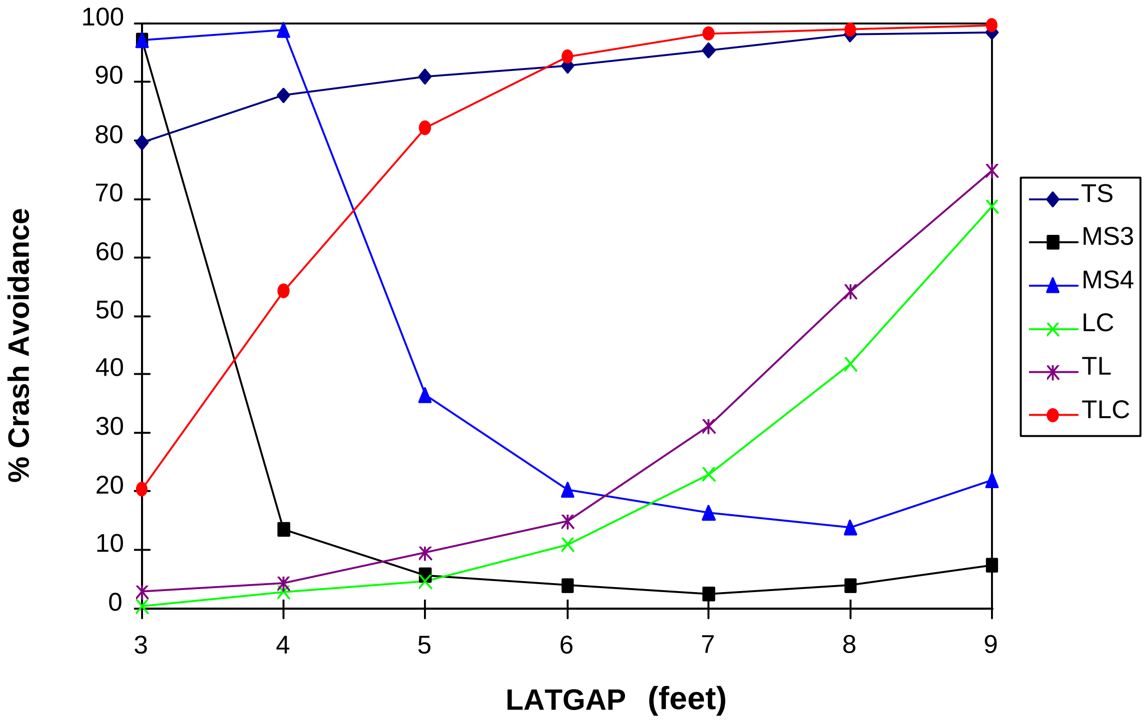


Figure 5-10. LATGAP vs. percentage crash avoidance for each warning rule, given the 50th percentile driver reaction time of 0.7866 seconds. These percentages represent all lane changes performed.

The line crossing and tolerance limit rules show fairly consistent increases in percentage of crash avoidance as LATGAP increases (See Figure 5-9 through Figure 5-11). Because the driver is warned at the same point in the maneuver for all levels of LATGAP for both of these rules, there is less irregularity in time available. Thus a more consistent trend exists in percentage of crash avoidance as LATGAP increases.

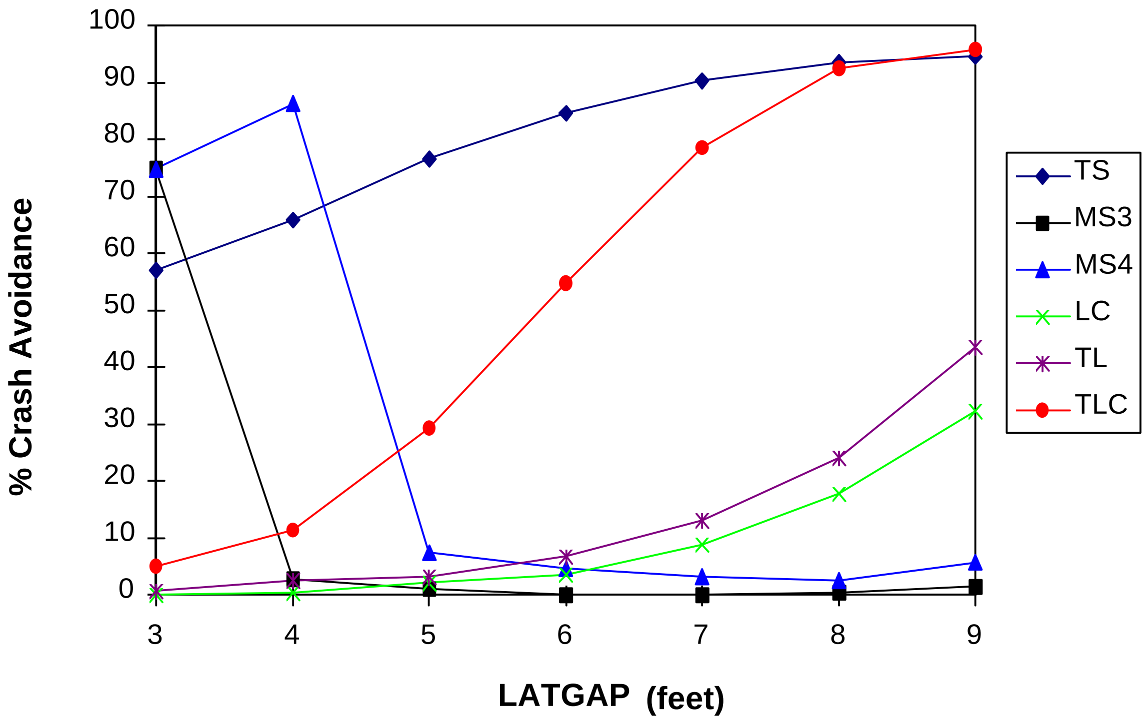


Figure 5-11. LATGAP vs. percentage crash avoidance for each warning rule, given the 95th percentile driver reaction time of 1.2613 seconds. These percentages represent all lane changes performed.

The percentage of crash avoidance for the TSO rule is consistently higher than the other rules as LATGAP increases with the exception of time-to-line crossing (See Figure 5-9 through Figure 5-11). As population representation increases to 95th percentile, or reaction time increases, the decrease in percentage crash avoidance is not drastic but rather subtle. Additionally, the increase in percentage of crash avoidance is gradual as LATGAP increases. The reason for these small differences in percentage crash avoidance may be due to the fact that the TSO rule is solely based on time, and the onset time is always the same for all levels of LATGAP.

6. CONCLUSION

This study consisted of two sequential parts: (1) on-the-road study to observe lane change behavior and (2) simulation of lane change crash hazard scenarios using five warning onset rules in LCAVOID. The lane change data collected in the first part were used in the second part to define parameters of crash hazard scenarios. The five warning onset rules simulated included: turn-signal onset (TSO), minimum separation MS), line crossing (LC), tolerance limit (TL), and time-to-line crossing (TLC).

6.1 Conclusions about Driver Lane Change Behavior

Based on the subject sample and methods used in this study, the following findings are reported:

- Driver age does not significantly affect lane change time, inter-lane change distance, initial vehicle lane position, or turn-signal onset time.
- Direction of lane change does not significantly affect lane change time, inter-lane change distance, initial vehicle lane position, or turn-signal onset time.
- Lane change time ranges from 3.41 to 13.62 seconds.
- Inter-lane change distance ranges from 8.84 to 15.19 feet.
- Ninety-two percent of the lane changes included turn signal activation.
- Turn-signal onset may occur as early as 4.28 seconds prior to lane change start or as late as 7.04 seconds after lane change start; however, normally, turn-signal onset ranges from 2.42 seconds before a lane change maneuver and 3.62 seconds after a lane change maneuver.

These conclusions are based on lane changes that were not performed under conflict conditions or SCAS instrumentation. They would be expected to change in actual SCAS testing.

6.2 Conclusions about Warning Onset Rules

Based on the subject sample and methods used in this study, the following findings are reported:

- The warning onset rule significantly affects the maximum time available to avoid a crash.
- Initial lateral gap (LATGAP) between subject vehicle (SV) and principal other vehicle (POV) significantly affects maximum time available to avoid a crash.
- The interaction of warning onset rule and LATGAP significantly affects maximum time available to avoid a crash.
- The three warning onset rules with significantly better or longer maximum time available means are turn-signal onset, time-to-line-crossing with a threshold of 1.25 s, and minimum separation at 4 feet, respectively. The remaining rules, line crossing and

tolerance limit, were not significantly different from one another, but were significantly lower than the top three.

- Estimated crash outcome (crash or no crash) is independent of age and direction for drivers when representing 50% of the driving population and is independent of direction when representing 95% of the driving population.
- Estimated crash outcome is not independent of warning onset rule and LATGAP for driver populations ranging from the 5^{th} percentile to the 95^{th} percentile.
- Only turn-signal onset and time-to-line crossing rules result in more estimated crashes avoided than crashes occurred for driver populations ranging from the 5^{th} percentile to the 95^{th} percentile.
- Estimated proportion of crashes avoided increased from LATGAPs of 5 feet through 9 feet.

These conclusions are based on simulations of lane change parameters taken from lane changes that were not performed under conflict conditions or SCAS instrumentation. They would be expected to change in actual SCAS testing.

6.3 Recommendations

The turn-signal onset rule is a very effective warning onset rule for SCAS; however, it becomes completely ineffective when a driver does not activate his or her turn-signal as he or she should. The time-to-line crossing rule seems to be the most promising alternative to the turn-signal onset rule. Because it relies on both vehicle distance to the line and lateral velocity, the time-to-line crossing rule provides a more accurate assessment of the lane change maneuver, or driver intent. The TLC threshold may be determined using a driver's lane change behavior patterns including lane change time, inter-lane change distance, and initial lane position (or lanekeeping position). Future SCAS should be "smart" enough to determine the TLC threshold specific for each driver so that it may be coded into the system.

Perhaps the ideal warning onset rule could be a combination of both the turn-signal onset rule and the time-to-line crossing rule. The rule whose conditions are met first would be applied for each lane change performed by the driver. Therefore, if the driver fails to activate his or her turn-signal, the time-to-line crossing rule would be applied when its conditions are met. If the driver activates his or her turn signal prior to reaching the time-to-line crossing threshold, then turn-signal activation would trigger the warning.

6.4 Final Overview

The following research objectives have been achieved:

- A literature review was conducted to understand the lane change crash problem and identify potential countermeasures.
- Lane change behavior was observed and quantified to provide baseline data.

- The potential effectiveness of five warning onset rules for lane crash avoidance warning systems was examined.
- Recommendations for the development of SCAS technologies have been provided which are based on the lane change behavior data and the warning onset rule evaluations.

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APPENDIX A
Script for Screening of Test Subjects

INITIAL CONTACT SCRIPT (BY PHONE OR IN PERSON)

EXPERIMENTER:

I am conducting an on-the-road vehicle study for my graduate research at Virginia Tech. The purpose of this research project is to evaluate driver behavior for applications to warning onset rules used in crash avoidance systems.

During the course of this experiment you will be asked to perform the following tasks:

1. Show a valid driver's license
2. Read and sign an Informed Consent Form.
3. Complete a brief health, medication, and drug screening questionnaire.
4. Listen to instructions about operation of the experimental vehicle.
5. Perform one experimental drive with the vehicle along a pre-determined route on Main Street and RT-460 in Blacksburg in which data will be collected.

At the end of the experimental run, you will drive back to the Center for Transportation Research, paid for your time, and debriefed. The total experiment time will be approximately 2.0 hours.

Would you be interested in participating?

POTENTIAL SUBJECT: yes or no

EXPERIMENTER: As part of the experiment, I need to ask you a few questions. Your answers will help me determine if I can include you as a subject in my study and if so, it will also help me group and sort the data from the study. This data will not be associated with your name, and will be treated confidentially.

See Initial Screening Oral Questionnaire

EXPERIMENTER: Now I'd like to schedule a time when you can come out to the Center for the experiment.

- Schedule a time DATE AND TIME:__________________________

EXPERIMENTER: Since you will be driving a vehicle, you must refrain from consuming drugs or alcohol for the 24 hours before the experiment. Do you agree to follow this requirement?

YES NO

I will be sending you a reminder of when the experiment is scheduled including directions to the Center as well as a copy of the Informed Consent Form. Please read over this form to ensure that you understand the study and your roles as a participant. This also explains your rights as a participant. Bring this form when you come for the study. What would be the best way to get this reminder to you? May I personally deliver it to you? Would you like me to meet you somewhere? Or would you like me to mail it to you by e-mail or through the post office? Keep in mind that it's important that you receive it prior to the study, given the date that I scheduled the experiment. Thank you! I'll see you <insert date and time>.

- e-mail to ____________________________
- meet at _____________________________
- personally deliver to ______________________________
- mail to address __________________________________

  ____

INITIAL SCREENING ORAL QUESTIONAIRE

Subject's Name:___________________________
Subject's Phone No.:______ **Gender: M or F Age:**________
Pass:________ **Fail:**________ **Date and Time:**______________________

NOTE TO EXPERIMENTER: Ask the subject the following questions and record his/her responses. Subjects are required to have a valid driver's license, drive at least twice a week, and not reveal any health conditions that indicate driving would pose an increased risk to the driver. If at any time in this screening questionnaire the potential subject does not meet the criteria of the study, thank the person for their time and explain that that criteria must be met in order to participate.

1) To participate, you need to have a valid driver's license. Do you have one?

YES NO

2) How many times per week do you drive?

4 + 2 -3 X 1X <1X

6) Are you in good general health? YES NO

7) Do you have a history of any of the following?

Visual Impairment YES NO
(If yes, please describe)

____

____

Hearing Impairment YES NO
(If yes, please describe)

____

____

Seizures or other lapses of consciousness YES NO
(If yes, please describe)

____

____

Any other disorders that would impair
your ability to drive YES NO
(If yes, please describe)

____

____

APPENDIX B
Informed Consent Form and
Health, Medication, and Drug Screening Questionnaire

VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIVERSITY
Informed Consent for Participants of Investigative Projects

Title of the Project: EVALUATION OF DRIVER BEHAVIOR FOR APPLICATIONS TO WARNING ONSET RULES USED IN CRASH AVOIDANCE SYSTEMS

Investigators: Shannon Hetrick and Thomas A. Dingus

I. The Purpose of this Research

The purpose of this research project is to evaluate driver behavior for applications to warning onset rules used in crash avoidance systems. Experimental tasks consist of driving an instrumented research vehicle along a predetermined route in Blacksburg and on the RT-460 Bypass. For safety considerations, data collection will occur only under "ideal" conditions, on dry pavement and in daylight. A ride-along observer will be present at all times in the instrumented vehicle. The observer's duties will be to operate equipment and look out for hazardous conditions. This research will provide baseline data for future studies to evaluate advanced driver systems.

II. Procedures

During the course of this experiment you will be asked to perform the following tasks:

1. Show a valid driver's license
2. Read and sign an Informed Consent Form.
3. Complete a brief health, medication, and drug screening questionnaire.
4. Listen to instructions about the operation of the experimental vehicle and the experimental drive.
5. Perform one experimental drive with the vehicle along a pre-determined route in which data will be collected.

At the end of the experimental run, you will drive back to the Center for Transportation Research, paid for your time, and debriefed. The total experiment time will be approximately 2.0 hours.

III. Risks

There are two risks or discomforts to which you may be exposed in volunteering for this research. They include the following:

(1) The risk of an accident normally associated with driving an automobile in light or moderate traffic, as well as on straight and curved roadways.
(2) Possible fatigue due to the length of the experiment. However, participants will be given rest breaks during the experimental session.

The following precautions will be taken to ensure minimal risk to you as a participant:

(1) An experimenter will monitor subjects driving and will ask subjects to stop if they feel the risks are too great to continue. However, as long as subjects are driving the research vehicle, it remains their responsibility to drive in a safe, legal manner.
(2) Subjects will be required to wear the lap and shoulder belt restraint system anytime the car is on the road. The vehicle is also equipped with a driver's side airbag supplemental restraint system.
(3) The vehicle is equipped with an experimenter brake pedal if a situation should warrant braking and the test participant fails to brake.
(4) The vehicle is equipped with a fire extinguisher, first-aid kit, and a cellular phone which may be used in an emergency.
(5) If an accident does occur, the experimenters will arrange medical transportation to a nearby hospital emergency room. Subjects will be required to undergo examination by medical personnel in the emergency room.
(6) All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard to the driver in any foreseeable case.
(7) None of the data collection equipment interferes with any part of the driver's normal field of view present in the automobile.

IV. Benefits of this Project

There are no direct benefits to you from this research other than payment for participation. No promise or guarantee of benefits are made to encourage you to participate. Your participation should make it possible to evaluate normal vehicle driving behavior. This may have a significant impact on the effectiveness of advanced systems that assist drivers in enhancing safety on the road.

V. Extent of Anonymity and Confidentiality

The data gathered in this experiment will be treated with confidentiality. Shortly after participation, your name will be separated from your data. A coding scheme will be employed to identify the data by subject number only (e.g., Subject No. 6). At no time will the researchers release the results of this study to anyone other than individuals working on the project without subjects' written consent.

VI. Compensation

You will be paid at the rate of $10.00 per hour for your time. This payment will be made to you at the end of your voluntary participation in this study for the portion of the experiment that you complete.

VII. Freedom to Withdraw

As a participant in this research, you are free to withdraw at any time without penalty. If you choose to withdraw, you will be compensated for the portion of time of the study for which you participated. Furthermore, you are free not to answer any questions or respond to experimental situations without penalty.

VIII. Approval of Research

This research has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Virginia Tech Center for Transportation Research.

IX. Subject's Responsibilities

If you voluntarily agree to participate in the study, you will have the following responsibilities: To be physically free from any illegal substances (alcohol, drugs, etc.) while driving and 24 hours prior to the experiment, to conform to the laws and regulations of driving or public roadways, and to relinquish control of the experimental vehicle to the experimenter if the experimenter so requests.

X. Subject's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rule of this project.

____

Participant's Signature   Date

Should I have any questions about this research or its conduct, I may contact:

Shannon Hetrick, Investigator	(540) 231-8350 or 552-5904
Thomas A. Dingus, Investigator	(540) 231-8831
H.T. Hurd, Chair, IRB	(540) 231-5281

HEALTH, MEDICATION, AND DRUG SCREENING QUESTIONNAIRE

1. Are you in good general health? Yes No

   If no, list any health-related conditions you are experiencing or have experienced in recent past.

   ____
   ____
   ____

2. Have you, in the last 24 hours, experienced any of the following conditions?

Inadequate sleep	Yes	No
Unusual hunger	Yes	No
Hangover	Yes	No
Headache	Yes	No
Cold symptoms	Yes	No
Depression	Yes	No
Allergies	Yes	No
Emotional upset	Yes	No

3. Do you have a history of any of the following?

   Visual Impairment Yes No

   (If yes, please describe.)

   ____
   ____
   ____

   Hearing Impairment Yes No

   (If yes, please describe.)

   ____
   ____
   ____

   Seizures or other lapses of consciousness Yes No

   (If yes, please describe.)

   ____

   Any disorders similar to the

above or that would impair
your driving ability Yes No

(If yes, please describe.)

____
____
____

4. List any prescription or non-prescription drugs you are currently taking or have taken in the last 24 hours.

____
____

5. List the approximate amount of alcohol (beer, wine, fortified wine, or liquor) you have consumed in the last 24 hours.

____
____

6. List the approximate amount of caffeine (coffee, tea, soft drinks, etc.) you have consumed in the last 6 hours.

____
____

7. Are you taking any drugs of any kind other than those listed in 4 or 5 above?

Yes No

8. If you are female, are you pregnant? Yes No

________________________ ________________________
Signature Date

APPENDIX C
Script of Test Plan and Instructions

TEST PLAN

1. INTRODUCTION (15 minutes)

   A. Driver's License

      - Have participant show a valid driver's license.

   B. Informed Consent Form

      - Give participant a copy of the informed consent form to read.

      FEEL FREE TO ASK ANY QUESTIONS ABOUT THIS INFORMED CONSENT FORM.

      - Answer any questions the participant might have about the study.
      - Have participant sign and date the informed consent form.
      - Give participant a copy of the informed consent form.

   C. Health, Medication, and Drug Questionnaire

      - Give participant a copy of the health, medication, and drug questionnaire to complete.
      - Have participant sign and date the health, medication, and drug questionnaire.
      - Review questionnaire to ensure that participant is fit to take part in the study.

   D. Initial Briefing

      DO YOU HAVE ANY ADDITIONAL QUESTIONS AT THIS POINT IN TIME?

      - Answer any general questions the participant might have.

      BEFORE WE PROCEED, I'D JUST LIKE TO TELL YOU THAT I'LL BE READING FROM A SCRIPT DURING THE INITIAL PART OF THE STUDY. THIS ENSURES THAT I DON'T FORGET TO TELL YOU ANYTHING. SO, IF I SOUND EXTREMELY FORMAL PLEASE UNDERSTAND THT THIS IS A REQUIREMENT OF THE STUDY.

2. VEHICLE BRIEFING (10 minutes)

      - Open front driver-side door for the participant and have them get into the front driver's seat.

- Get into back seat.

BEFORE WE BEGIN TODAY, I'D LIKE TO TAKE A FEW MOMENTS TO FAMILIARIZE YOU WITH THIS VEHICLE.

FIRST OF ALL, PLEASE ADJUST THE SEAT AND THE STEERING WHEEL SO THAT YOU ARE IN A COMFORTABLE DRIVING POSITION. THEN, FASTEN YOUR SEATBELT.

- Have the participant adjust the seat and steering wheel. Then have them fasten their seatbelt.

NOW, PLEASE ADJUST THE SIDE AND REAR-VIEW MIRRORS TO YOUR LIKING.

- Have the participant adjust the side and rear-view mirrors.

- Make sure the following system settings are achieved:

  (1) Connect all computer cables
  (2) Power up data collection computer
  (3) Load video cassette

- Have subject start-up the vehicle.

THE INSIDE TEMPERATURE OF THIS CAR IS CURRENTLY SET AT 72 DEGREES, IF YOU'D LIKE TO CHANGE THIS WE CAN DO IT NOW. IF AT ANY TIME DURING THE STUDY YOU'D LIKE TO CHANGE THE TEMPERATURE, PLEASE TELL ME.

PLEASE TURN ON THE RIGHT TURN SIGNAL. IF YOU LOOK ON THE BLACK SCREEN BEHIND THE STEERING WHEEL, YOU WILL SEE AN IMAGE OF THE TURN SIGNAL INDICATOR. IT IS THERE ONLY BECAUSE THE ORIGINAL TURN SIGNAL INDICATOR IS BLOCKED OUT BY THE DISPLAY WHICH IS USED FOR OTHER STUDIES, NOT THIS STUDY. GO AHEAD AND TURN OFF THE TURN-SIGNAL.

3. DRIVING SESSION (90 minutes)

YOU WILL BE DRIVING ALONG A PREDETERMINED ROUTE ON RT-460 IN BLACKSBURG. DURING THE FIRST SECTION YOU WILL BE DRIVING IN THE BUSINESS DISTRICT OF BLACKSBURG, AND DURING THE SECOND SECTION YOU WILL BE DRIVING ON THE 460-BYPASS. I WILL BE IN THE PASSENGER'S SEAT TO DIRECT YOU ON THIS ROUTE, JUST AS IF I WERE TELLING YOU HOW TO REACH A PARTICULAR DESTINATION. FOR THIS REASON, THE RADIO MUST REMAIN OFF AND WE CANNOT TALK THROUGHOUT THE DURATION OF THE STUDY UNLESS I AM INSTRUCTING YOU OR IF YOU HAVE A QUESTION; OTHERWISE, WE MAY FAIL TO FOLLOW OUR ROUTE. YOU ARE ENCOURAGED TO DRIVE AS YOU NORMALLY DO. FOR EXAMPLE, PERFORM LANE CHANGES WHEN YOU FEEL IT IS APPROPRIATE IN ORDER TO MAINTAIN DIRECTION OR SPEED, OR TO SIMPLY PASS ANOTHER VEHICLE. YOU WILL DRIVE STRAIGHT ON THE ROUTE UNLESS I INSTUCT YOU TO TURN, BUT TURN ONLY WHEN IT IS SAFE TO DO SO. IN OTHER WORDS, IF I INSTRUCT YOU TO TURN AND YOU DON'T THINK YOU HAVE ENOUGH TIME OR SIMPLY DON'T FEEL COMFORTABLE WITH THE TRAFFIC AROUND YOU, JUST CONTINUE TO GO STRAIGHT. WHEN TURNING, YOU ARE ADVISED TO TURN INTO THE APPROPRIATE LANE. FOR EXAMPLE, WHEN TURNING LEFT FROM THE LEFT LANE, ONTO A ROADWAY WITH MORE THAN ONE LANE,YOU SHOULD REMAIN IN THE LEFT LANE THROUGH THE TURN AND ONTO THE NEXT ROADWAY. THIS IS EXTREMELY IMPORTANT FOR SAFETY REASONS AND SINCE IT IS IN COMPLIANCE WITH TRAFFIC LAWS. REMEMBER THAT **YOU ARE RESPONSIBLE FOR DRIVING SAFELY AT ALL TIMES AND OBSERVING ALL TRAFFIC LAWS**. CTR WILL NOT BE RESPONSIBLE FOR ANY TRAFFIC FINES OR VIOLATIONS. SAFE DRIVING MUST COME FIRST. DO YOU HAVE ANY QUESTIONS?

- Answer any questions the participant might have about the vehicle or the study.

Go to starting point at South Main Street.

TURN LEFT AT THE LIGHT ONTO SOUTH MAIN STREET, HEADING WEST ON 460.

If they do not follow instructions:
AS A LITTLE REMINDER, WHEN TURNING, PLEASE TRY TO STAY IN THE LANE THAT YOU TURN FROM; IN OTHER WORDS, WHEN YOU TURN LEFT, REMAIN IN THE LEFT LANE.

CONTINUE GOING STRAIGHT AT THE LIGHT AHEAD.

K TURN RIGHT ONTO THE FIRST STREET ON YOUR RIGHT, MARLINGTON STREET, JUST BEFORE THE RED CARPET INN.

TURN LEFT ONTO THE FIRST STREET ON YOUR LEFT, GRAYLAND STREET, JUST PAST THIS BUILDING.

TURN LEFT AT THE STOP SIGN ONTO LANDSDOWNE DRIVE.

TURN RIGHT AT THE STOP SIGN ONTO MAIN STREET.

CONTINUE GOING STRAIGHT AT THE NEXT TWO LIGHTS AHEAD.

J TURN LEFT AT THE LIGHT ONTO AIRPORT ROAD.

TURN RIGHT ONTO THE FIRST STREET ON YOUR RIGHT, DRAPER ROAD, WHICH IS NOT MARKED.

CONTINUE GOING STRAIGHT AT THE STOP SIGN AHEAD.

CONTINUE GOING STRAIGHT AT THE STOP SIGN AHEAD.

CONTINUE GOING STRAIGHT AT THE LIGHT AHEAD.

TURN RIGHT AT THE STOP SIGN ONTO ROANOKE STREET.

TURN LEFT AT THE LIGHT ONTO MAIN STREET.

CONTINUE GOING STRAIGHT AT THE LIGHT AHEAD.

J TURN LEFT AT THE LIGHT ONTO TURNER STREET.

TURN RIGHT AT THE YIELD SIGN, ONTO PRICE’S FORK ROAD.

TURN RIGHT AT THE LIGHT ONTO MAIN STREET.

J TURN LEFT AT THE LIGHT ONTO TURNER STREET.

TURN LEFT AT THE LIGHT ONTO PROGRESS STREET.

CONTINUE GOING STRAIGHT AT THE LIGHT AHEAD.

TURN LEFT AT THE LIGHT ONTO MAIN STREET.

K TURN RIGHT AT THE LIGHT ONTO PRICE'S FORK ROAD.

J TURN LEFT AT THE LIGHT ONTO TOM'S CREEK ROAD.

TURN LEFT ONTO THE FIRST STREET ON YOUR LEFT, PERRY STREET.

TURN RIGHT AT THE STOP SIGN ONTO TURNER STREET.

TURN LEFT AT THE LIGHT ONTO MAIN STREET.

K TURN RIGHT ONTO THE FIRST STREET ON YOUR RIGHT, GILES ROAD, JUST PAST BOGEN'S RESTAURANT.

TURN RIGHT AT THE LIGHT ONTO PROGRESS STREET.

TURN RIGHT AT THE LIGHT ONTO TURNER STREET.

TURN RIGHT AT THE LIGHT ONTO MAIN STREET.

J TURN LEFT AT THE LIGHT ONTO PRICE'S FORK ROAD.

K TURN RIGHT AT THE LIGHT ONTO TOM'S CREEK ROAD.

TURN RIGHT AT THE FIRST STREET ON THE RIGHT AROUND THIS CURVE, WATSON AVENUE.

CONTINUE GOING STRAIGHT AT THE STOP SIGN AHEAD.

TURN RIGHT AT THE STOP SIGN ONTO PROGRESS STREET.

TURN LEFT AT THE LIGHT ONTO MAIN STREET.

K TURN RIGHT ONTO THE FIRST STREET ON YOUR RIGHT, LUCAS DRIVE, JUST PAST WADE'S.

TURN LEFT AT THE STOP SIGN ONTO GILES ROAD.

TURN LEFT ONTO THE FIRST STREET ON YOUR LEFT AROUND THIS CURVE, NORTHVIEW DRIVE.

TURN RIGHT AT THE STOP SIGN ONTO MAIN STREET.

J TURN LEFT AT THE LIGHT ONTO PATRICK HENRY DRIVE.

CONTINUE GOING STRAIGHT AT THE LIGHT AHEAD.

K TURN RIGHT AT THE LIGHT ONTO TOM'S CREEK ROAD.

TURN RIGHT INTO THE NEXT DRIVEWAY THAT LEADS INTO THE APARTMENT PARKING LOT AND PARK.

YOU HAVE JUST COMPLETED THE FIRST SECTION OF THE DATA COLLECTION. YOU WILL NOW BE DRIVING ON THE HIGHWAY, ALONG THE 460-BYPASS. DURING THIS PORTION OF THE STUDY, YOU ARE INSTRUCTED TO DRIVE IN THE RIGHT LANE AND PASS IN THE LEFT LANE UNLESS OTHERWISE TOLD TO DO SO. YOU MAY AT ANY TIME PASS A SLOWER MOVING LEAD VEHICLE AS LONG AS IT IS SAFE TO DO SO. FOR THIS PART OF THE ROAD STUDY THERE WILL BE TIMES WHEN I'LL INSTRUCT YOU TO TURN OFF THE HIGHWAY SO I MAY RECONFIGURE THE COMPUTER AT A SAFE LOCATION. SO, WHEN ENTERING OR EXITING THE HIGHWAY PLEASE DO SO WITH CAUTION. ALSO, REMEMBER THAT WHEN TURNING YOU SHOULD TURN INTO THE APPROPRIATE LANE; FOR EXAMPLE, WHEN TURNING FROM THE LEFT LANE, TURN INTO THE LEFT LANE.
**
TURN LEFT AT THE LIGHT ONTO RT-460 E
L
CONTINUE GOING STRAIGHT PAST THE EXIT AHEAD.

*J*TURN LEFT AT THE LIGHT ONTO SOUTHGATE DRIVE.

*K*TURN RIGHT INTO THE VT MAP OR VISITOR STATION.

TURN LEFT BACK ONTO SOUTHGATE DRIVE.

AT THE LIGHT, GET INTO THE FAR LEFT LANE AND TURN LEFT ONTO RT-460 E.
L
TAKE THE NEXT EXIT TOWARDS BLACKSBURG.

AT THE END OF THIS RAMP TURN LEFT AT THE STOP SIGN; WE'LL BE REENTERING 460, GOING WEST.

TURN LEFT JUST AFTER PASSING UNDERNEATH THE BRIDGE TO REENTER THE HIGHWAY ON RT-460 W

CONTINUE GOING STRAIGHT AT THE LIGHT AHEAD.

CONTINUE GOING STRAIGHT PAST THE EXIT AHEAD.

*J*TURN LEFT AT THE LIGHT ONTO TOM’S CREEK ROAD

AS SOON AS YOU TURN, TURN LEFT INTO THE GRAVEL DRIVEWAY.

TURN AROUND AND TURN LEFT AT THE LIGHT ONTO 460W
L
Pass the Main Street Exit

AROUND THIS CURVE, THERE WILL BE A BREAK IN THE MEDIAN. DO NOT TURN HERE, BUT SHORTLY AFTER IT IS FOLLOWED BY A LEFT TURN LANE; ENTER THE LANE AND TURN LEFT INTO THE PARKING LOT IN FRONT OF THE HOUSE.

TURN RIGHT ONTO RT-460E
***
*J*TURN LEFT AT THE LIGHT ONTO TOM’S CREEK ROAD.

TURN LEFT INTO THE DRIVEWAY LEADING TO THE APARTMENT PARKING LOT AS YOU DID EARLIER.

TURN AROUND AND TURN RIGHT BACK ONTO TOM’S CREEK ROAD

REPEAT **

***
CONTINUE GOING STRAIGHT AT THE LIGHT AHEAD.

*J*TURN LEFT AT THE LIGHT ONTO SOUTHGATE DRIVE.

WE ARE NOW FINISHED WITH THE STUDY. WE WILL NOW RETURN TO THE CENTER.

APPENDIX D
Proportion of Crash Outcome for All Factors

Table D1. Proportion of crash occurrence and proportion of crash avoidance for four factors: warning onset rule, LATGAP, age, and direction of maneuver. The 5th, 50th, and 95th percentile reaction times are 0.4908, 0.7866, and 1.2163, respectively.

		5th Percentile Reaction Time		50th Percentile Reaction Time		95th Percentile Reaction Time	
Factor	Level	Proportion of Crash Occurence	Proportion of Crash Avoidance	Proportion of Crash Occurence	Proportion of Crash Avoidance	Proportion of Crash Occurence	Proportion of Crash Avoidance
Warning Onset Rule	TSO	0.0435	0.9565	0.0710	0.9290	0.1722	0.8278
	MS	0.3606	0.6394	0.5462	0.4538	0.7169	0.2831
	LC	0.6542	0.3458	0.7613	0.2387	0.8902	0.1098
	TL	0.5801	0.4199	0.6977	0.3023	0.8458	0.1542
	TLC	0.0697	0.9303	0.2046	0.7954	0.4506	0.5494
LATGAP in feet	3	0.4832	0.5168	0.5963	0.4037	0.7093	0.2907
	4	0.4124	0.5876	0.4932	0.5068	0.6547	0.3453
	5	0.4286	0.5714	0.5429	0.4571	0.7528	0.2472
	6	0.4025	0.5975	0.5205	0.4795	0.6770	0.3230
	7	0.3230	0.6770	0.4584	0.5416	0.5963	0.4037
	8	0.2311	0.7689	0.3714	0.6286	0.5280	0.4720
	9	0.1491	0.8509	0.2584	0.7416	0.4410	0.5590
Age	18-25	0.3631	0.6369	0.4750	0.5250	0.6392	0.3608
	65-75	0.3336	0.6664	0.4528	0.5472	0.6088	0.3912
Direction	Left	0.3318	0.6682	0.4467	0.5533	0.6133	0.3867
	Right	0.3625	0.6375	0.4794	0.5206	0.6322	0.3678

VITA

for
Shannon Hetrick

Shannon Hetrick was born in Bien Hoa, South Vietnam. She resided in an orphanage near Saigon until the eventual takeover of the North Vietnamese. She was adopted and arrived to the United States of America in 1975. Her hometown is Roswell, Georgia located in the suburbs of Atlanta. Shannon attended Virginia Polytechnic Institute and State University, receiving a B.S. degree in Industrial and Systems Engineering in May 1995. She continued her education at VPI & SU to receive an M. S. degree in Industrial and Systems Engineering with a concentration in Human Factors Engineering in May 1997.

During her graduate studies at Virginia Tech, Shannon interned at the Transportation Research Center (TRC) in East Liberty, Ohio in the Crash Avoidance division where she also developed her thesis topic. She conducted her research at the Virginia Tech Center for Transportation Research (CTR) in Blacksburg, Virginia.

Shannon Hetrick is currently working in the Technical Research division of Honda Research and Development of North America, Inc. (HRA) in Raymond, Ohio. Her primary focus at HRA is on the development of Intelligent Transportation Systems (ITS) technologies.

Shannon enjoys various outdoor activities including soccer, mountain biking, hiking, camping, and climbing. Additionally she enjoys a less aerobic, yet intellectually stimulating activity such as playing chess.