Multisensory cueing design and evaluation in side collision avoidance system (SCAS): Auditory Representations of Time-to-Collision Enhance Lane-changing Decision-making

Yuanjing Sun

Michigan Technological University

Abstract

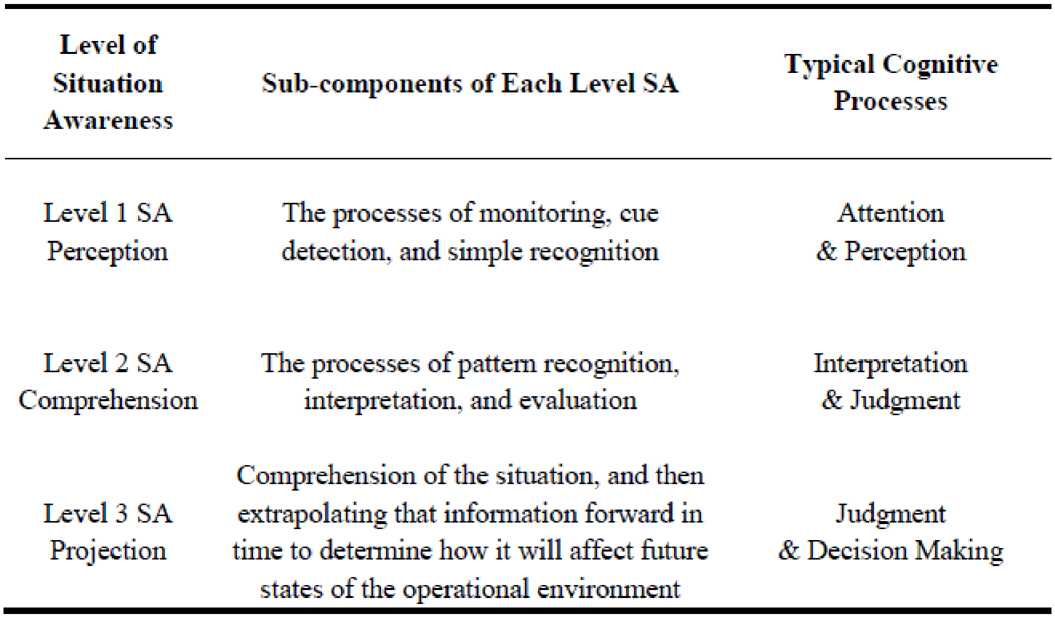
This report presents an analysis of key parameters on lane change crashes and current Collision Avoidance Technologies can detect the changing velocity of cars that might cause potential collisions. Simplify warning signal in a perceptive way can reduce driving workload and increase situation awareness of uncertainty in road. However, less research has been conducted on which modality could be most representative warning in certain traffic that enhance drivers' lane-changing decision making without distracting their attention. The author attempts to compare four combination of warning signal design in eight scenarios to see performance difference. These data also can be used as reference to calculate alerting function for versatile traffic situations. Participants need to follow a programmed leading car until lane-changing task occur. Simultaneously they make decision based on multimodal signal given.

Introduction

Driving is a complex task requiring both automatic motor activities and higher cognitive processes that perceive the road environment. Many institutes and organizations intend to develop well-designed in-vehicle systems to support driving task. But it is hard to tell whether these so called assistant system facilitate or distract driving performance because there's still some challenges in evaluation criteria of human-machine interface (HMI) For further analysis, In-vehicle systems can be roughly categorized into (1) Advanced Driver Assistance Systems (ADAS) and (2) In-vehicle Information Systems (IVIS). But there are still some techniques between these two such as a route-guidance or vehicle diagnostic message system.

1. *Advanced Driver Assistance Systems (ADAS):* Systems with the *main purpose* to enhance safety and/or comfort by *supporting the driver in performing the primary driving task.* Examples include lateral control support, collision warning, safe following, vision enhancement and driver fatigue monitoring.
2. *In-vehicle Information Systems (IVIS):* Systems with the main purpose of providing information to the driver *not directly related to the primary driving task*, including telematics and communication services, infotainment (radio, CD, DVD, mp3, email). These functions potentially impose a *secondary task* that may interfere with the primary driving task. An increasingly important sub-category of IVIS are so-called nomad systems, i.e. systems brought into the vehicle by the driver or passengers.

In fact, studies shows that 90 percent of car accidents relate to drivers' low situation awareness, which suggests drivers don't pay enough attention on potential changes in situation. Situation awareness (SA) Model in Table 1. refers to the goal-directed perceptual awareness of the environmental stimulus, along with a procedure of being aware of the situation, understanding the information and projecting the future based on the information perceived (Endsley, 1995).



Level of Situation Awareness	**Sub-components of Each Level SA**	**Typical Cognitive Processes**
Level 1 SA Perception	The processes of monitoring, cue detection, and simple recognition	Attention & Perception
Level 2 SA Comprehension	The processes of pattern recognition, interpretation, and evaluation	Interpretation & Judgment
Level 3 SA Projection	Comprehension of the situation, and then extrapolating that information forward in time to determine how it will affect future states of the operational environment	Judgment & Decision Making

Table 1. Relations between the level of situation awareness model (Endsley, 1995) and typical cognitive processes

Attention is a dynamic cognitive resource we applied corresponds with the density of traffic situation without exceeding cognitive workload limits. In other words, the attention capacity depends much on a person, their experience, their (mental) condition, and their surroundings as Figure 1shows. The "y" axis is attention resource, and "x" axis is task complexity. The solid line stands for the attention resources used for different levels of complexity, whereas the blue dotted line stands for the variation of average driving performance. The distance between the solid and dotted line is called "free attention capacity". The more free capacity you have the safer the drivers are. The intersection of solid line and dotted line is the threshold of cognitive overload.

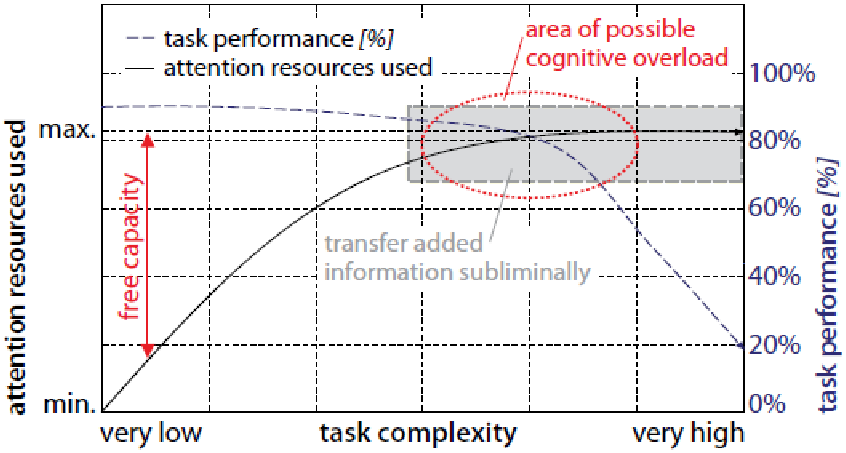


Figure1. Cognitive resources and its relation to task performance (Riener, 2012).

To my understanding, SA (In other words, Detection of Uncertainty of environment) + function (Task Complexity (how many parameter need), Task Performance (Reaction pattern based on experience))=Cognitive resource (might differ from individual's STM). The resolution either enhance training of driver so they can have pattern to decompose the task complexity or simplify parameters in a direct way so they can easily react.

(Angell et al., 2006)Global Position Systems (GPS) make sophisticated in-vehicle information systems (IVIS) plausible to dilute driving complexity and interpreted traditional traffic environments. However, it requires timesharing with safety-critical task of driving. To prevent information-overload that weakens driving performance, a graded likelihood warning alarm display (LAD) is used where information about risk is automatically computed by monitoring system such as Collision Avoidance System (CAS) (J. D. Lee, Hoffman, & Hayes, 2004). The goal of this study is to find perceptive way to design warning signals which can efficiently convey more information and to enhance lane-changing decision making accuracy without distracting drivers' attention resources.

Literature Review

Definitions, maneuver sequence, and relevant parameters of the Lane Changing task

The lane change crashes are defined as two vehicle crashes which occur when one vehicle encroaches into the path of another vehicle initially on a parallel path with the first vehicle and traveling in the same direction. It includes cases in which one vehicle changes lanes and is involved in a collision with a vehicle going straight in the adjacent lane and so on (S. E. Lee, Olsen, & Wierwille, 2004). The sequence for an idealized lane change maneuver made from the right lane into the left lane due to a slow vehicle ahead is presented by Wierwille (1984), as illustrated by diagram in Appendix A section (Chovan, Tijerina, Alexander, & Hendricks, 1994).

According to Appendix A, before a driver makes a lane-changing decision, he or she need to process information based on the back and forth monitoring of the original and destination lanes using visual saccades. If we dive into these complex information processes, we can focus on several relevant parameters including: velocity of leading and following cars, lane-changing duration, acceleration of POV, range between two vehicles, range-rate (at which the range between two vehicles is changing, measured in terms of relative velocity (ΔV, in which the velocity of one vehicle is subtracted from the velocity of the other vehicle.), time-to collision (TTC), vehicle position, turn signal use, eye glance position (left/right forward , side mirrors, rear mirror) etc. (Sen, Smith, & Najm, 2003). The majority of lane-change crashes are due to proximity of the leading car. In this case there is little or no longitudinal gap between the driver and the leading car, and the ΔV between vehicles is small (Chovan et al., 1994; Wang & Knipling, 1994). Young et al. (1995) found that 78 percent of lane-change collisions involve low closing speeds (i.e., relative speed < 15 mph) (Young, Eberhard, & Moffa, 1995) .

Luckily, current IVIS can not only detect POVs' speed and direction but also automatically translate it into one value: Time-to-Collision (TTC = range/range-rate.). It is the time required for two vehicles to collide if they continue on their present speed and path (Van Winsum & Heino, 1996 cited by Olsen, 2003). TTC is a candidate for use in Collision Avoidance System (CAS) to activate a warning for drivers (Olsen, 2003).

Key components of Driver Warning System (DWS): threshold, presentation modal, and stimuli magnitude

Three important factors of wardingLane Change Assistant (LCA) systems assist in monitoring the adjacent lanes by ultrasonic wave sensors. These sensors warn the driver if another vehicle is likely to come within endanger area that usually is vehicle's blind spot. Presently, the system would warn the driver of such a problem with a red flashing icon in the side mirror. Although these sensors can scan the distance and velocity change of surrounding vehicles, does it guarantee driver can correctly interpret and make right decision? In order to encode this information on a perceptual level, equation design and threshold setting based on principle of warning system design lie in alerting algorithm and multisensory threshold.

Auditory displays out-perform visual displays in representing dynamic distance

The TTC assumes a constant speed and does not account for vehicle acceleration(Smith, Najm, & Glassco, 2002). Additionally, the issue in lane changing crash lies in driver's need to monitor the changing velocity and estimate motion trajectory for front, rear and side cars at the same time. Although CAS helps to detect Principle Other Vehicle (POVs) motion trajectory once the driver activate turn signal, dynamic acceleration or deceleration of POVs still requires high situation awareness.

Binocular disparity refers to the difference in image location of an object seen by the left and right eyes, resulting from the eyes' horizontal separation (parallax). The brain uses binocular disparity to extract depth information from the two-dimensional retinal images in stereopsis. The images in the side or rear mirrors are distorted 2D image by which driver can only use monocular cues such as relative size or curvilinear perspective to perceive distance. Even though visual representation of TTC, such as a digital indicator or a dial gauge, could provide precise distance, frequent saccades to read it would reduce driver's fixation and focus time to recognize message and prolong reaction time(Horrey & Wickens, 2006) .

Auditory distance perception

The Doppler Effect is the change in frequency of a wave (or other periodic event) for an observer moving relative to its source. It is commonly heard when a vehicle sounding a siren or horn approaches, passes, and recedes from an observer. As figure 2 shows, method of triangulation, if the observer can sense change in azimuth of the source during the displacement or velocity the observer can in principle compute the distance of source (Speigle & Loomis, 1993).

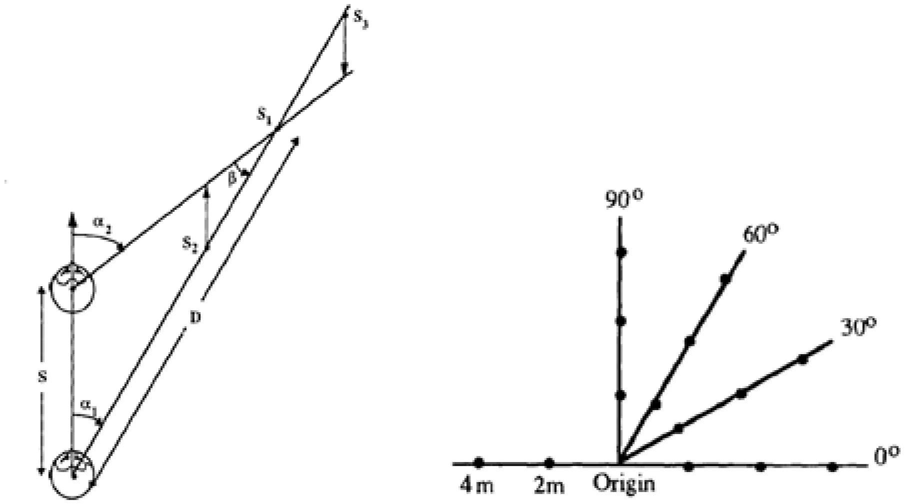


Figure 2,3 diagram of how people perceive dynamic distance by discriminate azimuth changing (Speigle & Loomis, 1993)

Time threshold in alert algorithm

Multimodal formats can convey a direct perceptive message about the POV_{fd} without adding to drivers' workload. Apart from equation design of alert media indication, the time threshold and threat algorithm is also important. Setting a threshold to alert early (and often) can prevent accidents from occurring but it would be at the expense of an increase in nuisance (Yang, Yang, Feron, & Kulkarni, 2003). Wakasugi (2005) conducted a field experiment aimed at finding suitable warning timing for a Lane Changing Decision Aid System. Ten subjects spent 70 minutes to drive 100 km on a four-lane road in the Chuo expressway. Based on headway-only distance measured in the study, 538 data points of execution in the lane-changing group concluded that the recommended minimum TTC in is 6.17 seconds, whereas the TTC was 9.98s in cancelation group. In addition, the average duration lane-changing execution is 5.3 ±1.0 second.(Wakasugi, 2005)

Method

Among the lane change family of crashes, each is characterized by distinct vehicle trajectories and distinct patterns of driver actions. The most common and severe lane change type crash scenario, expectedly, involves one vehicle changing lanes intentionally, and sideswiping or being sideswiped by a vehicle in the adjacent lane. These crashes constitute more than 38% of the target crash population. Most experiments simulates this type of lane changes (Sen et al., 2003).

Hypothesis

The author hypothesizes that multimodal warning signals, processed at direct perceptual levels (extra spatial audio cues), would have higher accuracy in LC decision making in highway scenario over extra number signal. And number signal would have higher accuracy in LC decision making in urban. A mixed subject experiment was designed to examine which signal or signal combination enables the driver to have high accuracy in lane-changing decisions in respective conditions.

Procedures

The participants must be naive to the aims of the experiment. Training practice without warning allows them get familiar with the simulator. They follow a programmed car on three-lane road and keep tracing until lane changing task occur. At that time, they will decide whether or not execute lane changing on basis of four combinations of multimodal signals they receive.

Experiment & Scenario Design

A 4 (TTC warning signal combination between subject) by 8 (scenarios within subject) factorial design dual task experiment will be implemented to test our hypothesis. The primary task will be a distance-keeping task in a driving simulator in two environments: highway (far leading car at 70m/h speed) and urban (near leading car at 40m/h speed). There are 2 (highway/urban)* 2 (Leading car change to left/right lane)*2(safe/danger) scenarios in the driving simulator. The leading car is programed to change into either the left or right lane and the participant has six seconds to decide whether or not to also change lanes based on the stimulus offered in a secondary task. The safe or danger scenario depends on SV’s TTC with POV_{fd}. In safe scenarios, TTC is 5 seconds or above, whereas danger scenario means TTC is below 3 seconds. It is based on results of two warning activation criterion experiments(J. D. Lee et al., 2004; Scott & Gray, 2008). However, considering alert threshold may differ from parameters in different scenarios of driving simulators. Pilot study shall be conducted before determining the threshold. The warning indication will be coded into three formats: video of a virtual scene in rear mirror, number digits in dashboard, and distance sonification (impulse frequency depending on urgent level).

Stimulus

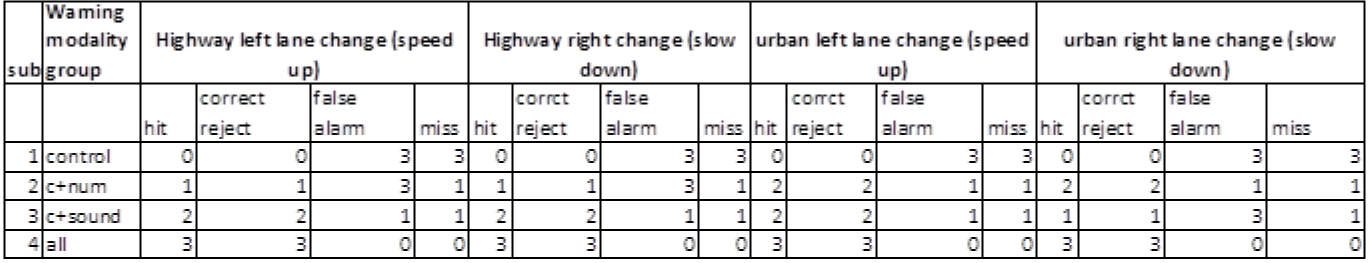
In the control group, a video simulating a six second scene in the rear and side mirrors will be displayed. In the digit number group, the stimulus are changing numbers to represent the dynamic distance from POV_{fd}.

In the auditory group, there are three levels of urgency to represent different TTC's. This is according to two field experiments using TTC as index of warning sound followed rules below (Scott & Gray, 2008; Wakasugi, 2005; Yang et al., 2003).

- 10 seconds and over : Unnecessary (no beep sound)
- 5 to 9.9 seconds : Adjustable range (2000Hz 60dB, three impulse per second)
- 3 to 4.9 seconds : Recommended(2000Hz,60dB,ten impulse per second)
- TTC Under2.9 seconds : Imperative(Continuous sound) (2s for correct previous LC)

Procedure

The participants must be naive to the aims of the experiment. They follow a programmed car on three-lane road and keep distance. Training practice drive without warning allows them get familiar with the simulator.



sub	Warning modality group	Highway left lane change (speed up)				Highway right change (slow down)				urban left lane change (speed up)				urban right lane change (slow down)			
		hit	correct reject	false alarm	miss	hit	corrct reject	false alarm	miss	hit	corrct reject	false alarm	miss	hit	corrct reject	false alarm	miss
1	control	0	0	3	3	0	0	3	3	0	0	3	3	0	0	3	3
2	c+num	1	1	3	1	1	1	3	1	2	2	1	1	2	2	1	1
3	c+sound	2	2	1	1	2	2	1	1	2	2	1	1	1	1	3	1
4	all	3	3	0	0	3	3	0	0	3	3	0	0	3	3	0	0

Table1 Expected data for participant over 8 scenarios

Result & Analysis

Based on false alarm rate (Probability of sum of false alarm and miss)and hit rate (Probability of sum of hit and correct rejection) statistics in Chart 1&2, the author can conclude a System Operating Characteristic (SOC) curve for each alert threshold functions, alerting sensitivity performance of each condition (Kuchar, 1996). We can suggest an optimal combination of warning display implement in CAS according to different (highway/urban) traffic environments.

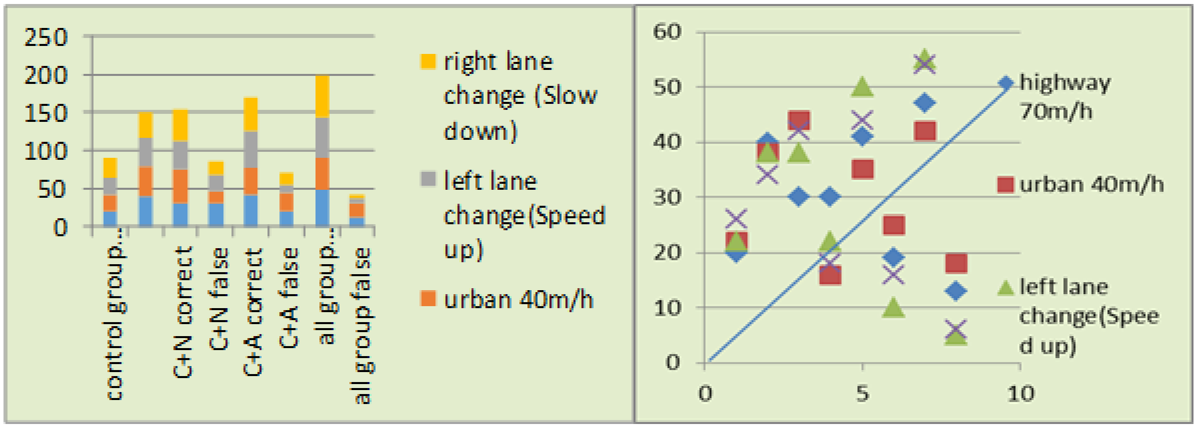


Chart 1. Expected hit and false alarm rate graph in respective group under Left/Right Condition and Highway/Urban Scenario

Discussion and Limitation

Limitation of Binaural warning sound

If the designer used binaural cues to indicate the dynamics of speed and angle of the rear car, performance might improve further. Everyone's head diameter is different, the efficiency might affect by head rotate and other movements. The direction of warning sound is still in debate . The distance calculation and sound presentation time need to be carefully compared with the driver's reaction time in emergency. Considering one single warning cue may be inoperable on some dysfunction accident when drivers might make decision depend on signal indication, multi-modality will reduce the probability of dysfunction at the same time. However, abuse of multimodal warning will cause information overload. There’s still a trade-off between reliability and warning pollution need further discussion.

Appendix

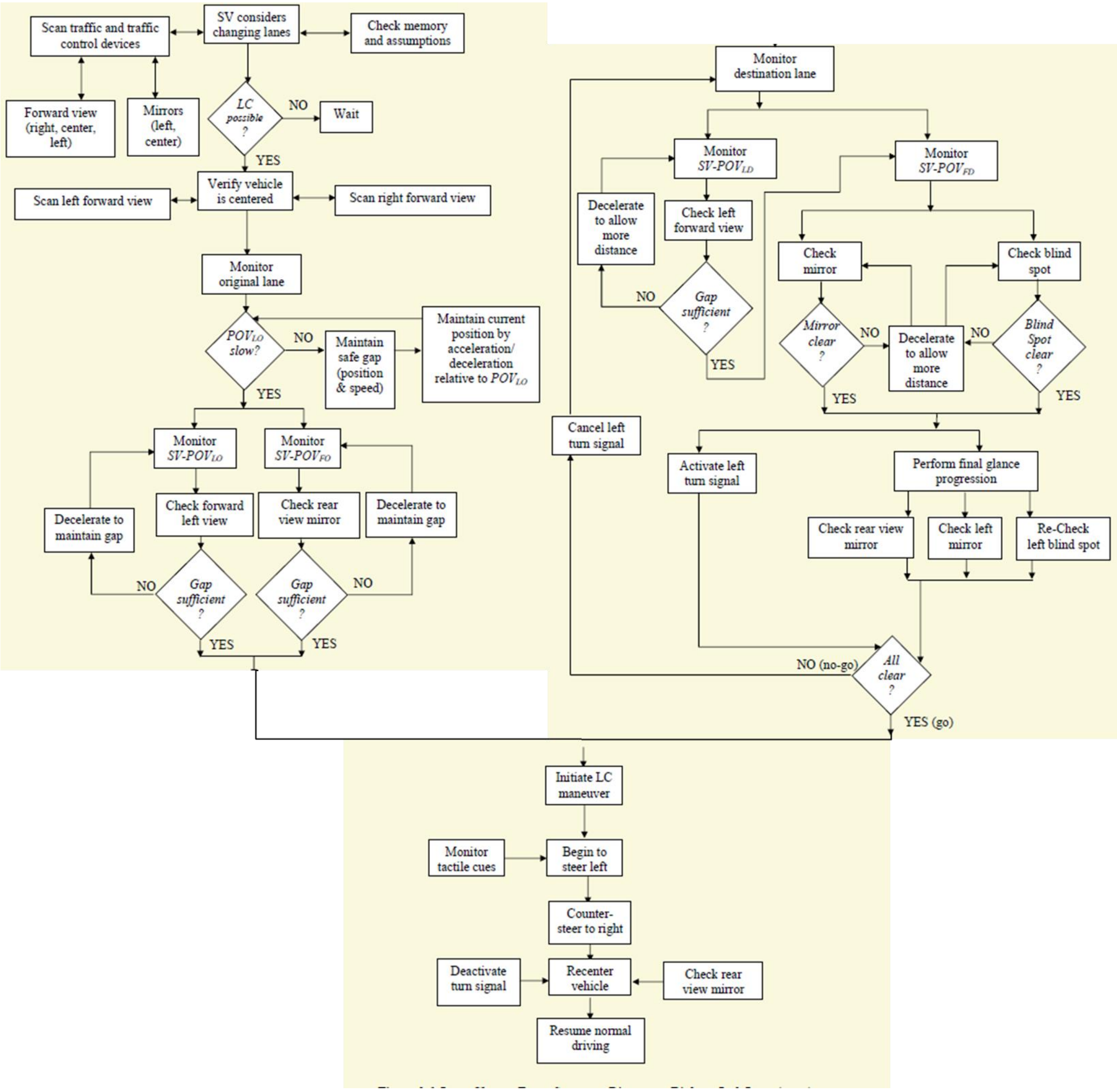


Figure .1 Appendix A. Diagram of sequence of lane changing maneuver

SV refers to the subject vehicle, POVL refers to the lead principal other vehicle, and POVF refers to the following POV. POV$_{LD}$ refers to the lead POV in the original lane, and POV$_{FO}$ refers to the following POV in the original lane; POV$_{LD}$ refers to the lead POV in the destination lane, and POVFD refers to the following POV in the destination lane. SV-POV$_{FD}$ refers to the gap between vehicles, as in “SV to following POV 3 0 in the destination lane;” SV-POVLO refers to the gap between the SV and the lead POV in the original lane, and so on (Jula, Kosmatopoulos, & Ioannou, 2000).

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