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The Research and Application of Lane Change Adviser

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Abstract

As technology progresses toward NHTSA defined Level 2 driver assistance systems with increasingly advanced sensing capabilities, opportunities arise to enhance driver assistance technologies beyond their current state and assist drivers in the completion of increasingly complex maneuvers. The Lane Change Advisor (LCA) is a feature that utilizes the capabilities of available on-board sensing modalities to infer driver intent to make a lane change and provide contextual environmental cues which when combined with observed driver actions inform a decision framework for the purpose of aiding the driver in maintaining their intended travel speed through the opportunistic identification of lane change maneuver opportunities. The driver intention inferences draw upon forward looking sensor measurements in lane of travel for both a dynamic perceptual model and a pseudo-steady-state traffic following component. The dynamic element utilizes the concept of visual looming, based the human perception of rapid visual image expansion on the retina as the distance between driver and obstacle ahead decrease over time. The steady-state component utilizes commands from Adaptive Cruise Control (ACC) during vehicle following for decision making. This presentation will present the decision framework, developed for a vehicle implementation of this feature as well as present results from on-road vehicle testing.

Keywords

Lane Change; Cruise Control; State Control; TTC; Validation.

1. Introduction

What we call the Lane Change Adviser (LCA) is intended to be a driver assistance feature that notifies an alert driver per NHTSA L2 guidelines [6] of an opportunity to make a lane change when one exists with the goal of allowing a driver to maintain his/her intended speed of travel in traffic.

We will begin with a review of a conceptual model of a lane change and the strategies a driver employs within those models, followed by strategic models of driver behavior and then move onto investigations of select individual driving strategies.

Michon [1] provides a conceptual model of human driving, more recently described by Gordon [2] which partitions the driving task into three fundamental activitie. These activities are strategic, tactical, and control levels which differ in time horizon over which they apply. The strategic level has to do with planning over a time horizon of days, hours, or minutes, while the tactical level involves short term decision making and maneuvering over a time horizon of seconds, and finally the control level involving feedback-based adjustment of vehicle interfaces such as steering, accelerator pedal, and brake over a time horizon of seconds to milliseconds. The work presented on the decision logic primarily involves the strategic level driving activity while the lane change maneuver execution work overlaps the tactical and control level processes.

Drivers may have several individual motivations that influence their intention to consider and execute a lane change. Gipps [3] summarizes the driver's decision process very simply as three rhetorical

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statements, Is it possible to change lanes? Is it necessary to change lanes? And ss it desirable to change lanes?

Gipps then goes on to present a framework which could be used to pose these questions relative to the strategic driving context, identifying six factors on which to develop a driver decision model.

The influence of speed is investigated by Keyvan-Ekbatani [4] studying the categorization of the lane change decision processes on freeways highlighting four individual driving strategies that influence when and how a driver chooses to execute a lane change of the participating Netherlands drivers,

Keyvan-Ekbatani [4] also found that the speed leading driver strategy was adopted by most of their participants. This work adopts this assumption and builds upon it as the foundational assumption behind the present LCA implementation. However, the research of Gipps and Keyvan-Ekbatani also remind us that not all drivers operate in this way, although all view their strategic behaviors “as an obvious behavior and expect all other drivers to drive in a similar way” [4].

Naturalistic driving data, however, tells the story a bit differently. Even though at the individual level the perception is that one driver may vastly differ from the next, at the control level, drivers’ are more similar then they would believe.

Lee [5] reported that 95% of drivers generally had 43 feet of space or more at the time the lane change began and roughly the same amount of space rearward (40 feet). The mean duration of a lane change was 6.26 s. Other scenarios are presented such as that of mean merge duration of 5.48 s and exit prep being 6.87 s.

Takeaways from this review also suggested that a single slow lead vehicle lane change should be approximately 6 seconds with a speed dependent minimum Time Headway (TH) envelope (40 feet at 50 mph equates to a minimum headway of 0.7 s) around the vehicle. The very next item that needs to be understood is when to recommend the lane change to the driver such that they have enough time to make the lane change. “A reasonable estimate is to present the message at least 6.7 s (the mean plus two standard deviations) before the beginning of the exit lane” [5](p.15) i.e. before the desired time for lane change initiation. This is supported by data that IKA Aachen presented, stating that naturalistic data from European testing confirms slow traffic in host vehicle lane as a significant factor affecting the driver motivation to perform a lane change.

While these reported metrics highlight the general trends found, it is important to keep in mind that these numbers reflect average behavior and that each of these characteristics are associated with potentially large variance due to the individual strategic driving differences which influence the how, when, and why decisions are made. These general trends, however, do serve as a basis for the research that follows.

2. Algorithm Concept

2.1 Lane Change Determination Factors

The LCA is a feature that utilizes the capabilities of available on-board sensing modalities to infer driver intent to make a lane change. Driving context from environmental cues which when combined with observed driver actions inform a decision framework for the purpose of aiding the driver in maintaining their intended travel speed through the opportunistic identification of lane change maneuver opportunities. The driver intention inferences draw upon forward looking sensor measurements in the current lane of travel for both a dynamic perceptual model and a pseudo steady-state traffic following component. The dynamic element utilizes the concept of visual looming, based on human perception of rapid visual image expansion on the retina as the distance between driver and obstacle ahead decrease over time. The steady-state component utilizes commands from the Adaptive Cruise Control (ACC) CAN network of signals during vehicle following for decision making.

The main objective of the Lane Change Advisor (LCA) algorithm is to generate a signal inferring the driver’s intention to perform a lane change based on contextual inferences derived from observed driver behaviors and information about the driving environment determined from available sensor

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data. In reference to the complete lane change task captured in Figure 1, LCA is best represented by the left "LC Decision Algorithm" block. LCA offers lane change recommendations to the driver, which can inform driver decisions regarding opportunities to execute lane changes providing the driver with the option of whether or not to manually act on the advice and execute a lane change maneuver. The emphasis of this work was on highway driving scenarios excluding entrance, exiting, and merging scenarios.

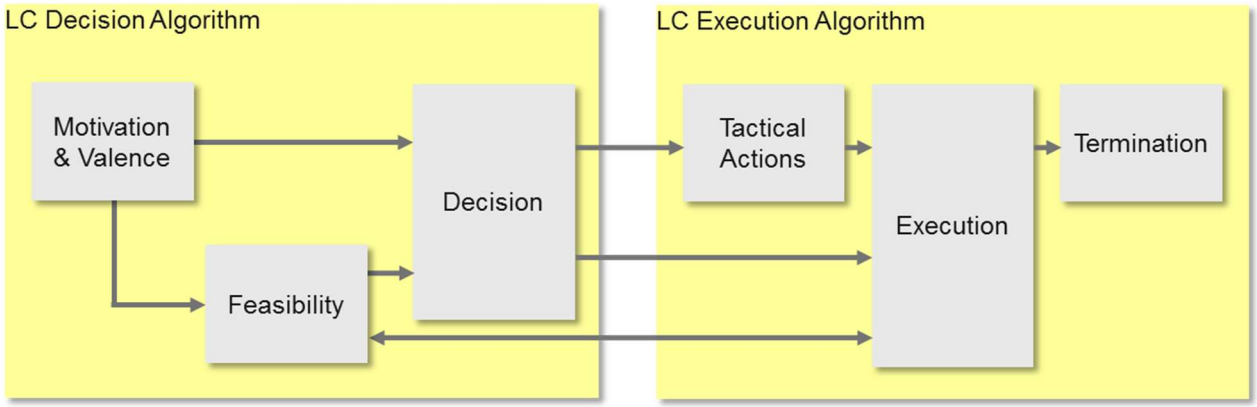


Figure 1. Lane Change Adviser (LCA) Algorithm Decision and Execution Blocks

The LCA block diagram is shown in Figure 2. The following subsections describe the details associated with each of these blocks.

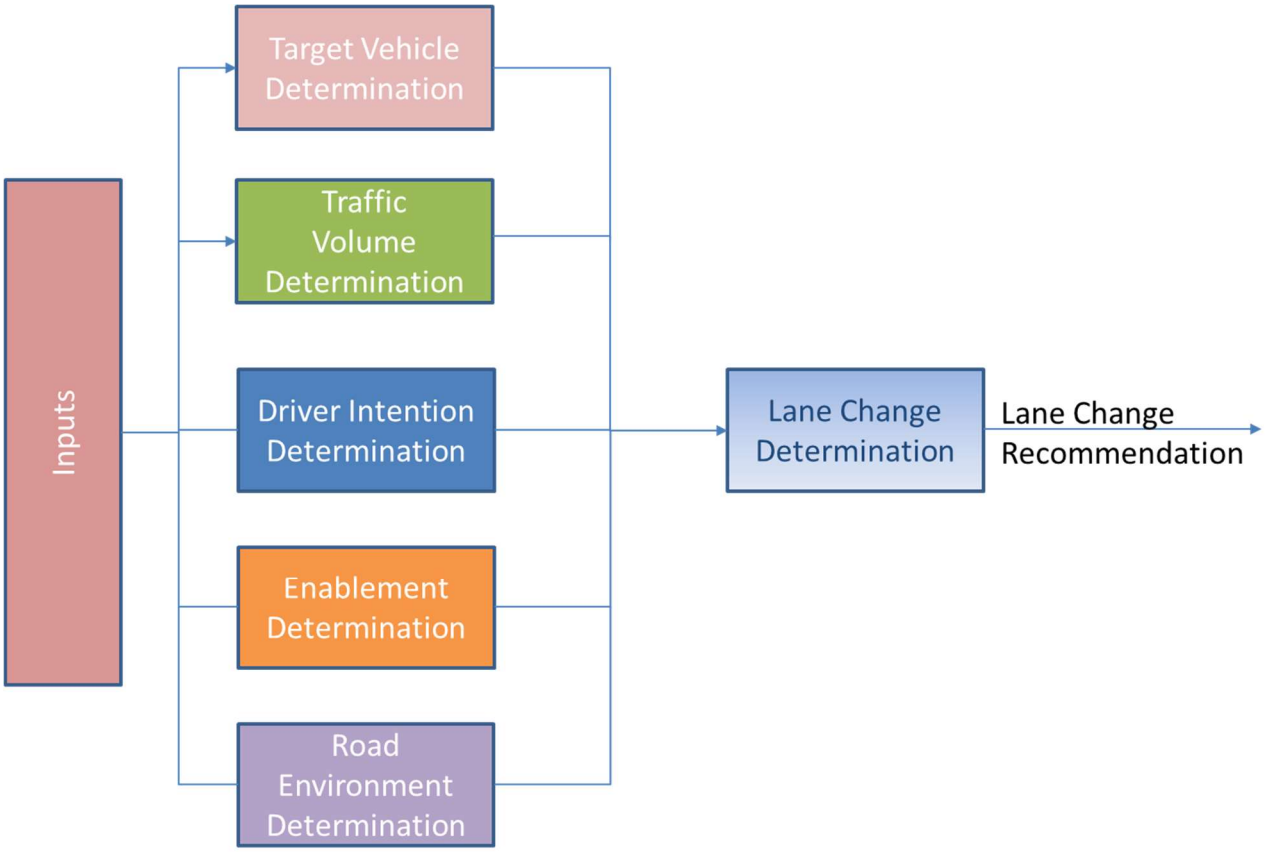


Figure 2. Lane Change Adviser (LCA) Algorithm

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2.2 Effect of Each Factors

2.2.1 Target Vehicle Determination

The current vehicle model implementation is based on a sensing capability available in the MKZ development test vehicle available for this work. This system in this vehicle included forward looking camera, a forward-looking radar and side looking BLIS radars. Processed BLIS status information, presence or absence of target vehicles, is also used by the lane change motivation algorithm to provide situational information related to vehicles located in the adjacent lane blind spots of the host vehicle. Also the existing ACC radar target processing capability was leveraged to identify the presence of a vehicle ahead in the subject vehicle's lane of travel.

Figure 3This radar system's development interface was accessed to provide essential ACC target vehicle information, including target vehicle range and range rate which are used to aid in accurately identifying slower moving vehicles in the lane of travel. Unfortunately, this system provided no information regarding targets in the adjacent lanes ahead.

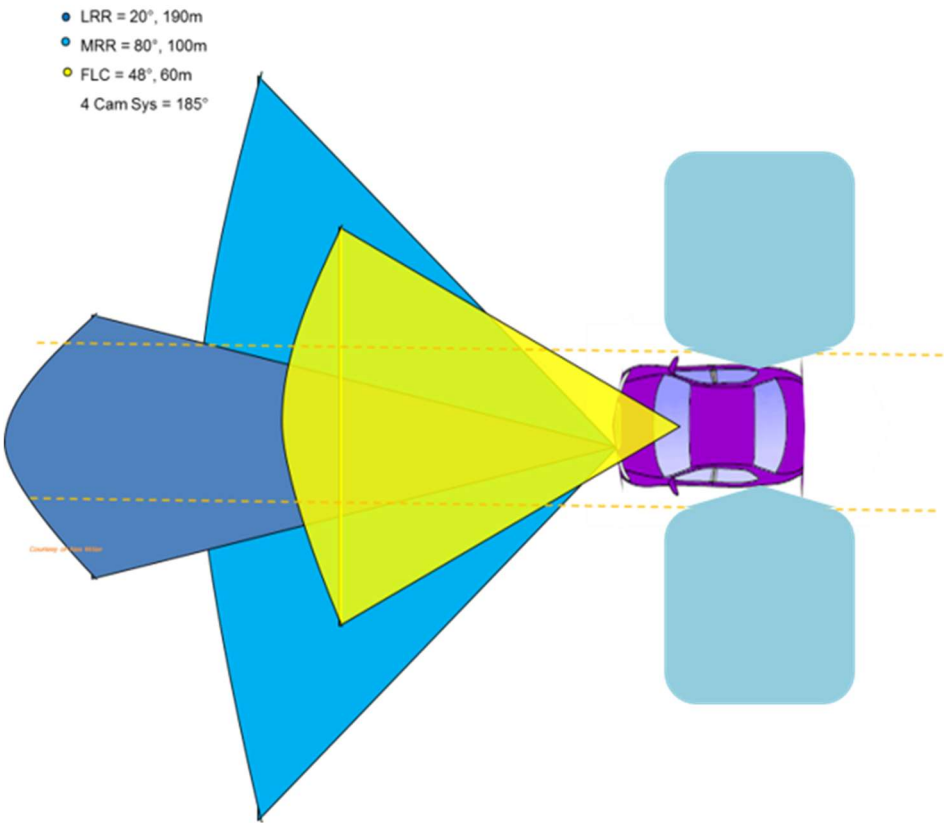


Figure 3. Lane Change Adviser (LCA) AlgorithmCADS3 Sensor Set on MKZ Test Vehicle

Similarly, the development vehicle's sensing system did not offer rear looking sensors capable of detecting the presence of vehicle targets in the lane of travel or either of the adjacent lanes beyond the blind spot detection zones. Availability of this type of information from the sensing system would make it possible to extend the capability of the implementation.

The ACC target range is defined as the distance, D, as determined by the sensing system, that a moving target (red car) is ahead of the blue subject vehicle as shown Figure 4, up to the detection range of the sensing system. Since the interface in the test vehicle provides range and range rate, but does not directly provide headway time it is possible to compute it from the range D, and the time rate of change of D, or range rate ($\dot{D}$) as it's more commonly known, as shown in the simple equation below.

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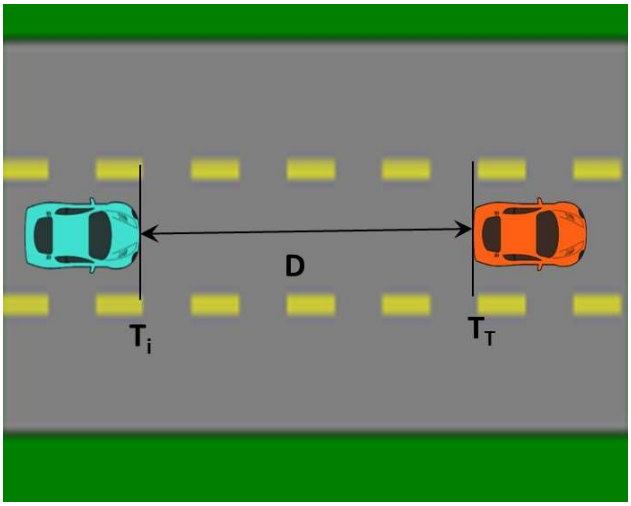


Figure 4. Target Vehicle Detection for Lane Change Decision Making

$$T_H = \frac{D}{\dot{D}} \quad (1)$$

Future implementation based upon enhanced sensing capabilities can offer 360 degree enhanced vehicle target tracking, on straight and curved roads and even occupancy grid information surrounding the vehicle that can further inform the LCA.

Ultimately, robustness will depend upon the ability to accurately locate and predict the presence of gaps into which the lane change maneuvers can be completed.

2.2.2 Enablement Determination

It may not yet be obvious from the above discussions, but the lane change recommendation trigger generated by the ACC entrainment or looming perceptual logic cannot be issued to the driver independently of additional contextual questions identified by the algorithm. The enablement logic block consists of contextual factors that influence whether or not lane change recommendations can be issued to the driver. Select vehicle state conditions were determined as precursors to allowing a recommendation to issue by the HMI. The following list contains a set of contextual conditions included in our implementation which influence whether a lane change recommendation is suppressed (i.e. will not be made to the driver).

2.2.3 Road Environment Determination

It is assumed that all of the necessary road context data will be provided by the sensing system, to provide processed signals along with an associated quality factor indicating the presence or absence of viable lanes adjacent to the host vehicle which are appropriate to support the completion of an automated lane change. Such information can be significantly enhanced through the inclusion of associated factors such as the available duration of the adjacent lane some specified distance into the future.

The development vehicle used for our work does not provide processed signals indicating the presence and availability of adjacent lanes. As this information was essential to the LCA, relatively low level processed sensor signal information about right and left lane markings provided by the on-board camera system interface were utilized to construct the necessary environmental context information.

Therefore, the road environment determination block was developed for this model utilizing both line type and color information to determine the viability of the adjacent lane. Because of the presence of real world noise factors, like intermittently missing or damaged markings, the presence of highway exit and entrance ramps, the instantaneous road marking measurements received from the camera

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must be further processed to determine the final lane boundary status before being used as described next.

This confidence estimate is then evaluated with respect to a calibrated threshold to determine the final adjacent lane viability determination. This structure provides an asymmetric capability to respond, for instance more quickly to the presence of newly available lanes but somewhat more slowly in response to short term drop outs, including entrance or exit ramps as can be seen in Figure 5.

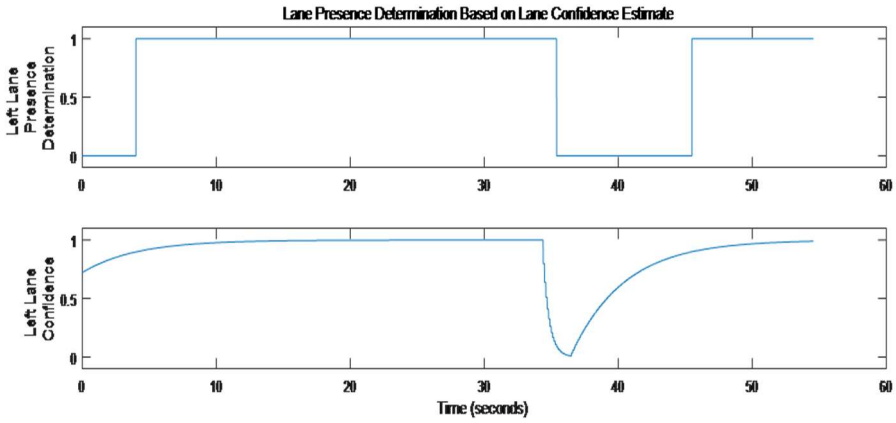


Figure 5. Adjacent Lane Presence Estimation

2.2.4 Traffic Density Determination

The cartoon diagram, Figure 6 (near 30 seconds), provides a driving scenario which would produce the traffic density plots shown in Figure 7 for the right and left lane traffic density.

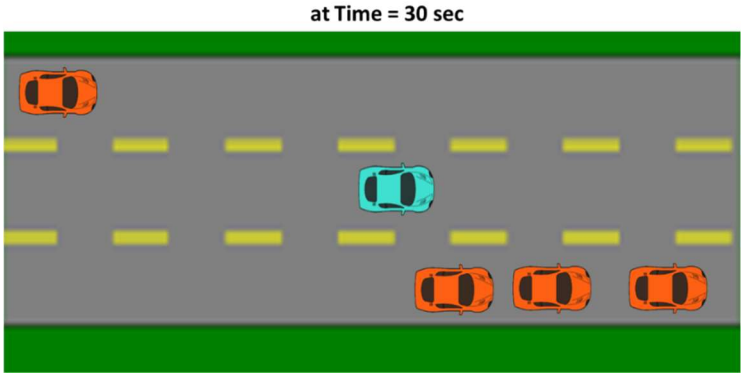


Figure 6. Driving Context Associated with Traffic Density Estimation Time Traces

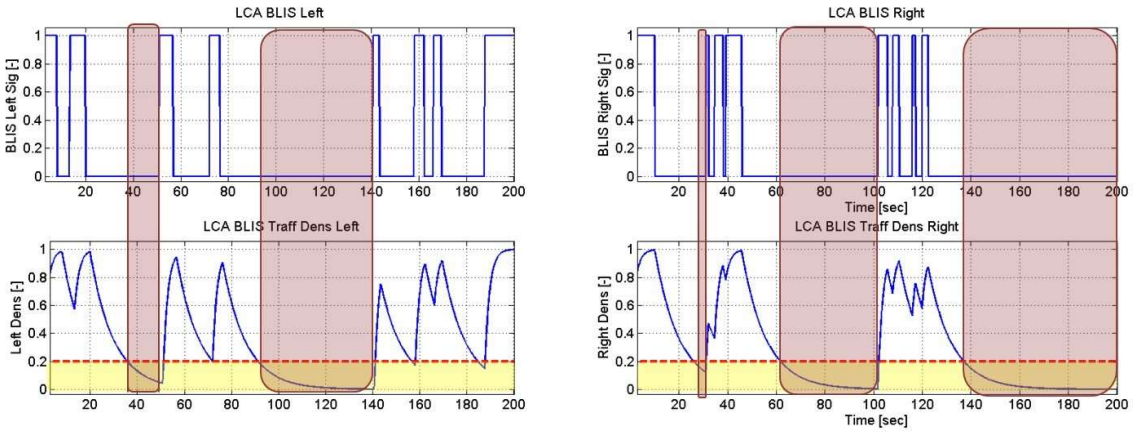


Figure 7. Traffic Density Estimation Response for Right and Left Adjacent Lanes

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An example of this scenario based on the current implementation is shown below where the subject vehicle is being passed by another vehicle traveling at a higher speed in the left lane as shown in the cartoon of Figure 8 (near 80 seconds), producing the associated actual traffic density responses captured in Figure 9 and the desired response shown in Figure 10. Notice in Figure 9, the delay from the time when the BLIS signal goes to zero at approximately 75 seconds until the density signal crosses the lower threshold at approximately 92 seconds. Figure 10 is showing that it is desirable to report the reduced traffic closer to 80 seconds thus increasing the overall responsiveness of the algorithm. One way to reduce this lag is to utilize independent forgetting factors for increasing and decreasing transitions so that the rate of each can be independently tuned. The second opportunity highlighted by the opposite end of the box in Figure 10 is the condition that by its design, BLIS does not provide information about approaching vehicles until they have entered the subject vehicle's blind spot. The traffic volume estimate would benefit from having information about approaching vehicle's so that the increasing traffic volume can be detected in anticipation to its actual arrival as detected by BLIS near 140 seconds. The availability of 360 degree radar with Enhanced Target Selection (ETSEL), will improve the performance of this algorithm by providing relative range and velocity measurements for surrounding vehicle targets for vehicles behind and to the sides, as well as in front, of the subject vehicle significantly improving awareness regarding the presence of target vehicles in the adjacent lanes and influence lane change decisions.

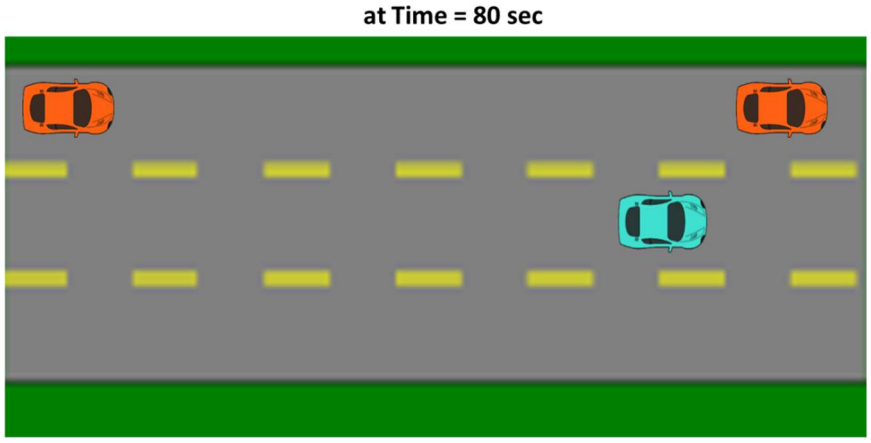


Figure 8. Driving Context Associated with Traffic Density Time Traces

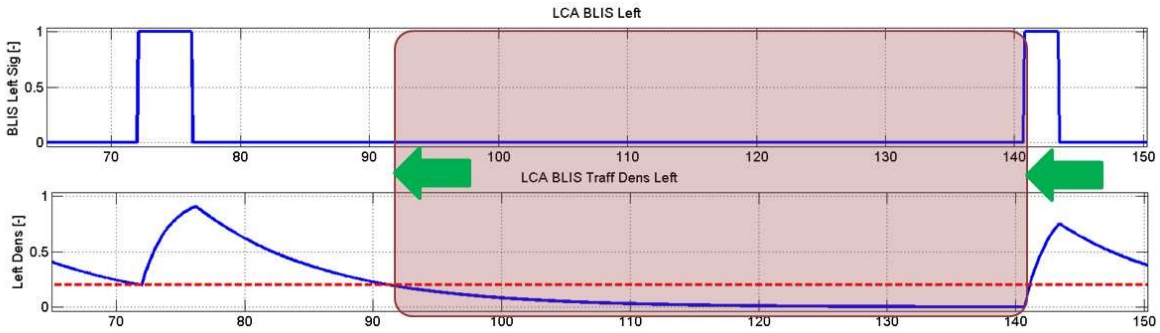


Figure 9. Traffic Density Estimate: Current Implementation

A recursive algorithm for the computation of the traffic density is given by,

$$\text{TrafficDensity}(k) = (1-\alpha)\text{TrafficDensity}(k-1) + \alpha f(k) \quad (2)$$

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...where,

f(k) =1, if vehicles detected as in or entering adjacent lane change region;

f(k) =0, if no vehicles are in the targeted lane change space;

and where α is a tunable forgetting factor, such that [0 ≤ α ≤ 1].

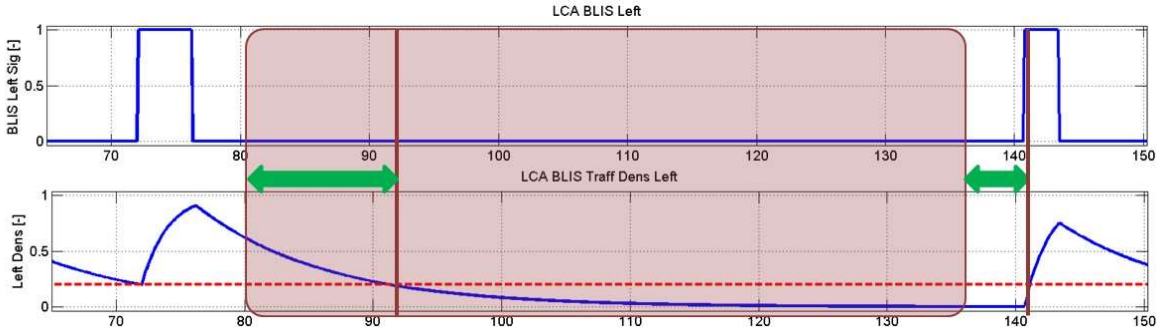


Figure 10. Traffic Density Estimate: Desired Implementation

2.2.5 Driver Intention Determination

There are many contextual nuances to determining driver intention 2.11. Within this LCA model we define two modes for identifying lane change motivation which we define in the sections below. The first being a transient activation schema, and the second being a schema for activation under approximately steady state conditions we term as looming and entrainment.

These individual methods can be used together during ACC speed control operation or operate independently. The Looming based determination can function with or without ACC speed control activated as long as target vehicle (i.e. lead vehicle) information is provided by the sensing system. Entrainment only operates when ACC is active, providing contextual information related to the driver's desired cruising speed and their gap setting preference. Due to their respective significance in determining driver intention for the LCA, these are the topics of the next two chapters.

The final output of the Looming model which along with the output of the model are supplied to the decision logic as shown in Figure 11. For the MKZ vehicle development, a simplified decision structure was implemented by the looming model and steady-state model decisions to create the final driver intention determination.

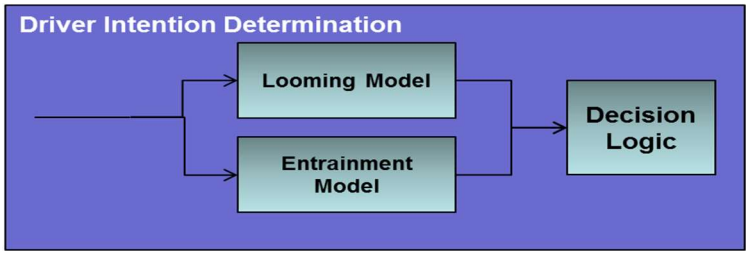


Figure 11. LCA Driver Intention Block Diagram

3. State Control and Road Validation

3.1 Transient And Steady State

3.1.1 Transient State

Motion perception in surface transportation, specifically highway driving, plays a larger role than visibility itself. Parlaying this to driver assistance features, specifically to the lane change adviser (LCA), this means that advising of a lane change 'should' likely be done when the driver can perceive the relative motion or 'looming'.

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Green [7], [8] goes on further to state that "drivers 'see' many vehicles on the roadway ahead, so the mere presence of a lead vehicle does not necessarily imply the need to respond". Drivers have a difficult time being able to quantify or tell anything about the rate of closing or the imminence of collision.

The psychophysical factors of looming are the quantifiable measures of the human eye's ability to sense object contrast, motion, etc. The decision on whether, when, and how to respond depends on the available response alternatives and their consequences.

Vagnoni et al. [9] stated that judged TTC increased monotonically with actual TTC though the rate of increase was substantially less than would be predicted from an ideal observer. From a design standpoint this means that the situation is more severe than it is perceived to be, especially at longer distances. Thus, it was deemed critical to advise of a lane change as soon as the average detection threshold was reached and held for approximately one-third of a second. Tuning is available for both the rise and hold time as well as for the actual threshold as mentioned.

Green [8] states that the decision on whether, when and how to respond depends on the available response alternatives and their consequences. The goal is to make the recommendation to steer around when it is physically verifiable, but the driver may be unsure of that alternative.

Perceived looming depends on detection of vehicle cross sectional area. It is possible to provide calibratable upper and lower bounds that constrain the impact of the extremes in vehicle size on the performance of the algorithm. Larger vehicles are perceived earlier than smaller ones thus it may be desirable to bound minimum size to small cars so that detection thresholds for even smaller vehicles like motorcycles or motor scooters occur at the same point as the small cars.

The transient aspect of the decision making is for situations in which the driver may be driving in any of three drive modes: adaptive cruise control, cruise control, or manual driving, and is rapidly approaching a slower moving, or stopped vehicle in their lane of travel. Most drivers, if they are alert with eyes on the road ahead, notice a rapid visual expansion of the lead vehicle as they are approaching it and either slow down (brake-only) or execute a lane change (brake-&-steer or steer-only).

This rapid optical expansion of the image on the retina is called visual 'looming', see Figure 12. The phenomenon occurs as the distance between the driver and obstacle ahead decreases over time. Looming is a primitive optical variable for obstacle avoidance, including braking:

$$\theta(\mathrm{t}) = \frac{-W * R(t)}{R(t)^2 + W^2} \tag{3}$$

...where W is the width of the vehicle ahead, R(t) is the range to the vehicle ahead, and θ(t) is the retinal image size or the subtended viewing angle.

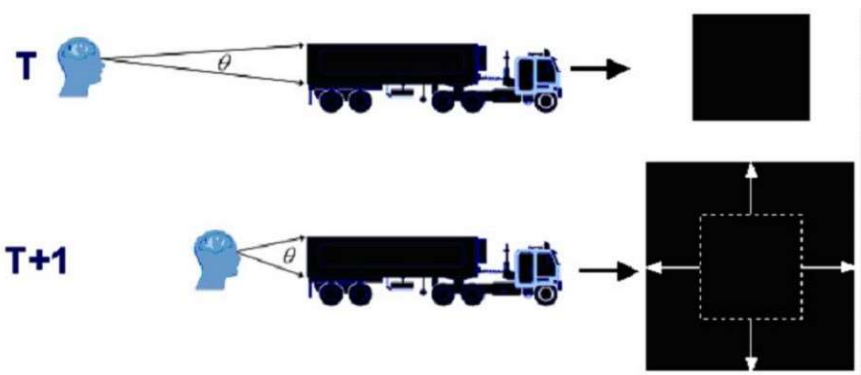


Figure 12. Visual Depiction of Looming (source Green)

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Mortimer [10] has indicated that the threshold for detection of angular rate of change, $\dot{\theta}$, in driving contexts is between 0.002 and 0.004 radians/s, with a nominal threshold value of 0.003 radians/s.

The conjecture is that a driver will visually verify the source of an alert or alarm and modulate their response accordingly. The goal of the LCA is to suggest a lane change when the driver can visually verify the need to change lanes. For example, assume that a lane change advisory is generated when $\dot{R}$ =10mph (15 ft per sec) and the system can sense this at 215 ft. A driver will not perceive that he/she is closing until R = 170 ft. Thus, for a $\frac{(215-170)ft}{15ft/sec} = 3$s, the LCA would be suggesting a maneuver that the driver sees no need for. At 170 ft, the driver will begin to see that he/she is closing and will then be able to make a decision.

To be compatible with driver perception, we believe it is most useful to present the recommendation at or beyond the human looming threshold, even if the sensor suite and algorithm can detect the opportunity or need to change lanes sooner. However, an earlier alert may also be beneficial provided the opportunity or need to change lanes becomes visually apparent within some time t s.

3.1.2 Steady State

When entrained or steady state, a common scenario that arises is a slowing of the subject vehicle toward the slower moving vehicle's speed of travel in the lane ahead based on the vehicle-to-vehicle separation and the subject vehicle's ACC gap setting. IKA Aachen research produced from their lane change Alliance project also identified this usage scenario as a significant factor affecting the driver motivation to perform a lane changes.

At times, this slowing can occur without the driver noticing that they have dropped below their desired speed of travel. The entrainment algorithm monitors this ACC initiated drop in cruising speed below the drivers targeted speed and once it exceeds an established threshold, initiates a countdown timer to determine the proper time to issue a lane change recommendation.

The entrainment or steady state element of the driver intention determination, unlike the looming aspect, operates only when the driver is operating in speed control with ACC active. This provides an option to control the timing of the lane change recommendation based the driver's ACC gap setting preference or alternatively in a fixed relation to the slower moving target vehicle in the host's lane of travel. This relatively simple algorithm utilizes the driver's speed control set-point, ACC system target speed request, and actual vehicle speed to decide when to issue lane change requests.

By comparing the ACC speed target with the actual vehicle speed so that if the driver decides to allow vehicle to slow the vehicle down to the steady state ACC target and remain there, the advisor should not continue to issue lane change recommendations to the driver. As implemented currently, the threshold for the second expression is tuned off so as to eliminate this element from the in-vehicle lane change recommendation determinations.

3.2 3.2 On-road Validation

Once the parameters were tuned against pre-recorded data to our liking, we were ready for an on-road evaluation. Each of the following scenarios were captured on a limited access highway, while driving manually at highway speeds. No ADAS feature was engaged including either ACC or normal cruise control.

n this looming scenario, the subject vehicle is rapidly approaching a slower moving lead vehicle. Both velocity and range to the target lead vehicle are given in Figure 13. The presence of the target lead vehicle is initially reported at a range of approximately 140 meters near 30 seconds. The range decreases as the subject vehicle accelerates, and once the range reaches approximately 100 m, near 50 s, the visual angle parameter begins to climb and TTC begins to decrease, as shown in Figure 14 and Figure 15.

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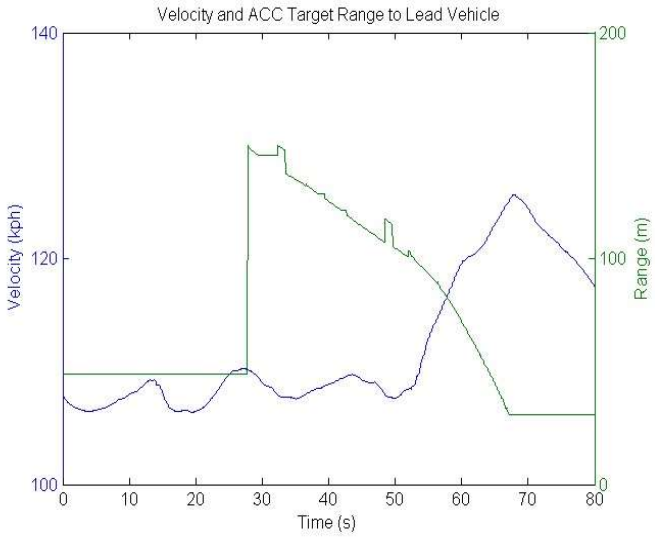


Figure 13. Velocity of subject vehicle and Range to Lead Vehicle

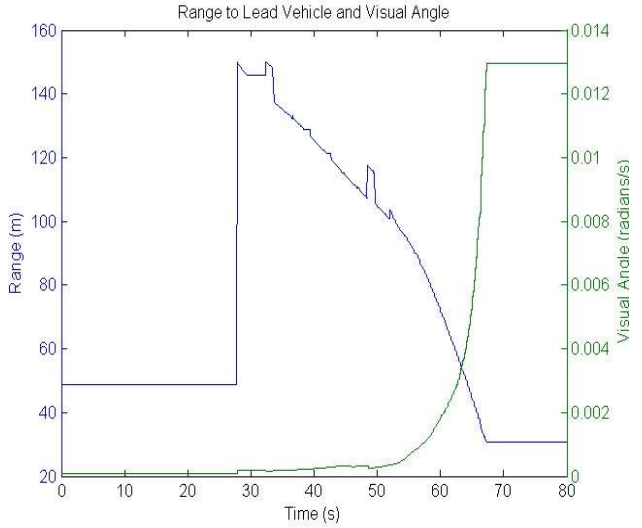


Figure 14. Range to Lead Vehicle and Visual Angle Rate

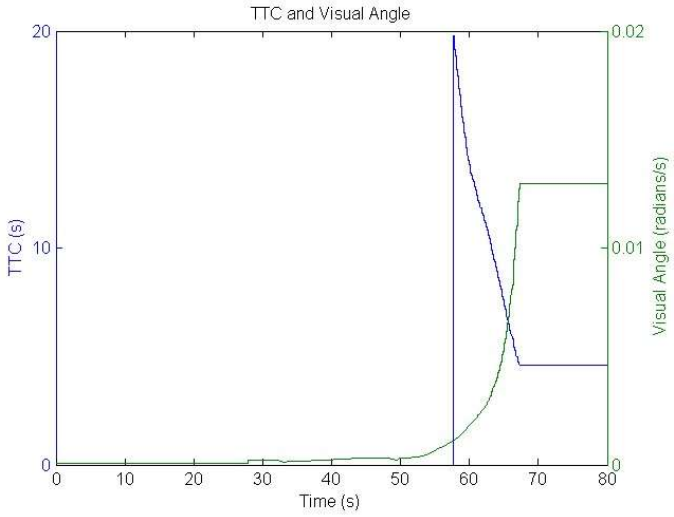


Figure 15. TTC to Lead Vehicle and Visual Angle Rate

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4. Conclusion

While Chapter 2 and Chapter 3 cover the technical details of both the looming and entrainment models, they don't capture the observed benefits of having a feature with both recommendation schema working in tandem. While the Looming model functions quite well for fast approaches it fails when the forward vehicle is quite far out and the range-rate isn't large. The entrainment model was designed to pick up on this more subtle difference and allow for the recommendation to be made far enough in advance that the driver has adequate time to ponder their decision to steer around. Whereas the looming model requires that the driver take immediate action or loose the benefit. Without the Entrainment model the driver is only left with a feature that triggers on fast approach, and without the looming model the driver is left with a feature that feels lacking.

Looking toward a feature use of the lane change adviser and taking the interaction paradigms into account leads us to believe that the adviser will benefit driver experience and can also be used for next lane change maneuver.

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