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# Communicating Driver Intents: A Layered Architecture for Cooperative Active Safety Applications

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*Abstract*— **The great promise of vehicle to vehicle communications includes a reduction or even elimination of collisions and fatalities on roadways, especially of those due to driver error. A major roadblock to the effectiveness of these systems is the market penetration of cooperative Driver Assistance Systems. Many proposed and existing implementations of cooperative systems are only effective if a majority of vehicles are capable of cooperating. We propose the use of a Layered Architecture for Cooperative Active Safety Applications (LACASA) that includes driver behavior or intent prediction as a fundamental building block for cooperative assistance systems. Simulation results show how such information could improve safety even in limited-deployment scenarios, and in wide-scale deployment, unsafe maneuvers are nearly eliminated.**

## I. INTRODUCTION

Every year it is estimated that over 2 million injuries and 35,000 fatalities occur as a result of traffic collisions on US roads [1], with over 10% occurring in California alone. The National Highway Safety and Transportation Administration has estimated that "inattention" is the contributing factor in up to 80% of all crashes [2]. The lives lost and significant costs associated with these collisions require new approaches, such as innovative embedded systems and communication networks [3], to make roads safer and more comfortable. Even a 1% improvement in safety countermeasures could lead to saving 400 lives, 30,000 injuries, and $2.3 billion annually [2].

The scope of this research aims directly at the problem of understanding driver behavior, and the driver's interactions with the surrounding environment that influence their behaviors, to improve *cooperative active safety* systems. With the anticipated increasing market penetration of modular V2V and V2I communications frameworks such as Intellidrive [4] and Car2Car [5], we propose a design for an integrated, intelligent Layered Architecture for Cooperative Active Safety Applications (LACASA), with a special focus on a human-centered advanced driver assistance systems implementation of LACASA. The key design components of the LACASA framework include the following features:

- **Holistic**. The system should incorporate any available information about the driver, vehicle, and environment, all through sensors on the ego-vehicle itself.
- **Cooperative**. The system should be able to operate in stand-alone mode, but should also be capable of improved performance through communications with other vehicles and infrastructure.
- **Modular**. It should be able to cooperate at different "levels": new vehicles and infrastructure will enter the market with varying sensory and communications capabilities, and each LACASA node must be able to utilize the best available information from all the other systems.

In this paper we demonstrate how the proposed layered framework could have an immediate effect in improving active safety in stand-alone vehicles, through the incorporation of Driver Intent detection [6], [7], [8], [9] as well as obstacle trajectory prediction [10]. As market penetration of the cooperative system increases, there will be a significant quantitative improvements in safety at various levels. The framework as a whole does not rely on a particular rate of market penetration to start improving active safety, thus overcoming a fundamental problem with many communication-based driver assistance systems. By utilizing all available production-level sensors existing in the ego-vehicle, as well as whatever level of information may be available from cooperative vehicles and infrastructure, the proposed framework demonstrates an elegant approach to implementing future active safety systems.

The examples in Figure 2 embody the overall objectives of the proposed LACASA framework: By sensing and analyzing relevant information from both the interior and exterior of the vehicle, we hypothesize that active safety systems will be able to provide more accurate predictions and allow the driver earlier awareness of dangerous situations. Additionally, cooperation at different levels with surrounding vehicles could provide a more accurate and useful context to determine situational criticality, and provide alerts and assistance to drivers even earlier.

## II. COOPERATIVE IMPLEMENTATION OF INTENT-BASED ADVANCE DRIVER ASSISTANCE SYSTEMS USING LACASA

### A. Market Penetration and "Layered" Framework

A major consideration in the design of cooperative active safety systems is the requirement for a significant number of vehicles to be equipped, in order for the system to work reasonably. However the market penetration of such systems is bound to advance slowly.

According to NHTSA [11], assuming every new vehicle on the road is equipped with an active safety system in each year since deployment, a best-case scenario, just 8% of vehicles on the roads would have the system after 3 years, and 27% of vehicles after 10 years. In order to overcome

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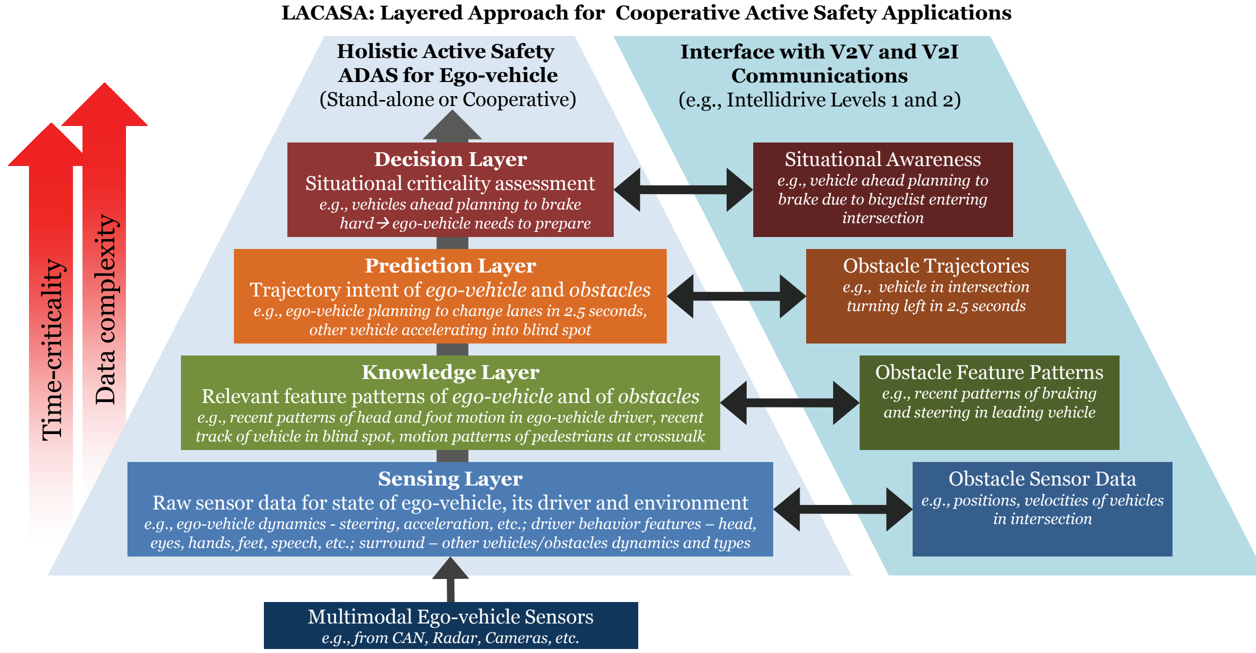



Fig. 1. Layered Architecture for Cooperative Active Safety Applications (LACASA). A LACASA Driver Assistance System could operate independently without communication; and various layers could communicate over V2V and V2I depending on the implementation in each vehicle.

this penetration issue, as shown in Figure 1, each layer of the cooperative DAS is capable of communicating and integrating information at various levels. This is designed explicitly to allow for various types of V2V protocols and devices that will come online in near future. Some vehicles may have after-market communications devices with limited sensors and communications. Other vehicles will have top-of-the-line sensors with built-in time-critical communications protocols.

Information received from either of these vehicles, should be useful to an ego-vehicle equipped with the proposed LACASA framework. As more informative information about obstacle positions, trajectories, and intents become available from more advanced systems, the ego-vehicle's estimate of the situational criticality should tangibly improve. Thus increasing market penetration of V2V Intellidrive-style systems, while not critical to the performance of a LACASA ADAS, would systematically improve its performance in an elegant manner.

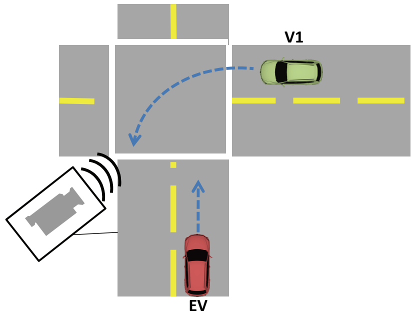
Additionally, V2I systems could be extremely useful for enhancing operational capabilities of vehicle-based active safety systems. Recently researchers have been successful in being able to predict vehicle trajectories and patterns from intelligent infrastructure [12], [13]; this information could feed directly into the "Prediction Layer" of a vehicle-based LACASA system.

A number of situations would benefit from intelligent cooperative DASs, including Forward Collision Warning, Lane Change Assist, and Intersection Assist. The improvements in these systems due to cooperation were somewhat dismissed by NHTSA [11], due to low estimated market penetration. However an implementation of the proposed framework does not suffer for lack of other such systems on the road. Indeed, as various systems come online, the ego-vehicle system would adapt and correspondingly update its performance, as demonstrated in the next section.

An example of a proposed protocol is the DOT-sponsored Intellidrive project [4]. The consortium has proposed several levels of communication protocols, where Level 1 includes stand-alone devices without access to the vehicle computer, and Level 2 includes built-in access to vehicle parameters. These levels are further subdivided into time-critical and non-time-critical applications. The proposed LACASA framework can incorporate information from either level of communication, with basic Level 1 position and velocity information sufficient to establish other vehicle's trajectories and baseline intentions. Level 2 information can provide more detailed information about other vehicle's trajectories, intents, and even their sense of the situational criticality.

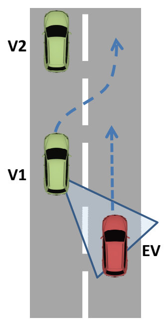
In the simulated results reported below, as well as the sample situations in Figure 2, we consider several different sample implementations of the driver assistance system. These are based on the proposed framework of Figure 1, including the vision of a modular roll-out of Intellidrive-style communications. Table I compares some example features of each implementation of the LACASA system.

An important consideration in communication networks is the limited data rate of the channel. Protocols could be considered under the proposed framework, where messages are only broadcast in potentially critical situations, as has been done in prior research [14].




**Situation 1**. Ego-vehicle (EV) with inattentive driver approaching (intelligent) intersection where Vehicle 1 (V1) is slowing in preparation to make a left turn.

| Ego-Vehicle LACASA DAS Implementation | Vehicle 1 LACASA DAS Implementation | Intelligent Infrastructure with LACASA | Situational Criticality |
|---|---|---|---|
| None | None | None | EV could collide with V1 since both are unaware of the other's intentions |
| HC-ADAS | None | None | Radar on EV detects V1 and notifies driver of potential obstacle |
| HC-ADAS | None | Camera or Loop Detectors | Infrastructure detects V1's trajectory and notifies EV driver of likely obstacle |
| HC-ADAS | After-market-GPS | None | EV radar detection is complemented by communication from V1 indicating more accurate position and velocity information |
| HC-ADAS | After-market-GPS | Camera or Loop Detectors | EV radar detection is complemented by communication from infrastructure and from V1, indicating more accurate position and velocity information |
| HC-ADAS | HC-ADAS | Camera or Loop Detectors | V1 communicates trajectory intent based on V1's driver behaviors, to infrastructure and to EV, which issues a critical warning to EV driver about upcoming obstacle |




**Situation 2**. Highway lane change. Vehicle 1 (V1) intends to change lanes, due to slow lead vehicle (V2), unaware of the ego-vehicle (EV) in its blind spot. EV driver is unaware of the potentially dangerous situation.

| Ego-Vehicle LACASA DAS Implementation | Vehicle 1 LACASA DAS Implementation | Situational Criticality |
|---|---|---|
| None | None | EV could collide with V1 if EV driver is inattentive or unable to respond fast enough. |
| HC-ADAS | None | EV detects lane change of V1 soon after the maneuver starts, and notifies EV driver to slow down |
| HC-ADAS | After-market-GPS | EV's calculated Trajectory Intent of V1 is complemented by (time-critical) communication from V1 with more accurate lane-position information. EV is able to predict V1's lane change earlier, in order to notify EV driver. |
| HC-ADAS | HC-ADAS | V1 communicates lane change intent based on V1 driver's head motions and situational awareness (slow V2 ahead), to Ego-vehicle. EV-driver is then alerted to prepare to slow down, even before V1 starts changing lanes. |

Fig. 2. Motivational examples for modular, cooperative LACASA framework. The ego-vehicle, equipped with a proposed human-centered advance driver assistance system (HC-ADAS) based on LACASA, can interact with the obstacle vehicle (V1) in various manners depending on V1's implementation. Without any communication from V1, the advanced version of EV+LACASA is still able to improve performance through advanced sensing. With each additional bit of information from V1 (more details in Table I), the ego-vehicle is able to make more accurate and timely assessments of the situational criticality. The same holds as increasing amounts of information come in from Intelligent Infrastructures, as seen in Example 1 (top).

TABLE I

SAMPLE "LEVELS" OF IMPLEMENTATIONS OF LACASA. FUTURE VEHICLES MAY HAVE ONE OF THESE TWO LACASA-BASED ADASS, OR INCLUDE SOME COMBINATION OR SUBSET OF THE SENSOR AND COMMUNICATIONS EQUIPMENT.

| *LACASA Implementation* | *Sensors* | *Communications* |
|---|---|---|
| After-Market with GPS (*AM-GPS*) | GPS, Lane-Camera | *Intellidrive Level 1*: Pos, Vel; Basic Features and Simplistic Trajectory Intent |
| Human-Centric, Holistic ADAS (*HC-ADAS*) | + Face-Camera, Radar, Vehicle Data | *Intellidrive Level 2*: Complex Features, Advanced Trajectory Intent and Situational Awareness |

## III. QUANTITATIVE IMPROVEMENTS OF COOPERATIVE LACASA-BASED SYSTEMS

To demonstrate the improvements in safety using the cooperative LACASA framework for driver assistance systems, the following section discusses some quantitative assessments of several example situations. These situations are built upon recent research into driver intent prediction [6], [8], [9], [7], with the aim to determine the relative improvement in safety gained through transmission of intents using the layered LACASA approach.

*1) Forward Collision Warning - Risk Assessment Calculations:* Recent research has shown how significant gains in safety can be achieved with relatively modest reductions in speed [16], [17]. These studies determined that at $60km/h$, every $5km/h$ reduction in speed results in between 33 and 50% reduction in crash fatalities. This is a clear case for such ADAS applications as Forward Collision and Early Brake Warning Systems. Advanced sensing through ACC

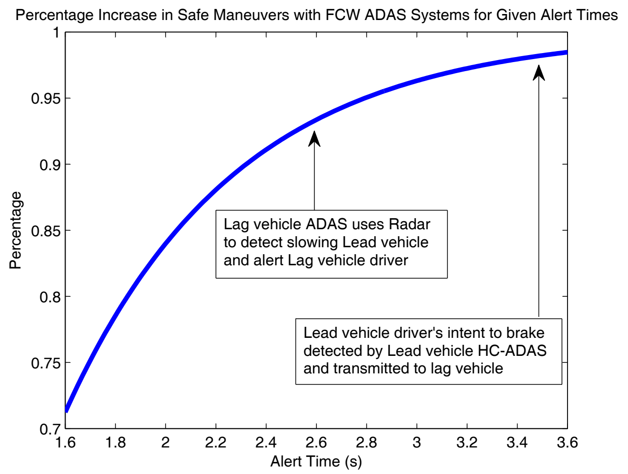



Fig. 3. Forward Collision Warning - Reduction in risk with earlier alert times. Recent research showed ACC radar affords a 2.6 second alert time before a crash [15]. By incorporating a lead vehicle driver's intent to brake [8] and transmitting that information using LACASA to the lag vehicle, a significant reduction in fatal crashes could result.

radar could potentially alert the driver up to 2.6 seconds in advance of a crash [15].

An inattentive driver in a vehicle with a holistic LACASA HC-ADAS might be alerted to the vehicle ahead slowing down through the ACC radar. With such input, the driver may become alert and begin braking; potentially reducing risk of involvement in a fatal crash by 93.36%.

Assuming the preceding vehicle also had a holistic, cooperative HC-ADAS as proposed, the preceding driver's intent to brake could be detected 1 to 2 seconds in advance of the action [8]. With a one second lead time in the alert of the inattentive driver in the ego-vehicle, the driver in the lag vehicle could begin braking earlier, reducing their speed even further and reducing risk of involvement in a fatal crash by 98.47%.

Figure 3 shows the fatal crash risk reduction as a function of alert time, with a fixed response time ($0.75s$) and deceleration ($0.5g$). These sample calculations show the power of adding the HC-ADAS system to cars, even if other cars are not equipped. As soon as other cars are able to transmit information, that becomes useful to the ego-vehicle to improve its situational awareness.

*2) Lane Change Warning - Monte Carlo Simulation:* Recent estimates find that 2% of traffic accidents every year occur due to poor lane changes, resulting in over 800 fatal collisions each year [1]. One such example is shown in situation 2 of Figure 2, where an unsafe lane change by the lead vehicle in front of the ego-vehicle, could lead to a potential collision.

A Monte Carlo Simulation was performed to quantify statistics about how different levels of LACASA Driver Assistance Systems would affect the collision rate in such circumstances. In the simulation, four conditions were considered, corresponding to the four conditions shown in Figure 2. In the case when both V1 (front car) and EV (rear car) have an advanced Human-Centric version of LACASA, termed the HC-ADAS, the front car is assumed to transmit its own intent to change lanes, 3 seconds before the actual lane crossing. This is in line with expected results from the lane change intent system developed in prior works [6], [7].

In the case when the front car V1 has only an after-market implementation of LACASA, it may still be able to accurately assess its lane position and transmit a confident lane change intent 2 seconds prior to the lane crossing, slightly after the maneuver has started [6], [7]. In the third case, V1 might have no DAS, in which case EV must rely on its own sensors, such as radar and camera systems, to detect the drifting V1; the system will at least be able to detect the maneuver as V1 begins to touch the lane boundary, 1 second before the center of V1 crosses the lane boundary. Finally, without any assistance from an ADAS, the rear (ego-vehicle) driver may not notice and be able to react to the lane change until the front vehicle crosses the lane boundary.

We define $t_{alert}$ as the time of communication of the lane change alert from the front vehicle to the rear vehicle. $t_{alert}$ is set to $[-3, -2, -1, 0]$ seconds, for the four conditions respectively. In each of these conditions, we uniformly vary the initial position ($-5m : +1m$), velocity ($-2.25m/s : 2.25m/s$), and acceleration ($-.1g : .1g$) of the rear vehicle relative to the front vehicle, as well as the braking force ($-.7g : -1g$) and reaction time ($abs[normal(m = .25sec, \sigma^2 = .5)]$) of the driver to the alert. We assume it takes an average of 6 seconds to complete the lane change [18], with the lane-crossing at $t_{LC} = 3$ seconds. The average braking force of the drivers is assumed to reduce to $0.4g$, 1.5 seconds after the initial brake. One million trials of each condition were conducted to obtain the results in Table II and Figure 4.

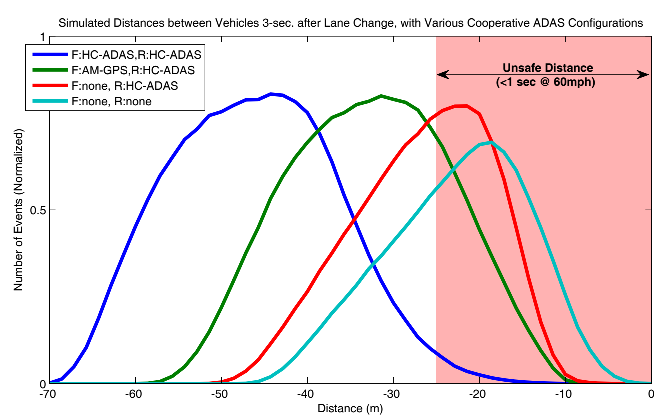



Fig. 4. Lane Change Simulation Results: For those vehicles that did not get into collisions, the distribution of distances between the front (F) and rear (R) vehicles after the finish of the lane change maneuver, 3 seconds after the lane-crossing. Each of the curves represents a simulated scenario in which the lead and lag cars have different levels of cooperation.

We find that the percentage of collisions (which occur when the preceding vehicle crosses the lane boundary and overlaps with the lag vehicle) is much higher when there are no alerts or driver assistance systems. However when the rear vehicle has an alert from the LACASA-based HC-ADAS,

TABLE II

LANE CHANGE SIMULATION OUTCOMES (WHEN FRONT-VEHICLE CROSSES LANE BOUNDARY)

| Front-car LACASA | Rear-car LACASA | $t_{alert}$ | Collisions | Close Calls | Safe Maneuvers |
|---|---|---|---|---|---|
| HC-ADAS | HC-ADAS | -3 sec | 00.02% | 28.90% | 71.09% |
| AM-GPS | HC-ADAS | -2 sec | 02.33% | 96.11% | 01.55% |
| none | HC-ADAS | -1 sec | 24.62% | 75.38% | 00.00% |
| none | none | 0 sec | 35.48% | 64.51% | 00.00% |

the amount of collisions reduces by a third, from 35.48% to 24.62%. As soon as the cooperative framework is introduced in the lead vehicle, the number of collisions nearly disappears - down to 2.33% with an "Intellidrive Level-1" style system, and .02% with a more advanced human-centric system. The number of "close calls", defined as any situation with a lag time less than 1 second, also reduces significantly when the lead vehicle ADAS is upgraded from an after-market system to a more advanced, built-in system.

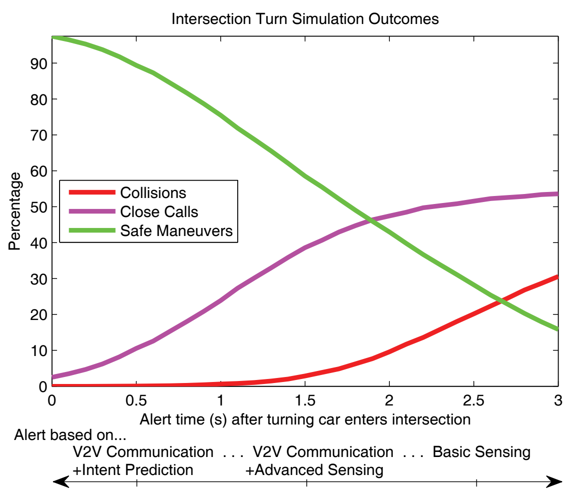



Fig. 5. Intersection Turn Simulation Results: Percentage of outcomes resulting in Collisions, Close Calls, or Safe Maneuvers, as a function of Alert Time. Earlier alert times are more likely to be generated by advanced sensing with intent prediction in a framework of V2V communications.

*3) Intersection Turn Warning - Monte Carlo Simulation:* A similar Monte Carlo simulation was performed on an intersection turn scenario. In this case, as seen in Figure 2, a driver is pulling out into an intersection with the intention of turning left. This driver is unaware of a driver in the oncoming lane who has right of way. The oncoming driver could be alerted in several ways, of a dangerous situation. In the most basic instance, neither vehicle has a LACASA system, so they may not notice the situation until too late. If the oncoming driver had an advanced LACASA implementation, with trajectory prediction capabilities, it may be able to detect the car using ACC radar and alert the oncoming driver.

In this case, $t_{alert}$ corresponds to the time of alert, after the turning car has entered the intersection. For each of the four conditions of $t_{alert}$, we vary the parameters as in the previous simulation. In this case the oncoming car starts to brake with a force between $0.7g$ and $1g$, with a delay corresponding to the given alert time plus a variable reaction time as stated

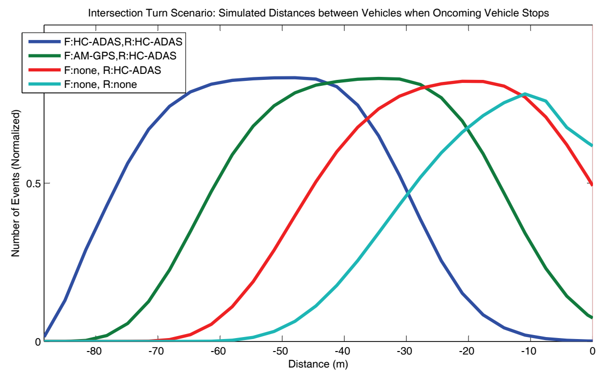



Fig. 6. Intersection Turn Simulation Results: the distribution of distances at which the oncoming car stops prior to the intersection. A position greater than zero indicates that the oncoming car was in a collision with the turning car; the percentage of cars in accidents can be seen in Table III. Each of the curves represents a simulated scenario in which the oncoming(R) and turning(F) cars have different levels of cooperation.

above. The turning car is assumed to take 4 seconds to fully exit the path of the oncoming vehicle, and the simulation ends when the oncoming car comes to a complete stop.

Recent research into turn-intent prediction [9] has shown the ability of an ADAS to predict a driver's intent to turn, 1 to 2 seconds before the turn. Given the turning vehicle in this case with a LACASA system with intent prediction, the system could predict the turning driver's intent, up to 2 seconds in advance of the turn. In the sample situations shown in Table III, a situation where both cars are able to predict and communicate intents shows a complete elimination of collisions, and an 87% reduction in close calls (where the vehicles come within an unsafe distance).

Figure 5 shows the percentage of outcomes which correspond to collisions, given the alert time of the ADAS system after the turning car has entered the intersection. The results demonstrate that an earlier alert time, achieved by a combination of advanced sensing and intent prediction, could reduce the number and severity of collisions significantly. Figure 6 shows the results of the four different LACASA configurations, for those vehicles that did not get into accidents. A clear advantage can be gained even with limited market penetration of the layered cooperative architecture.

## IV. CONCLUDING REMARKS

The future of Intelligent Transportation Systems is intertwined with the development and incremental implementation of distributed sensing and communications networks [3]. We have proposed a general, cooperative, holistic, Layered

TABLE III
INTERSECTION TURN SIMULATION OUTCOMES (WHEN TURNING-VEHICLE LEAVES INTERSECTION)

| Turning-car LACASA | Oncoming-car LACASA | $t_{alert}$ | Collisions | Close Calls | Safe Maneuvers |
|---|---|---|---|---|---|
| HC-ADAS | HC-ADAS | 0 sec | 00.00% | 03.01% | 96.99% |
| AM-GPS | HC-ADAS | +1 sec | 00.67% | 24.57% | 74.67% |
| none | HC-ADAS | +2 sec | 10.46% | 45.51% | 44.03% |
| none | none | +3 sec | 30.45% | 52.69% | 16.86% |

Architecture for Active Safety Applications, LACASA, that can make immediate and significant impacts on safety as part of a stand-alone driver assistance systems in vehicles. A fundamental contribution in the model is a layered framework for active safety which also incorporates a Human-Centric model for Intent and Trajectory Prediction. The framework draws on recent results into the predictability and responsiveness of drivers in various situations, as well as recent improvements in machine vision and artificial intelligence.

The cooperative modularity of the LACASA framework is such that as the market penetration of V2V and V2I sensing and networking improves, the safety benefits of the system grow tangibly as well. In other words, the system does not rely on a specific level of market penetration to see immediate quantitative safety benefits. In one particular application, the lane change warning, a single vehicle with the proposed LACASA framework can reduce the likelihood of collision by 30%, without any V2V communication.

By adding V2V or V2I communication, there is an opportunity to eliminate a significantly larger chunk of collisions. Vehicles may have different sets of sensors, or they may even just be enabled with after-market implementations of driver assistance systems. The layered approach to the integration of information in the LACASA framework allows such diverse ADASs to inter-operate seamlessly. "Here-I-am" signals from simple ADASs [3] can provide more accurate positional information to a more advanced LACASA systems in a neighboring vehicle, allowing it to improve its sense of obstacle trajectories and situational awareness. More complex informational signals can be drawn from an integrated, advanced LACASA implementation which incorporates *human-centric* information to get a more accurate prediction of the ego-vehicle's *intented trajectory*. Transmitting such detailed information could lead, in the case of the lane change warning, to a 70% decrease in the number of "close-call" dangerous situations, over the case when transmitting simple positional information.

Significant amount of work remains to be done in implementation and design of the interfaces between driver assistance systems and the communications framework. However the opportunity to improve active safety and save lives using LACASA is extremely promising. Through the use of advanced sensor-based intelligence and communications, the next generation of transportation systems will ultimately strive for the goal of accident-free roadways.

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