iLCAS: Intelligent Lane Changing Advisory System using Connected Vehicle Technology

Connected Vehicles Technology Challenge

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EXECUTIVE SUMMARY

Connected Vehicles Technology aims at bringing connectivity between vehicles, infrastructure and even mobile devices using Dedicated Short Range Communication. The technology is expected to make surface transportation safer, improve mobility and provide benefits to the environment. This document aims at conceptualizing a possible application when this technology is established and is named Intelligent Lane Changing Advisory System (ILCAS). It helps drivers make smarter decisions regarding lane-changes. The system is goal-oriented and can be chosen to provide smart trajectory advise using lane-change indications with a user-chosen goal to either minimize the total fuel consumed or to minimize total travel delay.

It uses vehicle-to-vehicle (V2V) communication to predict delay due to stopping/turning/slowing traffic in front of the subject vehicle and compares it with alternatives taking in to consideration, upcoming signal phase, presence of vehicles in the blind-spot and presence of left-turning vehicles waiting for a gap on alternate left-lane and advise the driver, an optimum decision using in-vehicle in-dash displays. The system is smart, safe and potentially green which were the goals of Connected Vehicle initiative. Vehicle-to-infrastructure (V2I) communication is used to get upcoming signal phase which helps the system judge if the vehicle is at advantage if it changes lane and speeds up.

The system is goal-oriented and hence the driver can choose to minimize total fuel consumed or to minimize total delay encountered. If minimizing fuel is the chosen goal, the system predicts the fuel consumed for various alternatives (such as staying in lane, or switching lanes) using state-of-the-art fuel consumption model calibrated for that particular vehicle and makes a smart judgment. If minimizing delay is the chosen goal, the system predicts the delay accumulated due to the possible alternative actions using complex car-following and vehicle dynamics model and advise the driver accordingly.
INTRODUCTION

Driving is a complex task which involves high level of cognition. For years, researchers have been trying to automate the task of driving, but the computational power required to do such a complex activity involving quick decisions is enormous. However, in recent years, computational capacity have become highly advanced. The super-computer, IBM Watson\(^1\) was defeated human participants in Jeopardy game, a quickness and knowledge-based game that demands human speech analysis and running search-and-find algorithms within its huge database to happen in fraction of seconds. According to Intel\(^2\), the CPU performance is 175 times what it was 13 years ago. Hence the goal of automating the complex task of driving is not far from realization.

A driver utilizing above-normal cognition while driving through a regular route daily tend to understand peculiar route characteristics. For example, consider an arterial which feeds many drive-ways and consisting of closely spaced intersections. Some drivers who take the route regularly can predict with a high level of accuracy, whether the left or right lane will slow-down at particular points on the route. Hyper-milers can even judge the signal changes and adjust their speed accordingly. But these drivers form a very small population of the total set of drivers. For most, when to change lanes, to avoid delays due to turning vehicles, signalized intersections and merging traffic, is a decision involving luck. This is where, a driver support tool which can provide with smart decisions help in mitigating overall traffic delay and reducing total fuel consumed and total tail pipe emissions, fall into place.

Connected vehicles technology, envisioned in the early 2000s as Vehicle Infrastructure Integration, aims at providing wireless connectivity between vehicles, infrastructure and mobile devices\(^3\). Low-latency requirements call for using Dedicated Short range Communication (DSRC) as the channel of communication. Preliminary proof-of-concept tests on connected-vehicle applications has shown that vehicles will be communicating "Here I am" messages to each other to improve safety by avoiding conflicts between vehicle trajectories. This may include details such as latitude, longitude, time, heading angle, speed, lateral acceleration, longitudinal acceleration, yaw rate, throttle position, brake status, steering angle, headlight status, turn-signal

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status, vehicle length, vehicle width, vehicle mass and bumper height\(^4\). This conglomeration of information gives all the necessary data to predict a vehicle's future movement to some degree of accuracy. This data is the key to how Intelligent Lane Changing Advisory System (ILCAS) makes smarter decisions.

This document is a submission for Connected Vehicle Challenge aiming at getting ideas for connected vehicle application. The next section deals with a model overview followed by logical diagrams of how the system will actually work. Later sections deal with how the advisory is communicated to the drivers. This is followed by the major implementation issues and challenges of the system along with concluding remarks.

**MODEL OVERVIEW**

Slow-downs due to turning vehicles on signalized arterials cost not only travel-time and fuel costs to road users, but also cause environmental degradation due to accumulation of carbon footprint near business centers. One efficient way to avoid the impact is adding turn-bays to streets. Turn-bays, by itself, provide a deceleration area for turning vehicles so that they needn't hinder the overall traffic. But in most cases, turn-bays are used only to help left-turners. Right-turning traffic still have to slow-down on the main streets to access drive-ways or parking lots. We also encounter a lot of drive-ways where even the left-turners slow down, if not stop, the entire traffic. Turn-signals provide turning information only to the vehicle right behind it.

Turn-indications, when wirelessly available to road-users around a turning vehicle, can be used wisely by other drivers to take smart decisions and avoid slowing down. However, sight limitations, perception reaction time, availability of gap to change lanes and even laziness to think about such a possible maneuver are challenges hindering this behavior. ICLAS aims at using this information along with other available information to notify drivers of alternate driving maneuvers that can be practiced at such situations.

Lane changes to avoid a slow-down has an entirely different meaning in case of freeways. Mostly, such situations occur at merge areas or when there are disabled vehicles on the freeways. One of the major disadvantage of a freeway slow-down is the associated shock-wave which may cause traffic to come to a complete halt and thereby costing both the road-users as

well as environment. Therefore, ICLAS can have two separate units, one for the arterial and another for the freeway. Together, they can make ICLAS a unified driver assistive device which uses connected vehicle technology to make smarter lane-changing decisions which are safe and environment-friendly.

ICLAS is also goal-oriented. Drivers can choose what to minimize: delay or fuel. In most cases, a reduced delay might cause drivers to get aggressive advisories and frequent lane-changes because the system keeps track of faster sections of lanes using speed measure sent by surrounding vehicles. This also depends on penetration of ICLAS. Minimization of fuel may cause drivers to advise a smoother trajectory rather than rapidly changing one. For example, the driver may be advised to stay in line, if it senses the other vehicle being hindered by a vehicle waiting for left-turn gap.

**Arterial Logic of ICLAS**

Consider a two-lane arterial highway with driveway access. Some vehicles might be turning to the driveway, whereas, some others have through movement. As soon as the turning vehicles have their turn-indicator on, this message is wirelessly communicated to vehicles behind them. This is show in Figure 1. ICLAS system computes the delay that will be caused if it stays in the lane against the benefits that will be yielded if it changes lane. The system also accounts for checking for gaps and detect any obstacles in the blind-spot before giving advisory. Figure 2 shows a logical diagram of the entire arterial-ICLAS system.

As the vehicle with DSRC capabilities move, it receives speed and other information discussed previously from neighboring vehicles. Once a slowing, stopped or turning vehicle(s) is intercepted, the ICLAS unit detects possible alternate lanes using embedded road-geometry information. These are considered alternate trajectories and are analyzed for predicted delay and predicted fuel consumed for each of them. Car-following models using the speed and accelerations of lead vehicles are used to generate a profile for the subject vehicle. Fuel consumption or emissions models are used to estimate the energy/emissions in each of these alternatives. Further to that, V2V communication also detects presence of blind-spot vehicles and availability of acceptable gap in lane change maneuvers. V2I communication is used to estimate the upcoming signal phase. This is used in delay or fuel calculations as well as in judging need to accelerate or slow down to prevent reaching the intersection at red-phase.
The performance measures of delay (travel-time) and fuel consumed or tail-pipe emissions for each available lane-change maneuver is then used to make judgment based on the goal set by the user. The advisory is then displayed to driver in an efficient and undistracted way such as CHANGE LANES TO LEFT or STAY IN LANE. The same procedure is repeated on detecting slowing/stopped/turning vehicles in any travel-lanes the subject vehicle is in.

FIGURE 1 - Arterial ICLAS at work
FIGURE 2 - Working logic for arterial ILCAS
**Freeway Logic of ILCAS**

Problems are different on a freeway. There are no driveways, but there are slowdowns. Merging traffic is one primary reason for differential lane slow-down rates. Merging traffic can be from right or left depending on the side of entrance ramp. Due to high-speed, lane changes in such situations demand faster decision making including finding gaps in alternate lanes and this is what ICLAS is expected to help drivers on a freeway. This is shown in Figure 3. As a vehicle is merging to the freeway, it communicates and "requests" clearance to other vehicles which ICLAS delivers to the freeway drivers. They can then choose to change lanes allowing merging traffic to merge smoothly without needing to slowdown.

![FIGURE 3 - Freeway ICLAS at work](image)
Figure 4 shows the logical diagram of how the lane-changing decision support tool ILCAS works on a freeway environment. As it detects stopped shoulder traffic or disabled vehicles or more importantly, merging vehicles, the system checks for possibility of lane-
changes. For the available alternatives, it does a predictive analysis finding out the expected delays and fuel consumed in various cases. These values are then used in making smart driver-advises based on the selected goal. ICLAS on freeways can help mitigate congestion on arterials feeding freeways and also help in avoiding traffic halts on freeways caused by shockwave of slowing vehicles.

VEHICLE DISPLAY

The system described in the previous sections is just a driver advisory system. It doesn't make smart driving decisions, but it makes smart decisions which the driver can adopt. Therefore, a means to get this information to the driver is as important as the algorithm itself. The desired method is dashboard display and a lot of human factors study is warranted before the design of the display. However, in this section, the major requirements are highlighted and briefed. The information display module should satisfy the following conditions:

1. **Less Distraction**
   The module shouldn't distract driver by beeping sounds or flashing displays. It should just remind the driver of a possible smart lane-changing decision without causing distraction.

2. **Advisory, not Regulatory**
   ICLAS is an advisory tool, not a regulatory tool. Hence it should silently display the advise and not mandate it. The tool shouldn't have physical control over the vehicle.

3. **Alert-mode**
   An alert-mode to warn drivers of dangerous situations ahead and unnoticed vehicles in blind-spots.

4. **Visibility Cone**
   The display should be on the dashboard and preferably within the visibility cone of the driver so that he/she needn't change view from road.

Figure 5 shows a computer-generated sample of desired HUD display for ILCAS system.
IMPLEMENTATION AND CHALLENGES

Connected Vehicles technology is in its early stages of development and is facing the chicken-egg problem. It deals with whether the vehicle systems should be upgraded first or the infrastructure communication capabilities. Both these developments should go hand-in-hand to expect some great benefits from this emerging technology. Field penetration holds the key to the success of implementations of ICLAS. Automotive companies have already started installing parts of such systems such as Adaptive Cruise Control or Blind-spot detection systems. Hence, there is a good possibility of such a system being available after the introduction of connected vehicles infrastructure.

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5 Edited and generated using Nissan Leaf’s dashboard.
But the challenges faced by the implementation of the system will still hold true. This includes:

1. Not all vehicles will be having communication capabilities and hence decisions in such environment should predict non-ICLAS vehicles in the network.
2. As more systems adds on to the vehicles, they become more complex to operate or asks for more cognition or education from the part of its users.
3. Drivers must be educated not to blindly follow the system and they should use their judgment while changing lanes.
4. The system should be fail-proof because, most humans tend to get used to the system and after a while they blindly believe the advisory. Hence an undetected vehicle in the blind-spot shouldn't create safety issues.
5. The system implementation should be distraction-free.

CONCLUSIONS
ICLAS has great potential to provide a safe, fast and fuel-efficient driving experience for road-users in a connected vehicle environment. It can help drivers make smart decisions regarding lane changes for a goal of their choice. However, the implementation depends on penetration of vehicles and infrastructure connectivity. Many studies are warranted before its implementation. But at the current level of in-vehicle advisory systems advancements, ILCAS is not far in future. It is definitely a feasible and easily implementable connected vehicle application.

ACKNOWLEDGEMENT
The author would like to acknowledge the contributions of Sudeeksha Murari, graduate student at Virginia Tech for her suggestions in conceptualizing ILCAS.