Session B11
Paper 8156

ADVANCED DRIVER ASSISTANCE SYSTEMS: AN ANALYSIS OF PEDESTRIAN PROTECTION SYSTEMS AND AUTOMATIC EMERGENCY BRAKING IN THE MODERN AUTOMOBILE

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Abstract*—Throughout this conference paper, an analysis of Advanced Driver Assistance Systems (ADAS) will be conducted. Specifically, this analysis will cover what ADAS are, how they operate, and why they are important for improving sustainability. Additionally, new topics of research in ADAS that have yet to be introduced into commercially available vehicles will be discussed. In industrialized countries, automobile accidents can be a large concern for public safety. Though general improvements in vehicle safety (i.e. better airbags, vehicle structure, materials, etc.) have led to a decrease of approximately 10,000 deaths per year of drivers and passengers in automobile accidents between 2004 and 2013, pedestrian deaths have remained somewhat constant.*

In recent years, one of the most promising innovations to combat this problem, as well as other driver safety concerns, is the Advanced Driver Assistance System. Some of the specific technologies encompassed by the term ADAS include: Collision Warning with Full Automatic Braking, Pedestrian Detection, Adaptive Cruise Control, and Lane Departure Warning. By integrating ADAS into the cars of the future, engineers can help to dramatically reduce the chance of injury or death when driving an automobile. Because ADAS has the potential to save thousands of lives, it is an area of research that is of great importance to engineers and to society at large.

Keywords—Adaptive Cruise Control (ACC), Advanced Driver Assistance Systems (ADAS), Automatic Emergency Braking Systems (AEB), Lane Departure Warning Systems, Pedestrian Protection Systems (PPS).

AN INTRODUCTION TO ADAS TECHNOLOGIES

Over the years, the ADAS industry has expanded and evolved significantly. With each new generation of ADAS, there are major improvements to the driving experience that change the way that the public thinks about cars. These changes make cars safer, smarter, and more efficient. ADAS systems began with devices as simple as navigation systems, inertial sensors, and electronic speed controllers (ESC) and have now evolved to include automated driving correction systems, advanced warning systems, and artificial intelligence-based systems [1]. Before the primary focus of this conference paper (Automatic Emergency Braking and Pedestrian Detection) is addressed, there will be an overview of a few examples of ADAS that are currently in use as well as new ADAS in development. In the following sections there will be a brief introduction to Lane Departure Warning Systems, Adaptive Cruise Control, and Cognitive Cars.

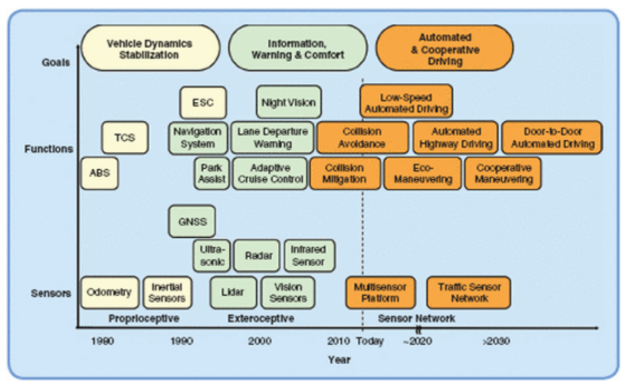

Figure 1 [1]
ADAS Advancement Timeline

In this figure, the history and predicted future of ADAS are plotted on a timeline. Currently, the ADAS industry is focusing on the third stage of goals depicted in this diagram: 'Automated and Cooperative Driving'. In this stage, engineers are working to design systems that go beyond providing warnings or making the driving experience more comfortable by actively assisting the driver or driving independently.

Lane Departure Warning Systems

Lane Departure Warning Systems are designed to assist groggy or distracted drivers in staying within the bounds of their lane during highway driving. Over the past 2 decades, this technology has been gaining more and more attention and is becoming a standard feature in an increasing number of modern vehicles [2]. “If the vehicle deviates from the lane or there is any trend of vehicle deviation, the system will warn the tired or absent-minded drivers to alter driving directions, thus reduce lane accidents” [2].

In order to define the boundaries of the lane, the cameras, mounted on the front of the vehicle, focus on images of the lane lines. The computer reads the lower portion of the image so as to reduce the effect of the road’s curvature and so that the computer can define a lane through the detection of straight parallel lines [2]. When it can clearly be discerned that a driver intends to change lanes (i.e. turn signal), the car overrides its detection analysis and recalibrates to the new lane lines once the lane change is complete [2].

Lane departure warning systems have proven to be functional and effective on open roads. These systems can rapidly read the right and left lane lines, as well as make appropriate decisions based on lane deviations, discerning whether they are purposeful or the inadvertent mistake of a drowsy or distracted driver. Once this determination is made, the system can warn the driver by sending an alert to the dashboard to avert a serious collision. As a result of their effectiveness at averting lane-departure collisions, Lane Departure Warning Systems have the potential to reduce highway and city driving fatalities significantly.

Adaptive Cruise Control

At the turn of the century, automakers began introducing Adaptive Cruise Control (ACC) into their vehicles in order to reduce driving accidents and improve the efficiency of their vehicles [3]. Benefits of cruise control include a reduction of driver fatigue, an increase in driver comfort, and assurance that the driver will not exceed the speed limit. ACC systems are enhancements on cruise control. They can detect the vehicle that is directly ahead and maintain a safe and constant spacing between the two vehicles [3]. This reduces strain on the driver because they do not have to constantly adjust cruise control speed in order to maintain proper spacing between their vehicle and the vehicle in front of them [3].

One possible drawback of ACC is that it may increase the likelihood that the driver will experience ‘highway hypnosis’. Highway hypnosis is a term used to describe a mental state in which the driver continues to drive normally but is not conscious of doing so. This mainly occurs in truck drivers driving for extended periods of time; however, this is a risk for any driver traveling long distances. By reducing the level of attention required by the driver, ACC may reduce the driver’s ability to maintain awareness while driving [3]. The ACC itself may partially solve this issue by maintaining ample spacing between the driver’s car and the vehicle ahead thereby giving the driver enough time to respond to any stimulus that requires their attention [3].

Expert opinions on the use of ACC are split. One faction promotes the use of ACC as a helpful automatic correction mechanism that minimizes driver effort while the other faction emphasizes the potential danger in reduced driver attention that could potentially be caused by ACC systems. However, regardless of which faction one might side with, it is clear that ACC systems do have the potential to add the sustainability of vehicles. A vehicle equipped with ACC would likely have lower fuel consumption than a similar vehicle without ACC due to the fact that maintaining the same speed as the vehicle ahead would reduce the need for over-braking and re-acceleration. As a result, ACC systems are likely to positively impact the environment.

New Frontiers in ADAS Research

In future years, many new types of ADAS will likely debut. One new type of ADAS currently being researched and evaluated to establish viability of concept is ‘cognitive cars’. Cognitive cars are described as follows: “…cognitive driving assistance systems, which utilize the findings of multidisciplinary engineering and cognition sciences to reduce the stress (or burden) placed upon drivers” [4]. This means that the cognition software should be able to act somewhat like a brain to notice driver mistakes or poor judgements and to perform corrections automatically to improve the comfort and safety of the driver. In order to achieve a higher understanding of driver thoughts and behaviors to predict when intervention is necessary, this system would incorporate elements of neuroscience and psychology into an artificial intelligence program which would be able to predict driver decisions and errors [4]. Incorporating these sciences into the artificial intelligence would allow the system to perform reactive corrections as current ADAS systems do while also performing proactive corrections based upon driver behavior projections.

Researchers have identified three main areas in need of investigation. These focuses are identifying which driver behaviors contribute (positively or negatively) to their safety and comfort, identifying factors that alter driver perceptions and behaviors, identifying the effect that each factor has on behaviors [4]. However, there also exist many formidable obstacles for researchers to overcome before a feasible prototype for this technology could ever be tested. These obstacles include: factors that lack a means of gathering empirical data, difficulty determining driver’s thoughts in response to factors, and difficulty in isolating factors to determine which factors trigger which responses (confounding variables) [4]. Though these obstacles are very challenging, once they are dealt with, the foundation will exist to create software that will evaluate a driver’s state of mind and decide whether to provide supplementary corrections to improve the driver experience or to completely override the driver in cases of erratic behavior or unconsciousness (sleep) [4]. Achieving a working cognitive car system would be an enormous leap for the ADAS industry as the capabilities of such a system far exceed those of any ADAS system commercially available today.

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COLLISION MITIGATION: AUTOMATIC EMERGENCY BRAKING AND PEDESTRIAN PROTECTION

Pedestrian Protection Systems

Pedestrian Protection Systems (PPS) have become widely used in the new vehicles of several different automobile manufacturers. It is a focus in marketing and an important safety feature. Vehicle manufacturers such as Subaru, Ford, and Volvo have made pedestrian protection and accident aversion a priority and have made PPS technology standard in many of their newer vehicle models. Pedestrian Protection Systems use cameras and radars, both mounted on the front of the vehicle, to identify the shape of a pedestrian's silhouette. The authors of "Survey of Pedestrian Detection for Advanced Driver Assistance Systems" split the pedestrian detection process into five steps [5]:

1. Preprocessing
2. Foreground Segmentation
3. Object Classification
4. Verification/Refinement
5. Tracking

The article notes, "Although not all proposed modules are not present in the surveyed works and others can be grouped into just one algorithm, we think that most of the systems can be conceptually broken down to fit this architecture for the purpose of comparison" [5]. This is to say that not every pedestrian detection system has identical processes, but most systems bear a resemblance strong enough that they are comparable technologies.

The focus of Preprocessing is to optimize the quality of the pictures captured by the camera in order to allow the computer to more accurately read visual information.

"The dynamic range of a subject is a measure of the range of light intensities from the shadows to the highlights" [6]. A camera must be adjusted to the environment's dynamic range in order to properly take in information and provide the most detailed picture. Since cars move so quickly, there can often be rapid changes in the environment's dynamic range. Commonplace roadway objects such as short tunnels, underpasses, and streetlights can cause major issues for cameras. Additionally, the rapid motion of the scene can result in images with oversaturated or under-saturated areas or poorly adjusted dynamic range [5]. To remedy this, many solutions include the use of High Dynamic Range (HDR) images, which can be described as follows: "…usually generated from an LDR (Low Dynamic Range) image stack by computing a weighted average of the aligned input images" [7]. Solutions using HDR are also useful for night-time vision.

Another point of concern is camera calibration. Here, the issue is based on camera focus as a subject must be in focus for a camera to read its shape. To solve this dilemma, algorithms approximate the shape, curvature, and slope of the road as compared to the horizon line and adjust the camera's focus accordingly.

The purpose of Foreground Segmentation is to isolate Regions of Interest (ROIs) from non-essential background information. It transfers a more refined list of ROIs to the Classification module [5]. One method used to achieve this is to select ROIs according to their color and intensity. These methods set up thresholds for color and intensity by removing anything below the threshold and, in effect, isolating the ROIs. Another method is to isolate moving objects. This method isolates objects that are changing location over a period of time (objects that move) and adds them to the list of ROIs.

A third method, which according to literature is the most effective method, uses Stereo-based systems [5]. Having a stereo-based system means that the vehicle uses two cameras rather than one in order to gauge the disparity between the two images in order to discern depth. This process is similar to that which human brains use to interpret data from our two eyes. In cars, this system makes use of disparity histograms to read depth and distance. Disparity histograms separate images into vertical slices and gauge the color of each slice. At the end of an object, the histogram changes color [8]. Now, using two cameras, and finding the edge of an object, the system can find depth. The system can measure the distance of an object from the car by reading the difference in location of the edge of the object between the two different histograms taken by the two different cameras [8]. The greater the disparity of the locations of the edges of an object between the two cameras, the closer the object is to the car.

Once the ROIs are identified, the shape of the ROIs is discerned so as to determine whether or not they are pedestrians.

"The simplest approach to this is the binary shape model, in which upper body shape is matched to an edge modulus image by simple correlation after symmetry-based segmentation" [5].

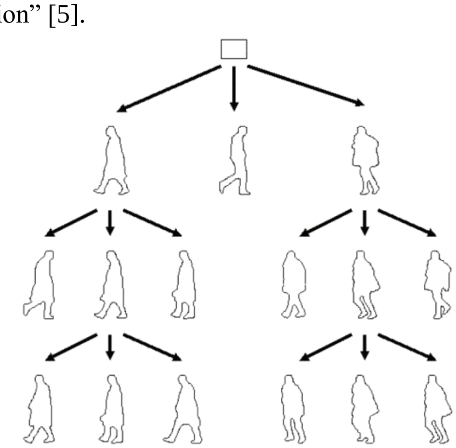

Figure 2 [5]
Silhouette Matching Hierarchy

In this figure, the arrows demonstrate how a PPS system will start from initial pedestrian recognition and identify more and more details about the silhouette until the system recognizes exactly where the pedestrian is facing.

This system is, in effect, a hierarchy of possible pedestrian silhouettes, starting with the broadest shapes and then narrowing down to finer images [5]. If the silhouette of an object matches the course outline of a pedestrian, the object's silhouette travels down the hierarchy towards the more detailed outlines until it can be confirmed that the ROI is a pedestrian.

Once the system has detected a pedestrian, there is an extra step that verifies the computer's assessment. This is to improve the reliability of the system by ensuring that the vehicle does not detect a pedestrian where there is none. One expert describes a particular technique saying, "the silhouette of the head and shoulders that is matched during Classification is taken as a reference for refining detection down to the feet by using vertical edges computed for the symmetry detection. The accurate location of the feet is then used to compute the distance to pedestrians by assuming a planar road" [5].

Tracking is meant to follow detected pedestrians as they change location over time. This step aims to avoid false detections by reading when a pedestrian will be out of harm's way by the time the car arrives at its location. A common choice for this serving this purpose is the use of two Kalman filters; one filter would control lateral motion while the other controls longitudinal motion allowing the determination of the speed and acceleration of the ROIs [5].

Despite what the name may imply, the Kalman filter is not a physical filter, but rather an algorithm that estimates a certain value. The function of a Kalman filter is described as follows: "…infers parameters of interest from indirect, inaccurate and uncertain observations" [9]. This is to say that from uncertain information, Kalman filters can make an estimate of what a certain dynamic object will do next. It does this by making an object's position a function of time in relation to its prior location while simultaneously adjusting for noise in the data. 'Noise' refers to inconsistencies in the data caused by the imperfect and nonlinear nature of real-world movement and camera detection [10]. The use of Kalman filters allow the computer to accurately estimate the movement of a pedestrian given its location at various times despite any significant 'noise' in the data.

$$\mathbf{x}_t = \mathbf{F}_t \mathbf{x}_{t-1} + \mathbf{B}_t \mathbf{u}_t + \mathbf{w}_t,$$

Figure 3 [10]
Kalman Filtering Equation

This figure shows an equation utilized in Kalman filters to estimate an object's location despite irregular data about its path of motion. 'x_t' is a matrix containing the position and velocity at time t, 'F_t' is a matrix containing data about velocity and position at time t-1, 'B_t' is a matrix containing information about driver inputs,'u_t' is a matrix that applies the effect of the throttle setting, and 'w_t' is a matrix containing information about the 'noise' in the data set [10].

The Kalman filter is applied to both lateral and longitudinal motion, and the combination of the two sets of data provide the full picture in terms of pedestrian movement [5]. The reason that both directions must be calculated is that pedestrians do not always travel parallel or perpendicular to the car. Their movement ranges across all angles, and so taking into account both the lateral and longitudinal motion can allow the car to read its movement across its field of vision as well as its change in distance from the car.

Automatic Emergency Braking and Collision Warning Systems

In the case of an impending rear-end frontal automobile accident (An accident occurring between the front of the host vehicle and the rear of another vehicle), Automatic Emergency Braking (AEB) and Collision Warning systems have the potential to save lives and mitigate or avert injuries and property damage. Combined Collision Warning and AEB systems will assess a situation and decide whether to issue a warning to the driver, automatically apply the brakes, or remain inactive if no action is warranted. One example of such an AEB system is Volvo's Collision Warning with Automatic Braking and Pedestrian Protection (CWAB-PD). Encompassed in this system is the capability to brake with acceleration reaching up to -10m/s², provide warning or braking assistance in both vehicle-vehicle and vehicle-pedestrian accidents, and to initiate collision avoidance [11]. This version of Volvo's ADAS was the first iteration to include the capability to take action in the case of accidents involving pedestrians [11].

To detect information about the vehicle's surroundings this system uses two different types of sensors. The system utilizes a black and white Forward-Looking Camera (FLC) to record video in a 48° field of view (FOV), and the system uses a long-range, scanning Forward-Looking Radar (FLR) to record data within a 60° FOV [11]. The FLC is used primarily for providing data needed to classify objects in the FOV such as pedestrians or vehicles whereas the FLR is used to record important data for the system to decide when action is needed such as the range (distance between the vehicle and the object), relative rate of change (relative speed at which the vehicle is approaching the object), and the azimuth angle [11]. The azimuth angle is defined as the horizontally measured angle between 'north' (the path of the vehicle) and the object in the FOV. The information gathered by the FLC is crucial to the operation of the system because AEB systems with Pedestrian Detection capabilities use different protocol to avoid pedestrians than to avoid other vehicles due to their different patterns of movement. Moreover, the data from the FLR is important because the calculations needed to predict when emergency braking is necessary are based upon the range, rate, and azimuth angle measurements taken by the

FLR. The data from the FLC and the FLR is sent to a third device called the Forward-Sensing Module (FSM) where the data is 'fused' [11].

In the FSM, the data obtained by the FLR and FLC sensors is fused. Data Fusion is defined as follows: "Data fusion techniques combine data from multiple sensors, and related information from associated databases, to achieve improved accuracies and more specific inferences than could be achieved by the use of a single sensor alone" [12]. Fusing the data obtained from the FLC and FLR accomplishes a few things. First, the risk of a false collision detection is dramatically reduced because the quality of the data is improved by the fusion [11]. Next, it allows the system to have increased confidence and accuracy of any data that it obtained because the system's measurements can be improved by the additional data [11]. Lastly, as a consequence of the two statements prior, the system can brake both hard and early with minimal risk of causing unnecessary disturbances to the driver because of the increased accuracy and low risk false detections [11]. This data fusion technology is one of the main factors that allows for AEB to be so effective because without such a technology AEB systems would likely be programmed to require a much higher threshold of certainty before any assistive action could be taken.

For the FSM to combine the data from multiple sensors and make decisions a complex algorithm is necessary. The software in an FSM uses a technique called 'gating' to establish a motion model for the object based upon its class, its relative position, and its relative velocity [13]. This motion model allows the system to predict where an object will be shortly after the measurement is taken. Then, the system will check for error between the projected motion and later measurements [13]. If the difference between the projection and the actual data exceeds the assigned error threshold, then the motion model is discarded while the system establishes a new model [13]. This process ensures that the system doesn't proceed with an erroneous projection as this could cause the system to believe an object is somewhere that it is not and to make mistakes such as early, late, or inappropriately hard or light braking.

After the gating process is successfully completed and a motion model has been adopted, the system predicts a track for the motion of the object [13]. At this point in the process, the FSM unit will fuse the track projections made from the data of each sensors to establish a 'fusion track' with greater accuracy than the two separate projections [13]. From the fusion track, the system will perform Time to Collision (TTC) calculations to contribute to deciding whether there is imminent danger [13].

$$t_{\text{collision}} = \begin{cases} -\frac{p_x}{\tilde{v_x}}, & \tilde{v_x} < 0 \text{ and } \tilde{a_x} = 0 \\ -\frac{\tilde{v_x}}{\tilde{a_x}} - \frac{\sqrt{\tilde{v_x}^2 - 2\tilde{p_x}\tilde{a_x}}}{\tilde{a_x}}, & \tilde{v_x} < 0 \text{ and } \tilde{a_x} \neq 0 \\ -\frac{\tilde{v_x}}{\tilde{a_x}} + \frac{\sqrt{\tilde{v_x}^2 - 2\tilde{p_x}\tilde{a_x}}}{\tilde{a_x}}, & \tilde{v_x} \geq 0 \text{ and } \tilde{a_x} < 0 \\ \text{undefined} & \tilde{v_x} \geq 0 \text{ and } \tilde{a_x} \geq 0 \\ \text{undefined} & \tilde{v_x}^2 - 2\, tilde\, p_x \tilde{a_x}, < 0 \end{cases}$$

Figure 4 [11]
TTC Calculation Diagram

In this figure, the methods for calculating the Time to Collison value are described for different conditions. 'v', 'a', and 'p' represent relative velocity, acceleration, and position respectively.

If the TTC value is calculated to be greater than the time required to brake to zero velocity from the driver's speed, then no collision is likely to take place. However, if the TTC value is calculated to be less than the time required to brake to zero velocity then the system is likely to predict a collision. In addition to TTC calculations, the system must also base its predictions upon the yaw rate (angular rate of change) as this may affect whether the vehicle's trajectory will still be in the direction of the object at the collision point [13]. This is an important factor because its inclusion prevents the system from predicting a collision with pedestrians any time that a driver is executing a turn near a city sidewalk and in many other similar situations.

For the purpose of simplifying calculations and projections, the object speed is assumed to be constant in a vehicle-pedestrian collision scenario [13]. However, the system does continually confirm that new measurements are in line with the system's projections in order to prevent error if the pedestrian were to rapidly accelerate [13]. In order to compare the TTC to the braking time, the system first calculates the braking distance by factoring in the driver's velocity, the vehicle's max acceleration under road conditions, and other factors [13]. In addition to the comparison to braking time, one must also consider the possibility that an AEB system might steer the car away from the object if it is equipped with collision avoidance capabilities. In this case, the system would also need to calculate the time needed to steer out of the object's path and compare this number to the TTC value [11].

$$\tilde{P}_{x,brake} = -\frac{a_{x,host} t_{brake}^2}{2} = -\frac{v_{x,0}^2}{2a_{x,host}}$$

$$ttc_{steer} = \min\left(\sqrt{\frac{2}{a_{y,host}}\left(y_0 \pm \frac{W_{host} + W_{target}}{2}\right)}\right)$$

Figure 5 [11]
Equation for Braking and Steering

This figure contains the equations used to calculate the braking time and the time to collision with steering. Variables with the host subscript denote information about the driver while variables with the target subscript denote information about the object. 'a', 'v', 'p', 'y', and 'w' represent acceleration, velocity, position, lateral displacement, and width of vehicle respectively.

Such a system may also use its calculations to decide whether braking or steering away has a higher likelihood of averting the collision. As the braking time approaches the TTC, the system would likely issue the driver a warning while waiting to initiate automatic emergency braking until after the braking time surpasses the TTC.

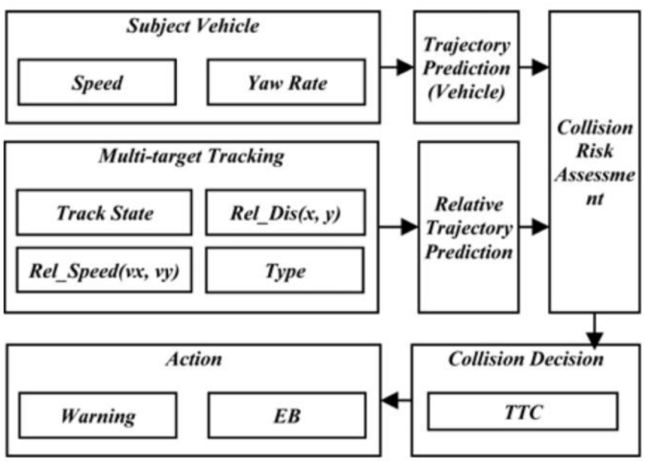

Figure 6 [13]
Flow Chart Describing Decision Making Architecture

In this figure, the arrows represent the steps in the decision-making process taking place in the FSM. Each box with multiple smaller boxes inside represents a step with a decision which would depend upon the data gathered in a particular instance.

Sustainable Impact of Automatic Emergency Braking and Pedestrian Protection Systems

To best assess the worth of a new technology or field of research, it is important to consider how sustainable it is. Sustainability can be defined as having qualities that are beneficent economically, environmentally, and socially. Though AEB and PPS systems do not have any particular effect on the environment, their potential to improve sustainability is tremendous nonetheless. Automatic Emergency Braking allows a vehicle to bypass the driver's control and slow the vehicle down before a collision while Pedestrian Protection Systems expand the potential of AEB to include the recognition of pedestrians. Together, these technologies can substantially lower the occurrence of rear-end frontal vehicle to vehicle collisions and pedestrian related accidents. Additionally, they are also likely to lower the fatality rate when these types of accidents do occur due to the fact that these systems mitigate most collisions that cannot be averted. These factors allow AEB and PPS systems to have a very positive social impact.

One example of an AEB system in practice is Volvo's 'City Safety' system. In vehicles where City Safety is installed and active, one study approximates that there is a 60% reduction in the injuries to vehicle occupants for rear-end frontal collisions at speeds up to 30 km/h [14]. This demonstrates significant value in having an AEB system because of the massive reduction in risk of injury even in the case that a collision does still occur. This same study also compared collision occurrences between Volvo XC60's and XC70's with the latter model having the City Safety equipped as a standard feature. It was found that the XC60's experienced a 30% reduction in rear-end frontal collisions from the XC70's [14]. This shows that, while able to reduce the risk of injury in a crash, the AEB systems can also stop a large portion of collisions from occurring at all.

In addition to the life-saving impacts of AEB and PPS systems, there are also the potential significant and positive economic consequences. These would primarily come from the fact that widespread use of these systems in vehicles would likely cause insurance rates to drop substantially due to a decrease in claims. This would positively impact both the insurance companies and the drivers because drivers would benefit from lower prices while insurance companies would benefit from having to pay fewer claims. One could also argue that the cost of the average insurance claim would also decrease due to the fact that AEB systems mitigate collisions which would likely decrease vehicle damage. If you consider all of the benefits of these ADAS systems, it becomes clear that the investment in an ADAS system is an investment in your safety as well as a financial investment.

Along with social and economic impact, another important consideration in sustainability is the cost of the technology. If a technology costs too much to ever be put into use, then the potential impact that it may have is not particularly meaningful. For Automatic Emergency Braking and Pedestrian Detection systems, there are two types of added cost to the vehicle. First, the purchase price of the vehicle increases. The amount of this increase varies based on the system used and ranges from several hundred dollars to a few thousand dollars. Secondly, there is the added maintenance cost. Because ADAS systems use additional hardware that would not otherwise be in the vehicle (i.e. Cameras, Lidar, Radar, etc.), there is cost associated with maintaining, realigning, and repairing these devices.

Though these added costs do exist, car buyers are unlikely to be deterred from purchasing ADAS equipped vehicles. Much of the cost could be offset by lowered insurance rates and reduced accident related expenses. Additionally, many buyers would likely be willing to pay slightly higher costs for features that are proven to make driving a safer experience. In the coming years, many car manufacturers plan to have ADAS systems as standard features in all of their vehicles. Due to this fact, it can be expected that car manufacturers will be able to produce ADAS equipped vehicles at a low enough cost that their prices would not cause adverse effects to their sales. In other words, the price of ADAS equipped vehicles can be expected to be affordable to the average new car shopper in the near future. Because of this fact, the cost of ADAS is not likely to subtract from the impact that it would have economically and socially.

SUMMARY OF RESEARCH FINDINGS

In this conference paper, there has been discussion of the uses of Advanced Driver Assistance Systems (ADAS), primarily Automatic Emergency Braking (AEB) and Pedestrian Protection Systems (PPS). The benefit of both of these innovations is significant. Their use has markedly decreased the amount of pedestrian injuries and deaths, reduced the number of rear-end collisions, and improved the general sustainability of an automobile. There was also an examination Adaptive Cruise Control and Lane Departure Warning. The effect of these innovations is much less clear. Accidents that could be prevented by Adaptive Cruise Control and Lane Departure Warning fall into the category of "distracted driving," and that category is dominated primarily by phone use, which neither innovation prevents.

In the future, ADAS will become more advanced and intuitive. Cognitive Cars, in theory, will notice driver errors and prevent any consequence of poor driving by knowing what decisions the driver will make in advance. This system would incorporate techniques not exclusive to computer engineering or engineering in general, as it will make use of elements of neuroscience and psychology to achieve a higher understanding of human thought patterns.

Based upon this research, one can conclude that ADAS has had a notable impact on the recent past and will have a tremendous impact on the future of driving. Despite the rapid increase of cars on the road, driving is becoming safer than ever. The rapid innovation and desire for driver and pedestrian safety can only lead to safer roads in the future.

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