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EVALUATING AND RATING THE SAFETY BENEFITS OF ADVANCED VEHICLE TECHNOLOGIES: DEVELOPING A TRANSPARENT APPROACH AND CONSUMER MESSAGING TO MAXIMIZE BENEFIT

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ABSTRACT

In 2012, a major traffic safety organization tasked the MIT AgeLab with developing a data-driven system for rating the effectiveness of new technologies intended to improve safety. Such a system was envisioned as having the potential to educate and guide consumers towards more confident and strategic purchasing decisions, ideally encouraging adoption of technologies with demonstrated safety benefit. In addition, an evaluation of the status and extent of existing data was seen as a way of identifying research gaps in the state of knowledge about safety systems. The focus was on technologies as a class, not on a rating review of individual vehicle model implementations. As conceptualized, the system aimed to complement traditional NCAP style ratings as well as to provide consumers with transparent information on early stage and often improving safety technologies. Development of the rating system and identification of data was undertaken in consultation with a range of academic, industrial, consumer, NGO, and governmental experts as well as with representatives of many of the major automotive manufacturers and suppliers.

A key observation that emerged was that data on objectively demonstrable real-world benefits were generally sparse and often lower than expectations based on theoretical considerations, simulation studies, or pre-production evaluations. A number of experts and industry representatives expressed some surprise at both the divergence between theoretical and observed benefits and the relative scarcity of data upon which to make objective assessments, while others were quite aware of these issues and the need for the development of objective data under real-world operating conditions. A number of factors that might be relevant to understanding why such differences between expected and observed benefits exist were identified. One outcome of this effort was the founding of the Advanced Vehicle Technology (AVT) consortium to collect and examine objective data under naturalistic driving conditions of how drivers interact with, engage or don't engage, various production safety and driver assistance systems. This ongoing effort is contributing to insights concerning actual benefits and reasons for benefit gaps.

Drawing from our initial work, as well as newer sources of data, we argue that the evaluation and rating of safety and driver assistance technologies for informing the consumer and the public at large should consider both theoretical potential and existing demonstrated benefit of specific technologies. This position is increasingly relevant as the effectiveness of many newer technologies have the potential to actually improve over the lifecycle of a vehicle through software updates. The emphasis on ratings based on observed benefit for actual drivers under real-world conditions is proposed to be complementary, rather than competing with, ratings focused largely on controlled test track evaluations of engineered capability. In addition, a case is made for providing ratings that assesses benefit relative to overall crash, injury, and fatality rates – and in relation to the specific scenario / crash event type that a given technology is intended to address. This approach should aid consumers in considering the extent to which a specific technology is or is not relevant to their particular driving needs.

INTRODUCTION

At first glance it might be assumed that the introduction of new automotive technologies designed to reduce the incidence of crashes, the severity of injuries, and in the number of deaths on our roadways should led to ready adoption and utilization. However, that is often not the case. Most new technologies come with a monetary cost and are generally introduced as upgrade options at the time of new vehicle purchase. What information concerning potential benefits is likely to encourage a consumer to decide to spend the money to acquire a given feature?

Moreover, if a technology is included in a package that a consumer has purchased for other reasons and is a feature that the consumer has to actively use to realize any benefit, what information is necessary to encourage the consumer to use the technology? In the latter case, think of the long-term research and messaging investment required to get the majority of the driving and riding population to regularly use seatbelts even after they became standard required equipment in most countries [1-3].

Governmental entities at the local, state, national, and international levels as well as numerous non-governmental entities have been concerned with these issues for some time. Approximately a decade ago, the AAA Foundation for Traffic Safety (AAA-FTS) issued a request for proposals to support research to identify and develop objective measures that could be used to construct a rating system designed to compare and contrast the effectiveness of relatively new in-vehicle technologies relevant to enhancing driver safety. Building on previous work supported by the U.S. Department of Transportation's funded New England University Transportation Center (NE-UTLC), the Santos Family Foundation, and other sponsors, the Massachusetts Institute of Technology (MIT) AgeLab believed that this undertaking had the potential to provide a useful tool to aid consumers in making informed decisions about the purchase and use of safety systems. We also saw this as an opportunity to stimulate discussion and possible action within the safety research and manufacturer communities relative to developing a more comprehensive approach to thinking about safety and methods for objectively evaluating new technologies. We proposed, and AAA-FTS approved, an approach to the project that, in addition to undertaking a review of the existing safety benefit literature, included engaging and actively consulting with a wide-range of academic, industrial, consumer, NGO, and governmental experts as well as with representatives of many of the major automotive manufacturers and suppliers. Details concerning the methods employed, feedback from individuals and entities consulted, the literature review, findings and recommendations can be found in our project report issued in 2014 [4]; a somewhat modified and abbreviated form of the report was subsequently issued by AAA-FTS [5].

It is important to note that the focus of the project was on technologies as a class, not a rating review of individual vehicle model implementations, and an emphasis on considering observed benefits under naturalistic conditions. Thus, the approach was seen as complementing rather than competing with ratings developed by the Insurance Institute for Highway Safety (IIHS) and the United States' National Highway Transportation Safety Administration (NHTSA) New Car Assessment Program (NCAP) which focus largely on controlled test evaluations of engineered capability of specific vehicle models.

The ratings approach proposed in the report [4,5] suggests that there is value in considering both the potential safety benefit of a technology (based on modeling, simulation, and/or test track evaluations] and observed benefit under actual real-world driving conditions of production systems. Two key findings from the literature review were that a) the latter values are often found to be lower than theoretical expectations and pre-production testing data, and b) that publicly available data on actual system performance in the hands of consumers under naturalistic driving conditions was extremely sparse or non-existent for many technologies. The case for why it is important for consumers to have ready access to information on both the theoretical potential benefit of a technology and information on what is known to date on performance benefits of actual production systems driven by consumers is developed further in the current paper.

An important outcome of the project was the dialog initiated between the MIT AgeLab research team and many of the individuals and groups engaged during the project. The identification of the major research gap between what was known about safety technologies from theoretical and experimental testing efforts and the need to develop richer objective data on how systems were actually being used (or not used) and observed objective benefit in consumers driving production vehicles under naturalistic conditions led to discussions concerning how the development of such research might be supported. This led to the launch of the Advanced Vehicle Technology (AVT) consortium at MIT in 2015 as an academic-industry partnership with the goal of developing a data-driven understanding of how, and to what extent, consumers engage with and leverage advanced driver assistance systems, automation features, and a range of in-vehicle and portable technologies for connectivity and infotainment appearing in modern vehicles. Now in its 8th year, the consortium brings together automakers, insurance companies, tier-1 suppliers, and research and consumer-oriented organizations in a unique collaborative effort. At the time of this writing, members included: Agero, Allstate, Aptiv, Arriver, Audi, Autoliv, BMW, Bosch, Cariad, Consumer Reports, Google, Honda, Insurance Institute for Highway Safety, Jaguar Land Rover, J.D. Power, Nissan, Progressive, Seeing Machines, Smart Eye, Subaru, The LAB (GIE Stellantis & Groupe Renault), Toyota, Travelers, Veoneer, Volvo Car, and Zenseact. (See https://agelab.mit.edu/avt for additional details and an up-to-date listing of sponsoring organizations.) Findings from AVT's efforts are both confirming and extending of the observations and concerns raised in the original ratings project work. Some of these are highlighted below.

EVALUATING AND COMMUNICATING SAFETY BENEFIT INFORMATION

Evaluating Safety Benefits: Methods & Stages

In many ways, the historic "gold standard" in safety benefit evaluation has been the collection of actuarial / epidemiological data on the instances of crashes, injuries, and/or deaths associated with otherwise comparable vehicles equipped with and without a given technology. In the U.S., data might be obtained from governmental sources (e.g., Fatality Analysis Reporting System, National Automotive Sampling System, National Motor Vehicle Crash Causation Survey, General Estimates System) or from insurance industry sources (e.g., Highway Loss Data Institute). As a prime example, electronic stability control (ESC) is a technology for which a significant body of such data and analysis has been developed over time. ESC was first introduced in the U.S. in 1995 and a 2004 analysis of the Fatality Analysis Reporting System (FARS) for all fatal crashes in the United States over 3 years (2001–2003) [6] found that it reduced single-vehicle fatal crash involvement risk by 56%. A follow-up analysis considering a ten-year period [7] reported somewhat smaller, but still substantial, effectiveness values for reductions in fatal cash involvement of 49% for single vehicle crashes and 20% for multiple vehicle crashes. Analyses drawing on the NASS General Estimates System and other sources that considered specific vehicle types found particularly marked reductions in crash events for sports utility vehicles (SUVs) as high as the 70% range [8,9]. Other work based on actuarial / epidemiological estimates further strengthened the safety case for ESC technology [10-13]. Such data supported efforts that led to legislation in the U.S. requiring ESC to be mandatory standard equipment for all passenger cars and most other vehicles by model year 2012. Follow-on actuarial work has continued to make a strong case for the safety benefits of vehicles equipped with ESC [14-16]

Simulation & pre-production testing - While the accumulation of objective actuarial data, as in the case for ESC, presents perhaps the ideal case for establishing safety benefit information that both the general public and regulators can act upon, there are important considerations to keep in mind in terms of evaluating technologies in their early phases of introduction. The most obvious is lack of such data when a technology is initially introduced as a production feature. When ESC was first released to the market in 1995, there were no actuarial data on ESC equipped vs. non-equipped vehicles to draw upon; it took about nine years for substantive analysis such as [6,10] to appear. Consequently, in the early stages of a technology's introduction, evaluations of its potential benefits may draw upon theoretical calculations, simulations, test track data, or, less frequently conducted, structured study of preproduction prototypes driven by research subjects (as opposed to experienced test drivers) on actual roadways. To the extent that such data is made available for outside evaluation, if appropriately framed, can provide useful forecasting information that can be shared with the public.

Post-production testing & naturalistic observation – It is important to recognize that many new technologies tend not to show the same level of benefit that might be anticipated from simulation or test track evaluations when studied as production systems in the field. Many factors can be at play when this occurs such as differences between the implementation of prototypes vs. production versions, a wider range of conditions (e.g., roadway characteristics, weather, traffic, etc.) in the real-world vs. idealized scenarios and experimental tests, sensor and actuator limitations, and driver behavior variables including misunderstanding, misuse, behavioral adaptation, turning a feature off or rarely or never turning a feature on – examples are presented in subsequent sections. Consequently, functional testing of production systems' performance when vehicles are driven by consumers and naturalistic observation of how consumers interact with them is a critical next stage in evaluating actual safety benefit. Besides providing a refined picture of potential safety benefit, learning from such observations can provide invaluable input to the industry to guide more targeted simulation and pre-production testing as well as overall system refinement and functional improvements that lead to increased safety benefits.

It is in this area of developing a data-driven understanding of how, and to what extent, consumers engage with and leverage advanced driver assistance systems, automation features, and a range of in-vehicle and portable technologies that the AVT consortium has been actively engaged in collecting naturalistic data in instrumented production vehicles. While the intent here is not to delve deeply into details of what has been done to date, some representative examples of work coming directly out of the consortium and through collaborations with consortium members may be useful to mention. One analysis coming out of the data collection effort considered FCW systems [17], a technology which has demonstrated safety benefits. However, there are questions around the extent to which the sensitivity characteristics and settings of an FCW system may trigger a high rate of alarms in situations where there appears to be no or a low probability of a collision, which may negatively impact driver responsiveness and satisfaction. Road type, speed, traffic density and deceleration profiles distinguished been categories of event severity. Modeling outcomes suggested patterns than may prove useful in adjusting algorithms to reduce nuisance alerts. Other analyses have looked at drivers' use of ACC as a function of roadway class and at how their frequency of use of the feature changed over their first four weeks of exposure [18,19]. A series of papers represent a portion of the work that has been carried out to date examining driver glance and hand control before, during, and after disengagement of the Tesla Autopilot ADAS feature [20-22]. Complementary analyses looking at driver hand and glance behavior associated with transfers of control in the Cadillac CT6's Super-Cruise implementation of an L2 ADAS feature have been released [23,24]. Speeding behavior during manual driving and with ACC engaged is being investigated [25-27]. Work characterizing the use of Tesla's auto lane change feature is underway [28].

Actuarial data: ideals & limitations – As already discussed, analysis of actuarial / epidemiological data that compares the relative rates of crashes, injuries, and/or deaths associated with vehicles equipped with a technology vs. those without represents the ideal safety benefit standard. While reaching this stage of evaluation takes time, when such data can be obtained, as has been the case with ESC, it can provide a solid basis for establishing objective guidance to the buying public and regulators. That being said, besides the issue of taking years to accumulate sufficient actuarial data, several qualifiers or limitations also need to be kept in mind.

Actuarial data may, in some instances, underestimate the potential benefit of a technology. ESC is a technology that is on by default in most, if not all, passenger vehicles. It has to be actively turned off and it is unadvisable to do so except in very specific cases such as when stuck in mud or snow. Even in these instances, many drivers may be unaware of the appropriateness of doing so under such conditions. Consequently, actuarial data for vehicles with and without the technology installed provide a fairly reasonable comparison of the degree of safety benefit inherent in the technology since it is functionally available for the vast majority of time a vehicle is driven. In contrast, other safety technologies, such as lane departure warning systems, can actively be turned-off and a significant number of drivers may do so if they find the warnings too frequent and/or annoying. An IIHS study [29] that looked at the settings of vehicles from nine manufactures that were taken to dealers for service found that 49% had their lane maintenance features turned off. For lane departure warning systems specifically, the percentage that were turned off ranged from 40% to 67% depending on the vehicle brand. Thus, simply because a vehicle is equipped with a technology does not mean that is actively functioning. As a result, any reduction in crashes, etc. in equipped vs. non-equipped vehicles may be less than what would be the case if the technology of interest was always active. An unused technology can confer no benefit. This is likely an even bigger issue when considering technologies that are off by default and must be activated by a driver. Some drivers may be unaware that a given technology is present in their vehicle, they may be unaware of circumstances where it is intended to be used or of how to turn it on, etc. Again, cases of limited or non-use of the technology will result in an underestimation of potential benefits in an actuarial comparison of vehicles with and without a technology installed. For some types of technologies, alternate approaches conceptually similar to efforts such as [30-33] but drawing upon field operational tests and related naturalistic data collection on post-production systems where a technology is known to be active vs. not active may provide useful alternatives or complementary perspectives.

A further factor to be considered is the potential for improvements in a technology. It is possible that changes in various characteristics of a technology ranging from improvements in sensor technology, algorithm adjustments, to enhancements in a user interface may result in initial actuarial data providing an underestimate of the benefits that may be present in newer releases. If simulation or experimental testing show evidence of a substantive improvement in a technology, naturalistic observation suggests enhanced understanding and/or use of a refined implementation, etc., there may be sufficient grounds for investing in an updated safety benefit assessment based on more recent actuarial data.

In summary, there are important roles for each stage and method of assessing safety benefit - for theoretical and experimental estimates of safety potential, for post-production testing of systems and naturalistic observation of actual consumers, and actuarial assessment of safety benefits throughout the lifecycle of a technology. How this might be translated into information and consumer messaging for the public is taken-up in sections that follow.

Rating a Technology Class vs. Specific Vehicle Implementations: Consumer Value in Both Approaches

In the development of the original AAA-FTS project, there were extensive discussions around whether the focus of the ratings should be on what would in essence be comparative safety benefit ratings of different technology types (e.g., land departure warnings vs. adaptive headlights) or on specific implementations of a technology (e.g., lane departure warnings on model A vs. model B. While we considered the question of to what extent and how specific implementations of a given technology type vary in effectiveness to be of significant interest, a number of considerations led to the decision to focus on a broad or top-level rating evaluation comparing different technology types.

From one perspective, the most appropriate assessment of actual safety benefit should be based on actuarial / epidemiological data examining the extent to which a given technology impacts crashes, injuries, and/or fatalities in the actual driving population. While the total number of adverse events per year is unacceptably high, the number of events per individual vehicle model, identifiable as being equipped with or without a given technology, is relatively low for purposes of calculating effect statistics. This is one consideration in seeing value in developing ratings focused broadly on a class of technology. Additionally, through NCAP, NHTSA provides the consumer with a resource listing for obtaining information on whether various vehicle models do or do not offer selected safety technologies that meet a minimum level of performance. EuroNCAP provides similar function in Europe. Also, IIHS had recently expanded their testing programs to begin to consider model specific performance of safety technologies, beginning with scenario specific test track evaluations of forward collision braking / mitigation systems. Early in the AAA-FTS project it was concluded that there is a place for developing technology level ratings that complement rather than attempt to duplicate these latter efforts.

A reasonable question that might be asked is “How is a technology type rating system going to help a consumer choose one car over another?”. In brief, the answer is that a top-level rating system is not intended as a car model buying guide, but rather is intended to serve as a technology feature buying guide. It is intended to assist the consumer in identifying safety technologies that they may wish to look for in their next vehicle or consider as options within specific vehicle models of interest to them. After a consumer identifies a safety technology of interest, resources such as NCAP listings and IIHS evaluations provide a means to obtain vehicle model specific information generally tied to defined testing scenarios. Another source of model / implementation level information that are consumer oriented are “expert” based evaluations of organizations such as Consumer Reports.

The original rating project report [4,5] included concise examples of content at the technology type level that it was hoped would help support the development of consumer oriented educational support materials. Each was introduced with a section called “What Is It?”, a short one to two paragraph description of what a technology is and the conditions under which it might be relevant. This was intended as a very brief, high level orientation to the technology. Subsequent sections included “Why Would I Use This Technology?”, “How Well Does It Work?”, “Who Benefits Most?”, “In What Situations Doesn’t It Work?”, “Not All Systems Are Alike”, and “Different Names, Same Idea”. Many of these elements that can help educate and support consumers at the technology type level can be found today in the “MyCarDoesWhat?” website (mycardoeswhat.org), initially developed with funding from the Toyota Safety Research and Education Program Settlement and currently operated by the National Safety Council.

The authors of the present paper continue to see important roles for providing the consumer (and the automotive industry) with both technology type and implementation level specific information on emerging as well as established technologies. Current efforts within the MIT AgeLab AVT consortium are invested in developing objective data on driver engagement and system performance from consumers collected under naturalistic conditions that can contribute to both types of technology assessment.

Projected Benefit vs. Observed Benefit

As already discussed, it takes many years to develop objective actuarial data on the extent to which benefits are (or are not) observed with a given technology in the real-world. In the interim, it is important to provide consumers with some guidance on new technologies for which epidemiological data are not yet available. We believe it is important to promote "projected safety benefit" while being "truthful" to the consumer regarding actual demonstrated value. Being truthful during the initial introduction of a technology may largely consist of making it clear that current projected benefits are based on simulations and/or controlled tests that are likely to represent best case scenarios and that actual benefits may be more modest during a technology's initial deployment or when operational conditions are limited, etc. As post-production studies and naturalistic observation of consumer experience and interaction with a technology provide additional data and insight, being truthful will likely involve providing the background information on ratings and newly acquired understanding of the conditions or other factors that impact the extent to which actual benefits are realized

Besides being truthful to the consumer, characterizing the extent to which there is a divergence between projected safety benefits and actual observed benefits can play a critically important role in identifying areas where, and ways in which, improvements in a technology may be possible. Are potential benefits being lost because drivers are turning-off a system and, if so, why? Are drivers unaware that their vehicle is equipped with a selectable technology or are they unsure of how it works, or what its benefits might be such that they never turn it on – or are confused by its functioning – and thus turn it off never to try it again? Are they unsure about what conditions under which the technology should provide benefits vs. conditions where it should not be used or relied upon? Are status icons or messages confusing? Are alerts or status displays annoying, distracting, or otherwise creating unintended negative consequences? Are drivers adapting to the presence of a technology such that they over-rely on or otherwise change their behavior in ways that reduce the net benefit? Such questions are important to ask as humans may frequently interact with systems and interface designs in ways that an engineering team did not anticipate. Another point worth noting is that some of the aforementioned reasons for possible gaps between potential and observed safety benefits is that in certain cases it may be possible to address them through training and educational efforts and consumers do not necessarily have to wait for changes in hardware to realize increased benefits from existing implementations.

Gaps between projected benefit and observed benefit are not, of course, always traceable to driver / system interactions. The presence of a difference between expected benefit and observed benefit may provide clues to the need of adjustment in algorithms, improvements in sensors or actuators, etc. It may sometimes be the case that careful analysis of observed benefits should led to a realistic reevaluation of the original projective benefit estimates. Sometimes a highly anticipated technology that was expected to provide one level of benefit actually proves to provide a more modest benefit. In such cases, ratings of expected benefit should be adjusted accordingly.

In the original project report [4,5], divergences between estimates of potential benefits and observed benefits of several technologies stood out. In the case of back-up cameras, observed scenario specific benefits were assigned a proposed rating one level less than the rating of anticipated benefits based on data available at that time. Averaged across three controlled experimental studies with research participants, Mazzae [34-36] reported that the use of back-up cameras reduced crashes during unexpected collision trials by approximately 30%. In proposed rules in the Federal Register, NHTSA [37] estimated that annual fatalities occurring from backing crashes could be reduced by 46% and a similar percentage was estimated for reductions in annual injuries if all vehicles were equipped with rearview camera technology. In contrast, actuarial assessments of observed performance during this time frame were mixed. Data from the Highway Loss Data Institute [38] considering an initial assessment of one vehicle brand with and without backup cameras showed no significant effect on any insurance coverage; however, this was considered a relatively weak analysis for injury effects involving pedestrians. An initial analysis considering another brand of vehicles [39] found that, contrary to expectations, there was an increase in collision frequency claims (3.1%), severity, and overall losses ($18), but a non-significant reduction in property damage / liability claims. Most relevant from a safety perspective, there was a reduction in the frequency of high severity bodily injury claims of 22.2%. To the extent this 22.2% reduction in high severity injury claims represented a then best-case assessment based on real-world observed safety benefit, a case could be made for consumers to consider looking for such technology in their next vehicle. It also made a case for researchers and the industry to dig into whether the estimates of expected benefits needed to be reassessed and/or whether enhancements in production systems or other factors could be identified to improve real-world benefits. Delving into what has emerged since in our understanding of this particular technology is beyond the scope of the current paper, but this brief summary of part of what was covered in the original project report should provide a useful example of some aspects of why we are interested in both types of benefit assessment.

Once again, the optimistic reason for studying any divergence between estimated potential and observed benefit is that such analyses may lead to insights that ultimately result in improvements in the technology. As discussed in more detail in a later section, this is particularly relevant to today's consumers as updateable software increasingly plays a role in some safety technologies, a consumer may not necessarily have to wait to purchase a future year's model to see improvements in a technology they purchase today. While this is not a certain proposition, it is increasingly something some consumers may wish to take into consideration in evaluating current ratings of potential vs. currently observed benefits – and – hence, another reason for providing the consumer with both types of information.

Overall Safety Benefit vs. Situation Specific Benefit

As highlighted in the 2014 report [4,5], a challenge that we spent significant time considering was how best to represent the safety benefit of one technology relative to another. From one perspective, a technology that offers the potential to save the largest absolute number of lives should logically receive a higher rating than a technology that may save a much smaller number of lives. However, what if the one technology is relevant to a large percentage of all possible crash events, but only actually works successfully in a modest percentage of those cases – while another technology is designed to function in a much more limited number of situations, but is highly successful in preventing loss of life under those conditions. It thus seems "unfair" in a sense to down-rate the second technology relative to the first. This may particularly be the case if the scenario that the second technology is designed to mitigate or eliminate is of particular interest or relevance to a subset of consumers.

These considerations led to the proposal to rate technologies both in terms of **Overall Safety Benefit** (considering the maximum number of lives, injuries, or crash events) and in terms of benefit within **Specific Scenarios** the technology is designed to address. We continue to feel that consumers are best informed to make personally relevant purchasing choices if safety benefit information is considered from both perspectives.

As already discussed, data collected on ESC made a clear case for a substantial overall safety benefit of purchasing a vehicle with the technology before it became a standard feature. Analyses such as [9] which reported a 56-67% reduction in single vehicle crash risk for individuals interested in purchasing an SUV made a particularly strong case of ESC, single vehicle crash risk reduction in the 33-35% range for standard passenger vehicles made a strong case for the technology regardless of the class of vehicle of interest. In contrast, a technology such as adaptive headlights offer relatively modest overall safety benefit when considered against all possible event types. Jamakian [40] estimated a potential reduction in all crash events of 2% and fatal crash events of 8%. However, when considering scenarios related to improving visibility when negotiating cures in darkness or twilight, adaptive headlights were estimated to have theoretical relevance to 90% of crashes that occur on curves at night - 91% for nonfatal injury crashes and 88% for fatal crashes. Thus, for individuals who drive primarily on highways and during daylight hours, their relative weighting of the personal value of such a technology might be quite different than that of an individual who frequently drives at night in rural or suburban locations with frequent curves, turns, and hills.

Another example of the argument for developing information for consumers that consider both overall and scenario specific benefits of a particular technology is that of back-up / rear-view cameras. In 2007, there were a reported 41,059 people killed in motor vehicle traffic crashes in the U.S. [41]. For the same period, there were approximately 71 deaths due to back-over events on public roadways and 221 non-traffic related back-up fatalities. This combined 292 deaths represents a relatively minor percentage of total vehicle related fatalities (0.7%). Consequently, a rating of the overall safety benefit of a technology such as back-up cameras that are intended, in part, to reduce the likelihood of such events would be fairly modest compared to the overall benefit rating of ESC. At the same time, there is a particularly high emotional cost associated with this type of event. NHTSA [42] estimated that 31% of all backup event fatalities involved children under 5 years of age and another 26% were adults 70 years and older; these events often involve family members or other close personal associations. Another NHTSA report [37] estimated that if all vehicles were equipped with rearview video technology that annual fatalities from back-over crashes could be reduced by 46%. A similar percentage reduction in annual injuries was also estimated along with substantive reductions in property damage and vehicle repair costs. With these scenario specific considerations in mind, such information might have been particularly relevant to parents with young children who park their vehicles in garages and/or have long driveways or older adults or others with restricted capacity to easily turnaround to look out the rear window when backing-up prior to the issuing of the requirement that all new cars were to be equipped with back-up cameras by 2018.

Again, see [5] for additional detail on the assessment and reporting on overall vs. scenario specific benefits in the cases of ESC, adaptive headlights, lane departure warning (LDW), forward collision warning (FCW), forward collision mitigation / automatic emergency braking (AEB), and adaptive cruise control (ACC).

Software Updates: Opportunities & Challenges

Historically, physically replacing hardware components in a customer's vehicle to improve a system's functionally has generally been limited, with some exceptions, to recall replacements to address defects. As advanced driver assistance systems (ADAS) and safety technologies have increasingly been made-up in part of software algorithms and software driven displays, the capability to potentially improve the functionality of a system through over-the-air (OTA) or dealer installed software updates is increasingly a part of the technology and user experience landscape. The positive side of this capability is the opportunity to provide a customer with an upgrade, often at no cost, that offers enhanced functional benefit in their existing vehicle. Over the course of AVT's FOT activity, we have observed software updates in our vehicles that have noticeably enhanced aspects of various ADAS systems. This capability can represent a significant win for both the customer and the automotive industry.

While software updates provide the opportunity for enhancing important features in a customer's vehicle, there are challenges that need to be appropriately addressed. At least one manufacturer is known for issuing very frequent OTAs, sometimes as often as multiples per month. Regardless of the frequency with which updates are provided, reasonable and appropriate testing procedures need to be followed to minimize the likelihood of errors or unintended consequences being introduced. Transparency should be provided to the user regarding important details of the changes associated with the update and the impact on safety benefits. What is the purpose of the update? Have the conditions under which a feature is active or inactive changed? Has the appearance or location of icons changed? Has a feature been temporarily or permanently disabled? Our experience in the AVT consortium with a fleet of vehicles across a number of manufacturers and over a number of years has been that, in many instances, clear information on the extent and implications of both OTA and dealer installed software updates as provided to us are generally very limited and, in some cases, lacking all together. Ultimately, both the consumer and the manufacturer will benefit from providing concise and clear information on what features have changed or been added with an update.

An additional, but hopefully positive challenge of software updates, are the implications for ratings of the safety benefit offered by a technology. As software updates ideally improve functionality, ongoing assessments will need to keep-up to date in making data driven information available to the public. As conceptualized, the original rating system allows room for characterizing changes in apparent benefits due to implementation advancements / refinements. The expectation would normally be that the long term "goal posts" for a technology (e.g., rated potential benefits) remain relatively fixed while observed benefit ratings are transparent concerning actual benefits that are documented over time.

Other Aspects of Consumer Messaging

Standardized naming of technologies – It does little good for governmental and non-governmental organizations to invest in developing quality information on various technologies if the consumer becomes confused about what to look for when they move to investigating specific vehicles online or at a dealership. Even a technology that is broadly available and fairly readily identifiable to the initiated, such as adaptive cruise control, may be called by a wide range of brand names that a consumer may or may not be able to connect with a feature that they would like to have in their next vehicle. This issue has been raised in both academic research [e.g., 43] and by consumer advocacy groups [e.g., 44;45] including an ongoing collaborative effort by AAA, Consumer Reports, J.D. Power, the National Safety Council, and SAE International called "Clearing the Confusion" [46,47]. We have had the experience within the AVT consortium of participants who have driven one of our FOT vehicles for a month and particularly appreciated an ADAS feature, later contact us for help, expressing frustration at trying to locate the same feature when looking to purchase a new vehicle. When looking for the feature in her preferred brand on-line, one former participant was confused as to whether or not it was available. Further, when contacting a local dealer, she was told the feature was not available when, in fact, the it was but was only identified under a brand specific name. It is unfortunate when consumers are actively looking for a technology that they have learned something useful about that may offer them a safety benefit that they are end-up purchasing a model without the option because of such confusion. While, as clearing the confusion suggests, manufactures do not necessarily need to entirely give-up the use of brand names for safety and ADAS technology implementations, we would argue that, if used, they should ideally be linked to a standardized technology naming convention.

Branding & capability confusion – Another issue with technology branding, and aspects of the advertising that may be associated with it, is the potential for some consumers to assume that a technology is more capable than it actually is. Perhaps the best-known examples are the terms "Autopilot" and "Full Self-Driving Capability" as used by Tesla to market its ACC ("Traffic-Aware Cruise Control") and lane centering ("Autosteer") features. While current Tesla webpages [e.g., 47] include statements such as "Autopilot, Enhanced Autopilot and Full Self-Driving Capability are intended for use with a fully attentive driver, who has their hands on the wheel and is prepared to take over at any moment", many consumers appear to read more into the names than is spelled-out in the qualifying text quoted. Such branding may also contribute to many in the general public being under the impression that truly self-driving or autonomous vehicles are available for purchase today [e.g., 43,49,50] and concerns have been raised that such misconceptions around terminology could not only impact proper use of current systems but also impact future uptake of increasingly advanced technologies as they are introduced [51-53]. The issue of potentially misleading naming is attracting some regulatory and other legal attention. The State of California recently passed Senate Bill No 1398 that dictates that a manufacture or dealer is not to name or describe a partial automation feature in a way that would "lead a reasonable person to believe" it can function autonomously "or otherwise has functionality not actually included in the feature" [54].

Obtaining accurate information & training at dealerships – Beyond the issue of standardization of naming for identifying a core technology of interest, consumers may go to a dealership to be told that a safety technology or ADAS system of interest to them is not available (when in fact it is), given inaccurate or no information about the operation of feature, or even actively discouraged from considering the option by a salesperson [e.g., 55,56]. Such interactions can lead to consumers not buying a safety technology that they otherwise would have, or being confused or otherwise misunderstanding the proper use of the technology such that they underuse or misuse the technology that undercuts its safety potential. This need not be a universal problem. The Abraham et al. [55] study found that sales staff from dealerships for some vehicle brands provided much more consistent and accurate information on such features than staff for other brands. Investment by manufactures in providing messaging consistent supporting materials (displays, handouts, user manuals, informational & training videos) and training programs for sales and support staff is part of the equation. Equally important is an investment at the dealership level to make use of such resources and to incentivize sales people and other staff to become knowledgeable and pass along clear and useful information to consumers. Such issues will only become more complex as software enabled features and services expand. As such, efforts to consistently align dealerships with manufacturer recommendations need to be accelerated.

Other sources of information & training – As much as dealerships can play a significant role in informing or misinforming consumers, it is not realistic to rely solely on improvements in dealer-based training to fully meet the needs of consumers in learning about the proliferation of safety and ADAS technologies since a consumer purchased their last vehicle. Realistically, there is generally only a limited amount of time and consumer energy and attention available to learn about all the features in a new vehicle at the time of delivery, particularly after what may be a stressful purchasing negotiation. Moreover, consumers vary in their preferred method of leaning [57] and proving alternate and multiple methods are likely to be to everyone's benefit. Abraham et al. [57] found that drivers who learned through their preferred methods of learning reported higher understanding and use of in-vehicle systems. Beyond direct dealer training during the sales process and/or at vehicle delivery, other potentially useful sources of information include on-line or in-car videos (for viewing when the car is not in motion), in-car training dialogs, the user's manual, and other manufacturer supplied materials that can be accessed at a consumer's preferred time, place, and pace.

The concept that one's car can potentially play a useful role in informing and educating a driver in how to use a technology is worthy of further attention. In [57], 25% of participants indicated an interest in the concept of "the car teaches me" while just under 5% indicated that they learned in that manner, likely due to the lack of such a feature. A perhaps less ideal finding was that over 50% of participants reported learning by trial and error.

A challenging but important service that manufacturers' need to invest in is keeping information on a technology consistent across information sources and up-to-date. It may be advantageous for printed materials, particularly printed user's guides supplied at the time of purchase, to include notes encouraging users to check on-line or dynamically updateable in-vehicle sources for the most up-to-date information, since the information in some printed materials may tend to lag behind an actual installed implementation. Being upfront about this reality is another important form of transparency. As already discussed, the increased availability of OTA and dealer installed software updates increases that challenge to keep user information up-to-date while also providing the valuable opportunity of on-going enhancement of systems across a vehicle's lifespan.

Leveraging consumer input – While the focus of this paper is on the use of objective data to evaluate and rate the safety benefits of advanced vehicle technologies that can be used to inform consumers, we also recognize the important role that subjective input from consumers can play in identifying possible explanations for gaps between projected and observed benefits. The AVT consortium uses questionnaires before and immediately after FOT participants' training drives in our instrumented production vehicles to gather data on their understanding of the function and limitations of various safety and ADAS technologies prior to and after what is designed to be reasonably equivalent to a comprehensive dealer introduction to key features of the vehicle. Following a month-long experience driving a vehicle, participants complete a post-experiential questionnaire and take part in a follow-up interview. Data sources such as these can help identify the extent to which there are pre and-post experience understanding / misunderstanding about safety relevant advanced technologies in various production vehicles, along with gathering subjective input on whether a participant feels a technology and a specific implementation enhances safety and whether or not they would be interested in having when purchasing their next vehicle. This input can also be considered in the context of the objective data collected on the extent to which these consumers used selectable features, experienced alerts, etc. Lack of use of a selectable feature or identifying confusion around where to use or how engage it can contribute to understanding the extent to which there are gaps between expected and actual safety benefits. Ideally, such data can also support the development insights that help address such gaps through refinements in the underlying technology, algorithm adjustments, user interface design enhancements, and/or updating marketing and training materials.

The self-report and questionnaire data collected as part of an FOT effort can be very rich, but is inherently limited in terms of sample size. Consequently, we see significant complementary value in survey-based means of gathering consumer input or, as J.D. Power puts it, "listening to the voice of the consumer". The MIT AgeLab and AVT have collected large scale survey data on consumer understanding and interest in driver support and highly automated technologies for a number of years [55,58,50] and, as previously mentioned, have recently joined in a collaborative effort in this area with J.D. Power and PAVE [52-53]. AAA and Consumer Reports are well known for collecting survey data on a regular basis. A recent report by Consumer Reports considers ADAS usability through the lens of staff testing in combination with a large-scale owner survey [59]. Integrating such "messaging" from consumers with the insights gained from hard data collection provides an opportunity for manufacturers, dealers, and governmental and non-governmental consumer facing organizations, as well as researchers, to enhance to messaging that we share with consumers in support of the common goal of improving safety.

CONCLUSIONS

Numerous technologies have been developed specifically to increase safety in modern vehicles or as ADAS marketed primarily as convenience features, but with the expectation that they may provide safety benefits as well. Such technologies are generally introduced as optional features that consumers need to evaluate as to whether they should spend additional money to acquire in their next vehicle. Consequently, there is a fundamental need for consumers to have access to realistic and understandable information on the relative safety benefits any given technology offers, so that they can make personally informed decisions. The need for such information has grown in recent years as number of different features available and the functional details that a user needs to understand to maximally benefit from some ADAS features has increased.

The growing number of safety relevant technologies and the evolving nature of their implementations presents a challenge for rating information and systems to stay current. On the positive side, a number of key organizations are openly invested in evolving and updating their approaches to providing information on and the rating of these technologies. NHTSA has actively solicited input on upgrades to NCAP [60], EuroNCAP updates target standards on a regular basis and has shared a vision for encouraging enhancements in safety [61], IIHS has recently announced the development of a new rating program that evaluates safeguards that help drivers stay focused on the road [62] and engaged in briefing stakeholders ranging from manufactures to academic researchers to other consumer-oriented organizations on plans to make other enhancements to their ratings. Consumer Reports also has a history of sharing information on ongoing considerations for future ratings [e.g., 44].

From a safety advocacy perspective, there is a case to be made that consumers are likely to maximally benefit if they have access to quality information to support two steps in the decision-making process. The first involves identifying technologies that offer a level of safety benefit that is meaningful to their driving situation and personal values. Next, with this information in mind, a consumer can then look into specific vehicle models to see if they offer the technologies of interest to them as well as consider any available information on the relative effectiveness of the implementations in those models.

In the body of this paper we argue that the evaluation and rating of safety and driver assistance technologies for informing the consumer and the public at large should consider both the estimated potential and the existing demonstrated benefit of such technologies. Data on objectively demonstratable real-world benefits are generally spare and often lower than expectations based on theoretical considerations, simulation studies, or pre-productions studies. Nonetheless, estimates of the safety potential of a technology provide important initial guidance during the introduction of a new technology when objective data from naturalistic studies is limited or unavailable, and there has not yet been sufficient time for actuarial data to have been accumulated. Moreover, as data from studies of production systems used in the field are developed and actuarial data is obtained, the identification of differences between expected potential benefit and objectively observed benefit are important in several ways. One fundamental is transparency; the consumer and the public at large deserve an honest presentation of what our current, best understanding of what a given technology is providing in terms of benefit. Without such transparency, trust in information sources may be impacted and effective technology uptake may decline. At the same time, the identification of gaps between expected and observed benefit can be critical in the process of improving the safety benefit of a technology. Among other considerations, identification of gaps can motivate a deeper dive into investigating why the gaps exist and how they might be addressed.

As we have discussed and provided examples from various sources including our AVT consortium work, post-production testing of systems and naturalistic observation of actual consumers' interaction with a technology can bring to light a range of areas where actions can be taken to improve net effectiveness. These may consist of improvements in or adjustments to sensor systems, actuators, or algorithms, as well as identifying driver related issues that may be involved. While consumers typically need to wait for the a new vehicle model to benefit from physical improvements in sensors or actuators, the identification of gaps due to driver related factors such as misunderstanding of how to optimally interact with a technology, confusion around conditions and situations where a technology is or is not useful, lack of knowledge of the availability of a system in their vehicle or even how to engage a feature, may be addressed through improvements in informational sources and other forms of training / education. As we have also highlighted, the increasing capability to address gaps through software updates that refine algorithms or even make improvements in software-based user displays have the potential to actually improve a technology over the lifecycle of an existing vehicle. These opportunities will be lost, however, if investments in studying, and comparing across implementations, actual performance and consumer experience and behavior in production systems are not made.

We have also argued that consumers will be able to make more informed decisions about what technologies to seek out and utilize if useful information is available on both the overall safety benefit of a technology and situation or scenario specific benefits. Such information may lead many consumers to consider a given technology because of a relatively broad and overall high safety benefit. At the same time, there are likely cases where some consumers may decide to also invest in a safety technology that they may not have considered otherwise because the scenario specific benefit is particularly relevant to their personal situation and driving needs. Since many consumers have limited resources, making available information that can aid individuals in making personally strategic buying decisions can increase the equity of the process.

Overall, investing in understanding where and why a given safety technology is or is not presently meeting its presumed safety potential is to the benefit of the consumer, the industry, and society as a whole. Investigating apparent gaps can lead to improvements in the underlying technology / implementation and in consumer understanding and appropriate utilization. Well informed consumers are more likely to consider investing in technologies that may increase their personal safety and the safety of those around them, both inside and outside their vehicle. Transparency regarding what given technologies may or may not provide is important in building trust and in proper use. Customers who are well positioned to actually realize the safety benefit of a given technology are more likely to invest in that acquiring and/or using the technology in future and in encouraging their family and friends to do likewise.

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