

## **Evaluation of a Pre-Production Head-on Crash Avoidance Assist System using an Extended “Safety Impact Methodology” (SIM)**

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### **ABSTRACT**

**Objective:** This paper describes the results of the Honda-DRI ACAT-II program initiated by the National Highway Traffic Safety Administration (NHTSA) to develop test and evaluation procedures and methods to assess the safety benefits and effectiveness of advanced driver assistance technologies. The objectives of the ACAT-II program were further development of a formalized Safety Impact Methodology (SIM) for estimating the capability of advanced technology applications installed in vehicles to address specific types of motor vehicle crashes, and to evaluate driver acceptance of the technologies.

**Methods:** This particular ACAT study extended earlier work by Honda and DRI in the NHTSA ACAT-I program by extending the SIM so as to be able to analyze head-on crashes more completely, and by using the extended SIM to evaluate of a pre-production version of a Honda Head-on Crash Avoidance Assist System (H-CAAS). More than 25 substantial SIM extensions and refinements were implemented, including: updated and extended FARS and NASS database extractions; improving the accident reconstruction process for NASS/CDS cases and developing a new special purpose reconstruction algorithm applicable to head-on cases with low lateral acceleration “drifts;” extending the driver-vehicle-ACAT-environment simulation to include a post-conflict recovery phase; and further automating the overall safety benefits evaluation steps. The extended SIM and results from objective tests were used to evaluate the safety impact of Honda’s pre-production H-CAAS based on a large number of simulations of a sample of reconstructed real-world head-on crashes.

**Results:** The effectiveness of the H-CAAS in reducing the number of two-vehicle “Same Trafficway, Opposite Direction” crashes (including non-H-CAAS technology relevant crashes) and fatalities if the H-CAAS were installed on one of the crash involved vehicles were estimated to be a 2.6% reduction in these types of crashes and a corresponding 11.3% reduction in fatalities based on simulation results. The overall benefits of the H-CAAS, in terms of reduction in number of crashes and fatalities, when projected to the annual US level were estimated to be a 2,966 reduction in the number of US crashes and a corresponding reduction of 450 US fatalities per year. The results are based on various assumptions, approximations, and limitations that are summarized herein and further documented in the supporting references, such as the representativeness and accuracy of the supporting data and reconstructed accident pre-crash scenarios.

**Conclusions:** Overall, this ACAT-II program was successful in extending and demonstrating a methodology that can be used to estimate the effectiveness and safety benefits and driver acceptance of frontal crash avoidance and mitigation countermeasures. The methods used are directly relevant to the test and evaluation procedures to assess the safety benefits and effectiveness of advanced driver assistance technologies.

Keywords: active safety, crash avoidance, countermeasures, driver assistance systems, evaluations

## INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA) initiated the Advanced Crash Avoidance Technologies (ACAT) program in 2006 to determine the safety impact of new and emerging crash avoidance technologies. This involved developing a Safety Impact Methodology (SIM) and framework, including objective tests, as summarized in Carter et al. (2009) and Funke et al. (2011). In 2008 NHTSA initiated a second phase of this program (ACAT-II), the primary objective being to further develop a formalized SIM methodology in order to evaluate specific types of vehicle crashes.

## BACKGROUND

Honda, Dynamic Research Inc. (DRI) and many others have been developing and applying safety impact analysis methods for many years. These methods are multi-disciplinary, involving accident data analysis, accident reconstruction, driver and vehicle modeling and simulation, and injury and fatality risk modeling, based on models ranging from theoretical to empirical depending on the sought for accuracy and available information. For example, Suzuki et al. (2006) described a prototype safety analysis system to forecast vehicle safety benefits using a fleet systems model based on real-world crash scenarios, accident and exposure data for existing vehicles, and estimated sales and technology effectiveness for future vehicles. The systems model incorporates the estimated effectiveness of various existing and proposed safety technologies in order to estimate the incremental and combined effects of these technologies, which may be complimentary or redundant. This tool was inspired by previous work by Henson (1978), Najm (1999, 2000), Kuchar (2001), and others. Sugimoto et al (2005) described a method to estimate the effectiveness of advanced driver assistance systems in avoiding or mitigating crashes using simulations of the driver, vehicle, technology, and environment during the pre-crash phase of reconstructed real-world crash scenarios. The driver model for these simulations was structured based on the NASA MIDAS model (Hart et al. 2001).

More recently Honda and DRI and other researchers have had Cooperative Agreements with NHTSA for either the ACAT-I program or subsequent ACAT-II program, or both programs. The ACAT-I program (Carter et al. 2009; Funke et al. 2011) comprised four research teams from Honda and DRI; Volvo, Ford, and the University of Michigan Transportation Research Institute (UMTRI); Toyota; and General Motors and Virginia Tech Transportation Institute (VTTI). In the ACAT-I program Honda and DRI extended the ACAT SIM tool based on their earlier work and used the SIM to evaluate a prototype Honda Advanced Collision Mitigation Braking System (A-CMBS), as described in Zellner et al. (2009), Sugimoto et al. (2010), and Van Auken et al. (2011a, 2011b). The Volvo-Ford-UMTRI team developed a SIM to estimate the benefits of a Lane Departure Warning (LDW) system (Gordon et al. 2010), Toyota developed a SIM to estimate the benefits of a Pre-Collision Safety System (PCS) (Aoki et al. 2009), and the GM-VTTI team developed a SIM to estimate the benefits of a Backing Crash Countermeasure (Perez et al. 2011).

The ACAT-II program comprised two research teams from Honda and DRI; and Nissan and UMTRI (NHTSA 2009). This paper summarizes the cooperative research by Honda and DRI under the ACAT-II program, which involved further extensions to the previously developed SIM tool and applying it to evaluate the effectiveness and safety benefits of a pre-production Honda Head-On Crash Avoidance Assist System (H-CAAS). Progress reports for this study were presented in Van Auken et al. (2011c), Sugimoto et al. (2011), and Zeller et al. (2012). More detailed methods and results from this study are presented in Zellner et al. (forthcoming).

In addition to the two NHTSA ACAT programs, the ACAT teams and other researchers are continuing to develop and refine ACAT SIMs. For example, Kusano et al. (2013) has developed a methodology for using advanced event data recorders (EDRs) to reconstruct vehicle trajectories for use in the SIMs. Kusano et al. (2012) has investigated the identification of target populations for active safety systems. Both of these examples correspond to activities in the NHTSA ACAT SIM framework described in Carter et al. (2009).

## **Project Aims**

The primary objective of the NHTSA ACAT-II program was to further develop a formalized SIM to estimate the capability of advanced technology applications installed in vehicles to address specific types of motor vehicle crashes. A secondary objective was to evaluate driver acceptance of the technologies and, if applicable, how that acceptance could be improved.

## **Scope of the Study**

The scope of this study involved:

- Theoretical and software extensions to the existing Honda-DRI ACAT-I SIM tool, which provides an estimate of advanced technology safety benefits at the US level;
- Refinement of the objective test procedures and apparatus (i.e., car Guided Soft Target (GST)) and the slowly increasing steer (SIS) test procedure in order to facilitate the use of the steering wheel torque model in the Crash Sequence Simulation Module (CSSM) simulations;
- Using the data from previous objective tests to parameterize, calibrate and validate the SIM tool;
- Delivering an extended SIM tool which includes improved modules for automated reconstruction of conflict and crash scenarios from available databases; automated definition and sampling of Technology Relevant Crash Types (TRCTs); dynamic simulations involving a human-vehicle-device-environmental model; and an overall safety effects estimator;
- An example application of the extended SIM tool using objective test data which involved safety effectiveness and benefits estimation for Honda's pre-production Head-on Crash Avoidance Assist System (H-CAAS).

## **SAFETY IMPACT METHODOLOGY**

NHTSA's Safety Impact Methodology framework (Carter et al. 2009) is illustrated in Figure 1. This framework comprises 22 different Functions (e.g., "Archival Data"). These functions are grouped into seven different activities illustrated by the large open boxes (e.g., "Data Usage"), which are also grouped into three main areas indicated by the box color coding (i.e., orange, blue, and purple). Of the 22 different Functions, 11 Functions were implemented by the Honda-DRI SIM tool and the other 11 Functions were accomplished "off-line".

An overview of the Honda-DRI ACAT SIM and the extensions made during the ACAT-II program are summarized in Zellner et al. (2012). The SIM is described in further detail in Van Auken et al. (2011b) and Zellner et al. (forthcoming). The extensions made to the SIM for the ACAT-II program are further described in Zellner et al. (forthcoming).

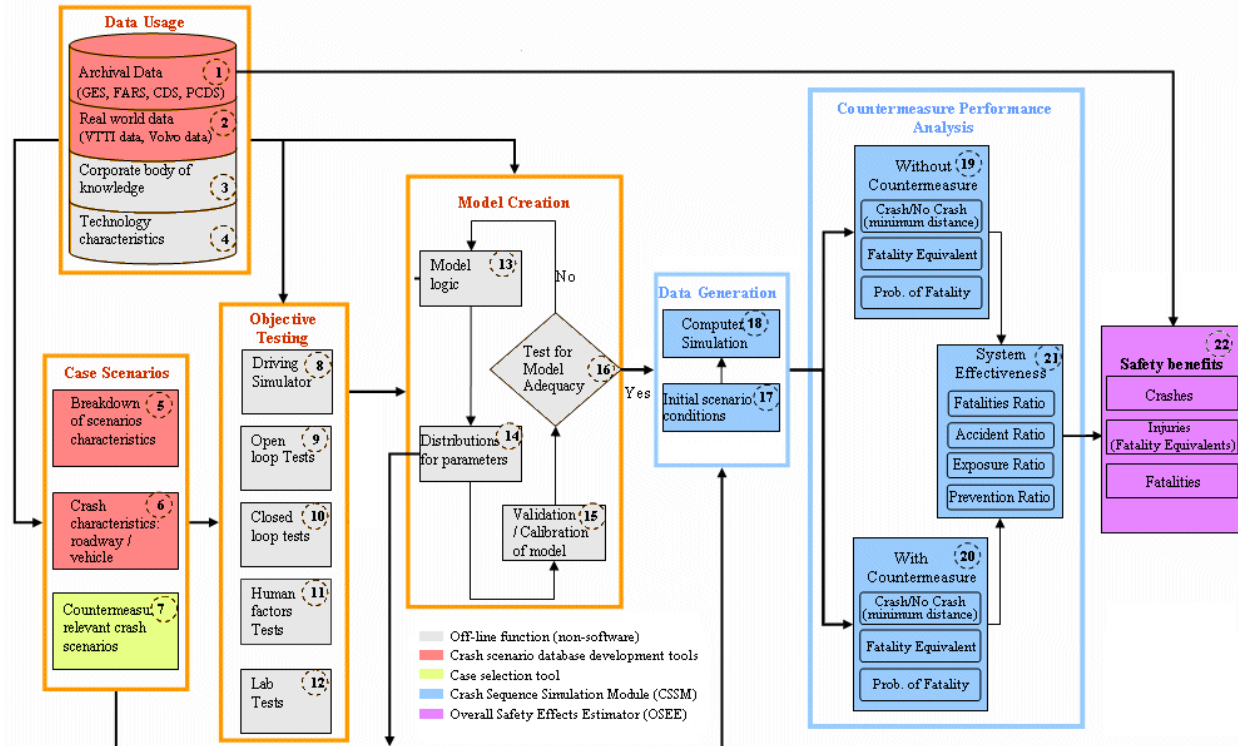


Figure 1. NHTSA ACAT SIM Framework (Carter et al. 2009).

## ADVANCED TECHNOLOGY AND SAFETY AREA ADDRESSED

A pre-production Honda Head-On Crash Avoidance Assist System (H-CAAS) was selected as an example of an advanced technology to be evaluated using the ACAT-II SIM. The pre-production H-CAAS was designed to be installed on light passenger vehicles (i.e., passenger cars and light trucks) to prevent or mitigate certain types of head-on crashes. These crash types primarily include head-on crashes where driver inattention (e.g., distraction, drowsiness, and/or impairment) is a contributing factor. It is assumed that the subject vehicle in these cases drifts with up to 0.05 g lateral acceleration, which is assumed to be not noticeable kinesthetically (i.e., sub-threshold) by the driver in the absence of visual cues (e.g., visual distraction, drowsiness, etc.) based on published literature (e.g., Young (1973)).

### The Size of the Crash Problem

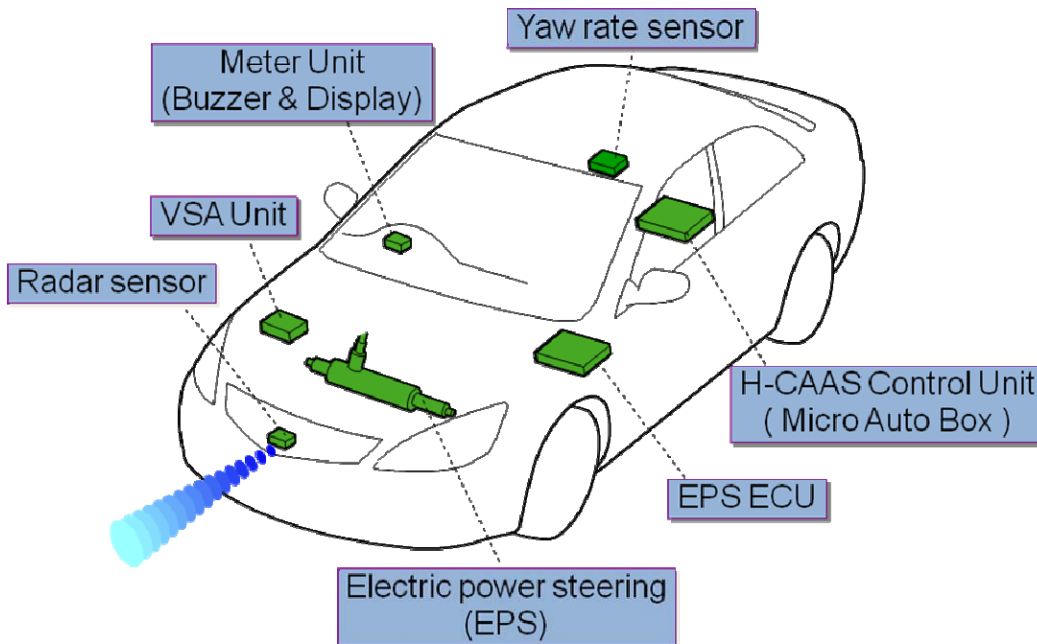
The potential numbers of crashes, involved vehicles, and fatalities that represent the size of the problem for the entire US motor vehicle fleet are listed in Table 1 in terms non-technology specific crash types that have been broadly defined in terms of NASS Crash Configurations (e.g., “Same Trafficway, Opposite Direction” or simply “Opposite Direction”) (NASS 2000). Some of these crashes were not expected to be addressable by the H-CAAS due to either vehicle application (e.g., passenger car vs. motorcycle), vehicle role (e.g., struck vehicle), or other technology relevant factors. For example, the results in Table 1 include 239,000 crashes involving non-light passenger vehicles (e.g., motorcycle only crashes), on which the pre-production H-CAAS was not designed to be installed, involving 253,000 vehicles and 3,953 fatalities.

**Table 1.**  
**Estimated Crash Problem Size for the Entire US Motor Vehicle Fleet in the 2009 Calendar Year**

Crash Category	Crash Type	Estimated Number of		
		Crashes (1000s)	Vehicles (1000s)	Fatalities
1-vehicle	All	1,749	1,749	19,869
2-vehicle	Opposite Direction	116	232	4,024
	Other 2-Vehicle	3,303	6,605	7,747
3 or more Vehicles	3 or More Vehicles	328	1,048	2,168
Total		5,496	9,635	33,808

**H-CAAS Description**

The pre-production Head-on Crash Avoidance Assist System (H-CAAS) is illustrated in Figure 2. The H-CASS automatically predicts certain types of impending head-on collisions, warns the driver, and applies braking in order to reduce the effects of an impact on occupants and vehicle damage as illustrated in Figure 3. The H-CAAS sensors, operation scenario, and mapping between the crash sequences and the H-CAAS internal and warning states are described in Zellner et al. (2012). Note that this pre-production H-CASS was still under development at the time of this evaluation. Many issues (e.g., reliability verification through field operational tests using product level sensors) were yet to be resolved before any mass production could occur. Therefore the performance and effectiveness of the pre-production H-CAAS for this program is not related to any current or possible future production H-CAAS or other ACAT.



*Figure 2. H-CAAS System Configuration.*

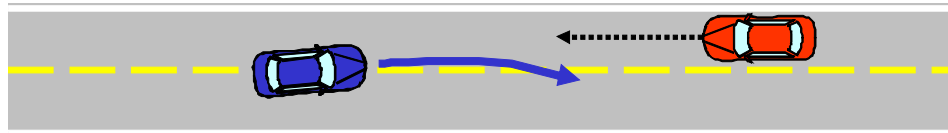
1. Subject Vehicle travels forward along its intended path.



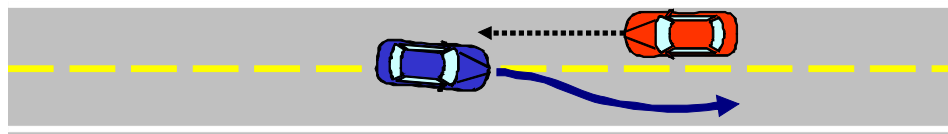
2. When the driver is inattentive (e.g., distracted, drowsy and/or impaired), the Subject Vehicle begins departing from its intended path. Then an oncoming vehicle approaches.



3. H-CAAS activates steering control and gives a warning (buzzer) to the driver.



4. The driver reacts to the warning and steers to avoid crash and resumes its intended path.



*Figure 3. Proposed Head-On Crash Avoidance Assist System Operation Scenario.*

### Technology Relevant Crash Types

It is generally assumed that the ACAT effectiveness in reducing the probability of conflicts, crashes, injuries, and fatalities depends on the numerous variables related to the crash circumstances. In order to estimate the safety benefits it is necessary to first quantify the ACAT collision and fatality effectiveness in Technology Relevant Crash Types (TRCTs) for which the ACAT is intended to be effective, based on a detailed technical understanding of the ACAT functionality. The H-CAAS has seven TRCTs that were defined by the ACAT designer based on coded crash scenario database variables as described in Zellner et al. (2012).

### The Size of the Problem Addressed

The numbers of addressable crashes, fatalities, and vehicles involved in each H-CAAS TRCT listed in Table 5 of Zellner et al. (2012) were then estimated using the OSEE Fleet Systems model as described in Van Auken (2011b). The Fleet Systems model was used with the H-CAAS TRCT classification criteria in Tables 3 and 4 of Zellner et al. (2012) in combination with the corresponding in-depth crash scenario database, in order to effectively interpolate the FARS (Tessmer 2006) and GES (NASS 2009) results in Table 1 to the H-CAAS TRCT level of detail (see, for example Najm et al. (2007)).

### OBJECTIVE TESTS

Objective testing in the ACAT-II program involved upgrades to the Guided Soft Target (GST) developed during ACAT-I; and detailed analysis of driver responses collected in previous Driving Simulator tests using an earlier prototype Crash Avoidance Assist System (CAAS). The second generation GST system is described in further detail in Kelly et al. (2011).

## Driving Simulator Tests

Data from a previous series of driving simulator tests using a prototype Crash Avoidance Assist System (CAAS) were used to quantify driver responses to (and corresponding driver response parameter values for) head-on conflicts with and without the ACAT, and also driver acceptance of the ACAT. The prototype CAAS system was an earlier version of the pre-production H-CAAS system, and was assumed to be sufficiently similar to the H-CAAS system for the purposes of this program. The driving simulator tests were conducted using the DRI Driving Simulator, as using established internal protocols for treatment of participants, as described in Zellner et al. (2012). These tests, which included 8 “distracted” driver subjects and 5 “drowsy” driver subjects, are further described in Zellner et al. (2012).

## Driver Model Parameters

During emergency driving it was assumed that the driver uses a pre-cognitive emergency driving procedure to attempt to avoid the crash. This emergency driving procedure was modeled by switched, open-loop driver braking and steering wheel angle or torque time histories. The emergency driving response time histories were modeled by a parsimonious set of parameters described in Zellner et al. (2012) in order to characterize different “driver behaviors.” The parametric steering time history was also refined for the H-CAAS evaluation in order to allow for asymmetric steering responses as illustrated in Figure 4, which was the typical steering response observed in the Driving Simulator tests for head-on drift scenarios. The asymmetric steering response represents a half sinusoid emergency steering maneuver followed by a second half sinusoid recovery maneuver with smaller amplitude and longer duration intended to bring the driver back into the original travel lane.

The driver specific emergency steering and braking response parameter values were determined by fitting the driving simulator test data for each driver subject, as described in Zellner et al. (2012). The resulting modeled emergency responses for the driver subjects are then assumed to be a representative distribution of “driver behaviors”.

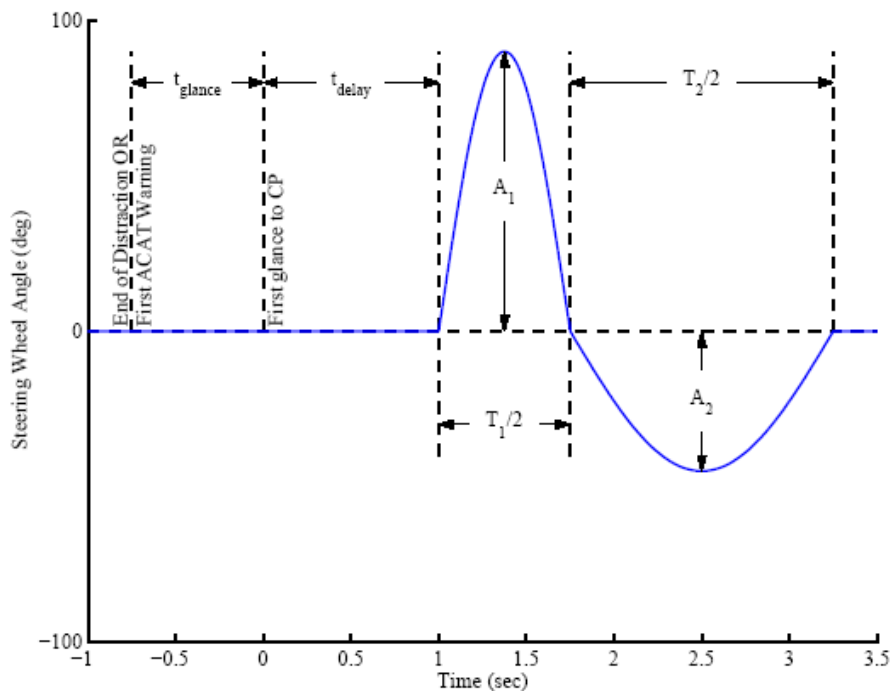


Figure 4. Parametric Form of the Assumed Driver Pre-Cognitive Emergency Steering Procedure.

## **SIMULATION RESULTS**

The effectiveness and benefits of the H-CAAS were estimated based on the results from the Crash Sequence Simulation Module and Overall Safety Effects Estimator.

### **CSSM Simulation Results**

The CSSM was used to simulate the conflict scenario with each of the unique driver-behavior combinations and with and without the ACAT, in order to estimate the relative reductions in numbers of crashes, injuries, and fatalities due to the ACAT. There were 106 unique simulation cases that were sampled using the Technology Relevant Case Sub-Sampling Tool (SIM Module 2) covering 5 of the 7 TRCTs (The other two TRCTs were the “S2” TRCT, which involved loss-of-control and were therefore not reconstructable by the current AART, and the “S6” TRCT, for which there were also no reconstructable cases in the 2000 through 2007 calendar year crash scenario dataset used; therefore these TRCTs have been omitted from the remainder of this analysis and are treated as H-CAAS having no safety effect.). There were a total of 26 different driver-behavior combinations observed in the simulator test results, which were simulated both with and without the ACAT. Therefore the total number of CSSM simulations was  $103 \times 26 \times 2 = 5,512$  simulations. With an approximate time per simulation of 1.5 minutes, the total simulation run time was about 138 CPU-hours or 5.75 CPU-days. The CSSM simulation results are further described in Appendix A.

### **OSEE Results**

The Overall Safety Effects Estimator was used to estimate at the US level the number of crashes, vehicles, and fatalities for the 2009 model year modeled fleet with and without the ACAT in the 2009 calendar year based on the CSSM results which are summarized in Table A3. These estimates were based on actual accident and exposure data for individual make-model vehicles in the 2008 model year fleet in the 2008 calendar year, using the Fleet Systems model described in Suzuki et al. (2006) and Van Auken et al. (2011b). The modeled fleet comprised Honda and Acura vehicles.

For example, one exemplar make-model vehicle in the modeled fleet (a 2008 model year 4-door Honda Civic) was involved in 1,830 accidents involving 2 vehicles in the 2008 calendar year resulting in 14 fatalities, based on VIN decoded NASS/GES and FARS data. Based on this information and other information about the 2008 and 2009 make-model vehicle (i.e., vehicle size, weight, safety equipment, sampled distribution of driver ages and sexes, and assumed vehicle registration year exposure), it was estimated by the Fleet Systems model that the 2009 model year make-model vehicle would have been involved in 1,276.5 accidents and 7.9 fatalities in the 2009 calendar year without the H-CAAS, and 1,274.4 accidents and 7.5 fatalities with the H-CAAS. These results are based on the assumption that the 2-vehicle crash cases in the Fleet Systems model, which were derived from NASS/CDS, PCDS, GES data (NASS 2000, 2002, 2009), are a representative sample of 2-vehicle crashes in the US. Therefore the number of crashes, vehicles, and fatalities can in effect be interpolated to the non-technology specific crash type and by TRCT level of detail by the Fleet Systems Model.

Repeating these assumptions and analysis for 1-vehicle, 2-vehicle, and 3-vehicle crashes and summing the results, it was estimated that the 2009 model year exemplar make-model vehicle would have been involved in 2,437.7 accidents and 15.5 fatalities in the 2009 calendar year without the H-CAAS, and 2,435.7 accidents and 15.1 fatalities with the H-CAAS.

The total number of accidents, vehicles, and fatalities in the modeled fleet with and without the H-CAAS were then estimated, at the same level of crash type detail, by repeating this process using the Fleet Systems Model for all make-model vehicles in the modeled fleet. The results were that the 2009 model year modeled fleet would have been involved in 10,221 accidents and 55.4 fatalities in the 2009 calendar year without the H-CAAS, and 10,208 accidents and 54.0 fatalities with the H-CAAS. Of these totals it was estimated that there were 495 accidents and 12.8 fatalities in non-technology specific “Opposite Direction” crashes without the H-CAAS, and 482 accidents and 11.3 fatalities with the H-CAAS.



## US Level Safety Benefits

The benefits of the Honda H-CAAS projected to the entire US Light Passenger Vehicle Fleet in the 2009 calendar year were estimated according to the methods described in (Burgett et al. 2008). The results are based on the size of the crash problem listed in Table 1 and the estimates of effectiveness for each TRCT from the Overall Safety Effects Estimator that are listed in Table A3. The overall benefits for each crash type listed in Table 2 can be calculated by multiplying the TRCT effectiveness values in Table A3 by the corresponding ratio of the number of TRCT crashes in Table 5 of Zellner et al. (2012) to the total number of crashes in Table 1. The benefits for each TRCT in Table 3 are then equal to the baseline problem size in Table 1 times the overall effectiveness in Table 2 according to Eq. (2) in Zellner et al. (2012).

**Table 2.**  
**Overall Estimates of Effectiveness of the H-CAAS by Non-Technology Specific Crash Type Projected to the Entire US Light Passenger Vehicle Fleet in the 2009 Calendar Year**

Non-Technology Specific Crash Type	Estimated Effectiveness		
	Crashes	Vehicles	Fatalities
2-Vehicle Opposite Direction	2.6%	2.6%	11.3%
Other crash types	0.0%	0.0%	0.0%
Overall	0.1%	0.1%	1.3%

## DRIVER ACCEPTANCE

Preliminary subjective ratings and objective data related to "driver acceptance" were also collected in the previous Driving Simulator tests with a prototype CAAS described herein. These data indicated that, in regard to CAAS "effectiveness," the driver subjective ratings were favorable, indicating that the participants found the system to be helpful, with most ratings among distracted and drowsy drivers being similar. Eighty-two percent found the system to be "Effective," "Very Effective" or "Extremely Effective." Eighteen percent rated the system "Somewhat Effective," while none of the participants rated the system "Not at All" effective. Drowsy drivers found the system to be more effective than distracted drivers, with 79% rating the system as "Very Effective" or "Extremely Effective." When asked if the participant would like to have the system installed in their vehicle, only two of the 20 participants said "No." Interestingly, the two participants who indicated "No" were from the drowsy group, which rated the system more favorably, on average.

Participants placed a monetary value on the prototype CAAS system somewhere between \$250 and \$1000. Seventy-seven percent of all participants placed the value of the system above \$250, while 55% valued the system at a level above \$500. Again, the drowsy drivers tended to assign a higher value than did the distracted drivers.

In regard to the "acceptance" (i.e., annoyance) evaluation tests, which were intended to quantify the effect of the False Positive steering wheel torque pulses, the subjective ratings were very favorable (i.e., not annoying) in terms of Ease of Performing the Driving Task and Sense of Discomfort/Risk, for all chosen steering torque pulse levels. In addition, objective measurements showed no appreciable degradation of driver performance over baseline driving during the False Positive events.

## ASSUMPTIONS AND LIMITATIONS

The accuracy of the ACAT-II SIM and results presented herein are based on various assumptions, approximations, and limitations in data, which are described in detail in Van Auken et al. (2011b) and Zellner et al (forthcoming). For example, it is assumed that the reconstructed crash cases in the simulation and test case samples are representative of all H-CAAS technology relevant crashes. However since the outcome of each crash (in general) is assumed to depend on numerous factors, including the time-space trajectories of the vehicles, the driver behaviors, environmental factors, and other crash circumstances, all of which are subject to some form of random variation, the accuracy of the results depends on the number of cases in the

representative case samples that were used at each stage of the SIM analysis (e.g., testing, simulations, overall safety effects estimation. The OSEE Fleet Systems model currently assumes that the ACAT is only installed on one vehicle in each crash. The projection to the US level does not account for the potential benefits of the ACAT if it were to also be installed on the crash partners as well.

## SUMMARY AND CONCLUSIONS

The Advanced Crash Avoidance Technology (ACAT) Phase II program was a proof-of-concept effort that sought to determine the feasibility of developing estimates of effectiveness for specific safety technologies in the absence of data from real world crashes or field operational tests. This project was successful at developing and demonstrating a methodology that could be used to estimate the safety benefits of the particular crash countermeasure evaluated in this research project.

The Safety Impact Methodology (SIM) tool developed was used to provide an estimate of safety benefits of a pre-production Honda Head-on Crash Avoidance Assist System (H-CAAS) in terms of reduction in crashes and fatalities. When projected to the US level (including all non-Technology Relevant Crashes) in the calendar year 2009, this corresponded to estimated total collision and fatality effectiveness values for all police-reported crashes of 0.1% and 1.3% respectively, and this corresponds to estimated safety benefits of 2,966 fewer head-on collisions and 450 fewer fatalities, as summarized in Table 3. These overall safety benefits are estimated based on more detailed safety benefits and effectiveness results described in Zellner et al. (forthcoming).

**Table 3.**  
**Overall Estimates of Benefits of the H-CAAS Projected to the Entire US Light Passenger Vehicle Fleet in the 2009 Calendar Year**

Crash Type		Estimated Benefits		
		Crashes	Vehicles	Fatalities
H-CAAS Technology Relevant Crash Type (See Zellner et al. (2012))	Primary (P1)	1,790	3,581	120
	Secondary 1 (S1)	506	1,013	44
	Secondary 3 (S3)	0	0	0
	Secondary 4 (S4)	670	1,339	277
	Secondary 5 (S5)	0	0	9
Other crash types (Non-H-CAAS Technology Relevant)		0	0	0
Total Estimate		2,966	5,933	450

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**APPENDIX A - SIMULATION RESULTS**

This appendix further describes the CSSM crash avoidance and mitigation and post-conflict conflict recovery simulation results.

**Crash avoidance and mitigation results:**

If the pre-crash simulation results in a collision, then the CSSM uses a US Air Force Articulated Total Body (ATB) crash simulation (Fleck 1981) to estimate the crash Delta-V, and an Injury Outcome Estimator to estimate the Fatality Equivalent injuries and the probability of fatality for the both the subject vehicle and collision partner drivers. The weighted number of collisions and fatalities are used to calculate the effectiveness of the ACAT within each TRCT.

The estimated annual numbers of collisions for each TRCT, without and with the ACAT, based on the CSSM simulations, are listed in Table A1. The product of the Exposure Ratio (ER) and Prevention Ratio (PR) can be calculated from the information in this table. For example, the annual numbers of vehicles involved in the Primary TRCT crashes without and with the H-CAAS technology were estimated to be 1,654 and 1,497 respectively. These results are based on simulation results from 41 different Primary TRCT crash scenarios, each with up to 26 different driver-behavior combinations for a total of 1,066 different crash scenarios x driver-behavior combinations. Assuming that the Exposure Ratio is 1, the ERxPR product for the Primary TRCT crashes is 0.905, which is equal to 1,497 divided by 1,654.

**Table A1.  
Estimated Effect of H-CAAS on the Number of Collisions by TRCT**

H-CAAS Technology Relevant Crash Type (See Zellner et al. (2012))	Estimated Number of Collisions Based on Simulations		Estimated ERxPR
	Without H-CAAS	With H-CAAS	
Primary (P1)	1,654	1,497	0.905
Secondary 1 (S1)	2,187	2,098	0.959
Secondary 3 (S3)	24	24	1.000
Secondary 4 (S4)	985	860	0.873
Secondary 5 (S5)	5,307	5,307	1.000

The annual number subject vehicle drivers and collision partner fatalities and Fatality Equivalent injuries were also estimated without and with the exemplar ACAT using the simulations. Example results for the subject vehicle driver are listed in Table A2. The data in this table was used to calculate ERxPRxFRsv, which is the number of subject vehicle driver fatalities with the H-CAAS divided by the number of fatalities without the H-CAAS (i.e., the same basic approach that was used to calculate ERxPR), and where FR is the Fatality Ratio. For example, the annual number of subject vehicle driver fatalities (in this weighted simulation sample) in Primary TRCT crashes without and with the H-CAAS technology was estimated to be 204.6 and 138.6 respectively, and the resulting ERxPRxFRsv product is 0.667. The Fatality Ratio can then be determined by dividing the ERxPRxFRsv product by the ERxPR product, resulting in FRsv=0.748.

**Table A2.**  
**Estimated Effect of H-CAAS on the Number of Subject Vehicle Driver Fatalities by TRCT**

H-CAAS Technology Relevant Crash Type (See Zellner et al. (2012))	Estimated Number of Subject Vehicle Driver Fatalities Based on Simulations		Estimated ERxPRxFRsv
	Without H-CAAS	With H-CAAS	
Primary (P1)	204.6	138.6	0.677
Secondary 1 (S1)	169.6	158.8	0.936
Secondary 3 (S3)	1.2	1.2	1.000
Secondary 4 (S4)	214.5	104.8	0.489
Secondary 5 (S5)	368.9	368.3	0.998

The resulting estimates of H-CAAS collision and fatality effectiveness based on these CSSM simulation results are listed in Table A3. The collision effectiveness is equal to the  $(1-ERxPR)x100\%$ ; the fatality effectiveness is  $(1-ERxPRxFR)x100\%$ . These results were used to estimate the overall effectiveness and benefits of the H-CAAS.

**Table A3.**  
**Estimated H-CAAS Effectiveness by TRCT**

H-CAAS Technology Relevant Crash Type (See Zellner et al. (2012))	Collision Effectiveness (1-ERxPR)	Fatality Effectiveness (1-ERxPRxFR)	
		SV	CP
Primary (P1)	9.5%	32.3%	39.3%
Secondary 1 (S1)	4.1%	6.4%	6.9%
Secondary 3 (S3)	0.0%	0.0%	0.0%
Secondary 4 (S4)	12.7%	51.1%	58.9%
Secondary 5 (S5)	0.0%	0.2%	0.7%

**Post-conflict recovery results:**

The CSSM was also extended to simulate the post-conflict recovery phase of the scenario in order to consider this phase in the ACAT evaluation as well. The simulation results for the recovery phase are used to assess the ability of the simulated driver to maneuver the vehicle back into the intended travel lane, after the driver's response to the warning.

The recovery phase was implemented in the CSSM simulations by transitioning back to normal driving (i.e., closed-loop path following) either after the completion of the open-loop emergency steering (half-sine) crash avoidance maneuver, or as soon as the collision partner is no longer visible in the forward view (i.e., is next to or behind the subject vehicle), whichever is sooner. The simulated driver attempts to regain the "intended path" by means of combined feed-forward/feedback control during the recovery phase, as opposed to following the reconstructed trajectory that resulted in a collision.

Application of the model in the CSSM simulations indicated that modeled drivers that successfully avoided the crash were also able to recover from the crash avoidance maneuver without overshoot. This result is consistent with the recorded trajectories of distracted and drowsy drivers in the original Driving Simulator experiments used to develop the driver models.