

SAFETY IMPACT METHODOLOGY (SIM): EVALUATION OF PRE- PRODUCTION SYSTEMS

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ABSTRACT

This paper describes a basic framework for Safety Impact Methodologies (SIM) to estimate potential safety benefits of pre-production advanced Driver Assistance Systems (DAS). A common flow-chart, showing the interaction between data usage, crash scenarios development, model development, testing, data generation, and benefits estimation activities, is used to describe the basic framework. Although the framework applies to all types of evaluation of DAS, this paper focuses on those aspects that support evaluation of pre-production systems.

The paper then describes three approaches to implementing the SIM framework for pre-production systems. Two of these approaches describe effectiveness in terms of reduction in number of crashes with the system active. The third approach describes the effectiveness in terms of fatality and injury reduction, rather than estimating crashes avoided.

The paper concludes with descriptions of how the three approaches are being implemented in the SIMs that are being developed by the four teams participating in NHTSA's Advanced Crash Avoidance Technology (ACAT) program. The paper also includes brief descriptions of other benefits evaluations as a means of highlighting how the framework accommodates evaluation of production systems and near-production systems as well as pre-production systems.

The framework developed in this paper provides a cornerstone for development of safety impact methodologies for evaluating pre-production driver assistance systems and for comparisons of methodologies that are used to evaluate production and near-production systems.

INTRODUCTION

The automotive industry has made significant progress in the development of advanced technologies intended to prevent crashes and their consequences. Advanced technologies that include sensing, computing, positioning, and communications appear to have the ability to help drivers avoid imminent crashes or events that often lead to crashes and to reduce the severity of crashes that do occur. For example, some of these technologies address goals such as preventing rollovers, improving visibility, reducing tailgating, and reducing speed for safety related conflict conditions.

A key question about these technologies is how effective they will be in preventing crashes and reducing the severity of injuries to vehicle occupants.

To answer this question NHTSA initiated the ACAT program to determine if there is a methodology, or one can be developed, that will effectively measure the link between technological performance of pre-production systems and their safety impact. Benefits estimates from such a methodology can be used in many ways: 1) as part of the design process of new systems, 2) to evaluate the performance of pre-production systems before marketing, 3) to provide guidance to safety advocates, such as NHTSA, on new safety improvements, and 4) to form the basis for regulatory evaluations of potential new requirements.

Methodologies that have been used for estimating safety benefits include:

1. Gathering crash data for systems that have been available to consumers for sufficient time to establish a record of numbers of crashes. This is a common method for evaluating the impact of new requirements in Federal safety standards.

An example of a regulatory evaluation that uses this methodology is provided in Appendix A.

2. Implementing Field Operational Tests (FOT) with selected near-production systems to create a database of driver/system performance that can be used to estimate safety impact. An example of an evaluation of a technology based on FOT data is provided in Appendix A.
3. Performing laboratory tests with pre-production systems and extrapolating the results to estimate the safety impact.

The third of these methods is the most feasible for early assessment of pre-production systems. For this reason, this methodology is the focus of the NHTSA ACAT program, and this paper.

In summary, part of NHTSA’s goal for the ACAT Program is to establish a Safety Impact Methodology (SIM) that will support the evaluation of an ACAT countermeasure and produce safety benefit estimates.

NHTSA SIM FRAMEWORK

The above three methodologies used to estimate safety benefits are based on the benefits equation $B = N_{wo} - N_w$ [Appendix B] and its derivatives. Where,

B = benefits, (which can be the number of crashes, number of fatalities, “harm,” or other such measures).

N_{wo} = value of this measure, (for example, number of crashes) that occurs without the system.

N_w = value of the measure with the system fully deployed.

In this paper a SIM framework is developed to populate the various components of the benefits equation. This framework identifies the principle components of SIM and interaction between these components. The framework does not dictate a specific approach or method. The framework communicates NHTSA’s operational vision of a SIM and the activities NHTSA identifies as critical to developing a sound methodology. The elements of the SIM include activities, functions, and interactions. This framework can be adjusted to accommodate and communicate various approaches. The framework corresponding to the SIM structure is shown below in Figure 1. The highlighted portion of the framework in Figure 1 is the core of the ACAT SIM methodology and is the focus of this project. The rest of the activities are similar to other methodologies (i.e. evaluation of FOTs and Regulatory Evaluation, examples of which are available in the Appendix A) involved in the benefits estimation process.

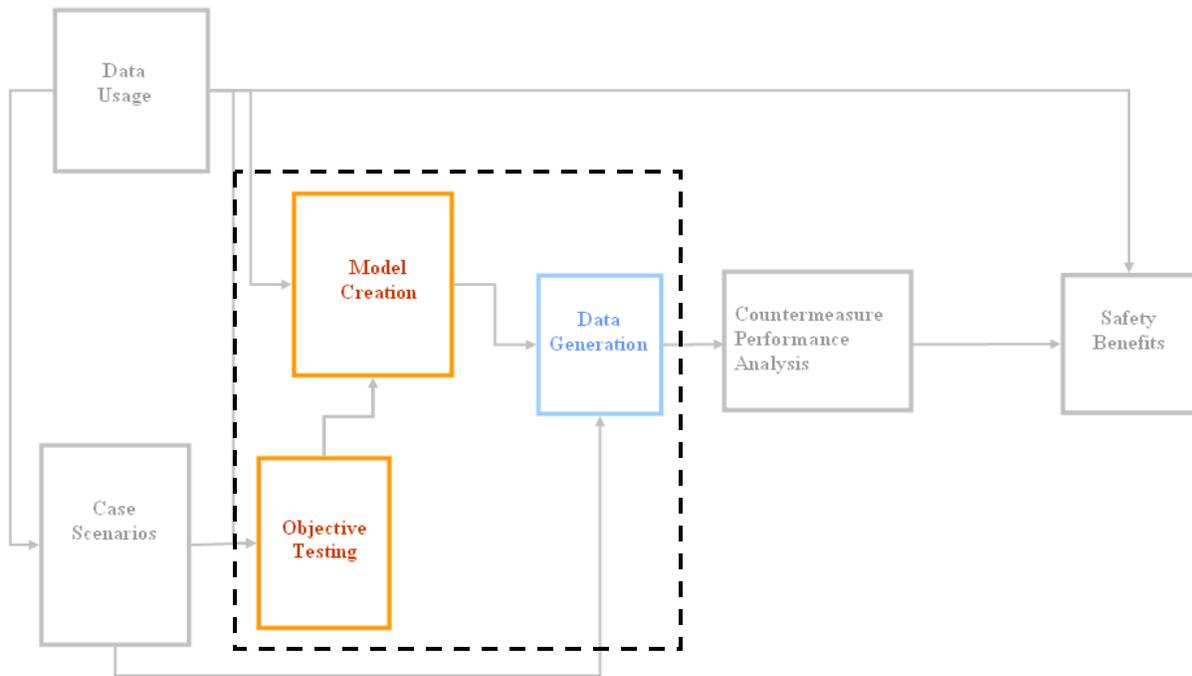


Figure 1: SIM Framework

Details of the framework

The SIM structure and framework in Figure 1 is expanded to show the details of the functions within each activity in Figure 2. The high level activity boxes in Figure 2 are the same activities as in Figure 1 and correspond to the section titles of their description. Functions identified within each activity are assigned numbers ([1], [2], etc.). The different outline colors of the activity boxes represent two distinct areas of the SIM framework, namely the model *development* activities (shown in **orange**) and the model *execution and analysis* (shown in **blue**). *Model development* activities include development of data and information needed to create the model, model inputs for data generation, and data to support the validation and calibration of the model. Not all of these activities need to be executed if there exists a completed evaluation of a similar ACAT countermeasure. *Model execution and analysis* activities include running the model to generate the necessary data to calculate safety benefits estimates of the subject ACAT countermeasure. The details of the various components of the SIM, as shown in Figure 2, are discussed in the remainder of this section.

Data Usage:

This activity describes the available data that is used in the development of a SIM. The available data includes crash data files like General Estimates System (GES)[GES, 2006], Crashworthiness Data System (CDS) [CDS, 2006], National Motor Vehicle Crash Causation Study (NMVCCS), [NMVCCS, 2008] etc. [1], naturalistic driving data (such as the 100-Car Naturalistic Driving Study and Field Operation Tests [Dingus, 2006], etc.) [2], Corporate body of knowledge [3], and a technical description of the ACAT countermeasure [4]. The functions included in this activity are as follows:

- The identification of all technology relevant crash types and countermeasure data sources.
- Defining and estimating the magnitude of the crash problem in relation to the subject ACAT countermeasure.
- The identification of real world pre-crash scenarios that can be addressed by the subject ACAT countermeasure.
- Documenting the functional characteristics of the ACAT countermeasure

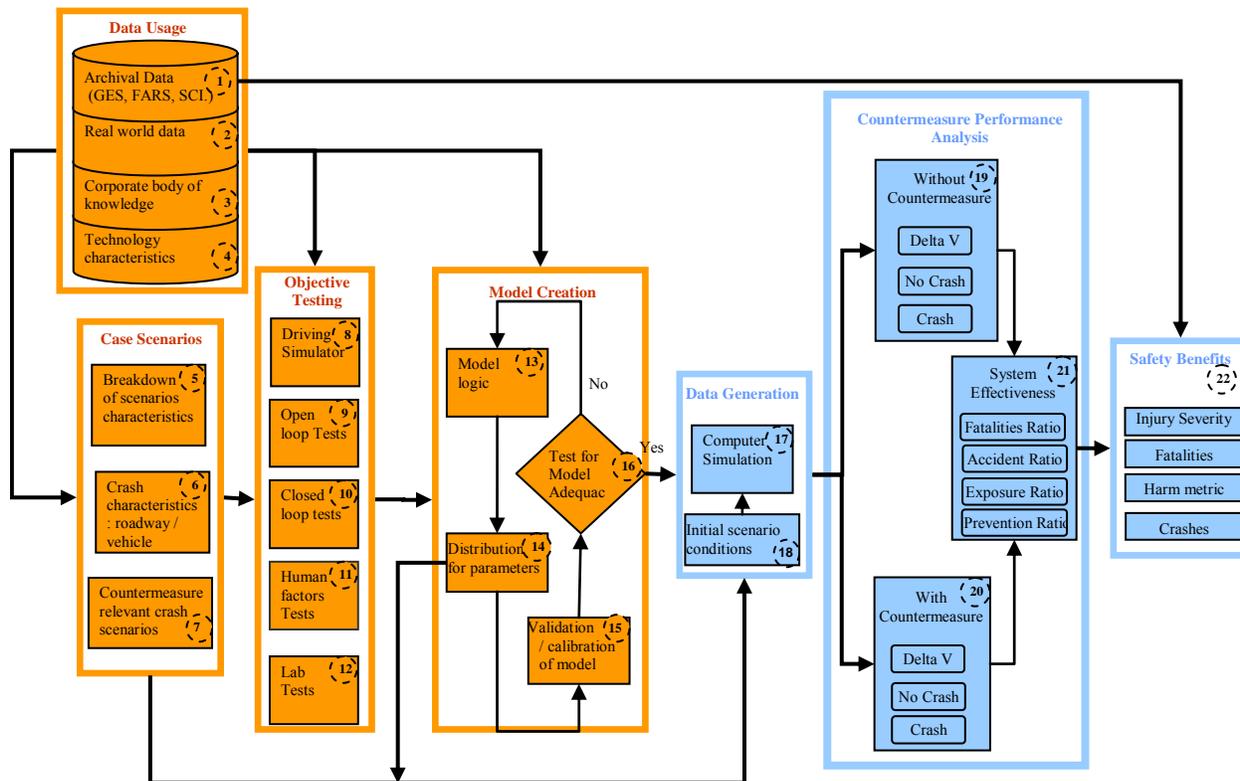


Figure 2: Details of NHTSA SIM Framework

Case Scenarios:

In this activity, the SIM developer consolidates the crashes that are relevant to the specific ACAT countermeasure. The activities include breakdown of scenarios [5], crash characteristics [6] and countermeasure relevant scenarios [7]. One starting point is the Universal Description (updated to most-recent year of data) which is a high-level description of events and conditions that precede crashes [Burgett, 2008] The Universal Description utilizes the central variables (Critical Event, Corrective Action Attempted, and First Harmful Event) of the National Automotive Sampling System's Critical Crash Envelope¹ [GES, 2006] to describe mutually-exclusive scenarios that are potentially relevant to ACAT countermeasures. Each relevant scenario can be further refined through development of a Crash Phase Time Line² [Burgett, 2008]. The phases of the crash time line are defined by specific values of Time-to-Collision (TTC). The logic for interaction of the ACAT countermeasure is described in terms of the phases and anticipated driver reactions. The Case Scenarios activity has three functions :

- The first area is to identify the broad characteristics of representative crashes that are to be addressed.
- The next area identifies the attributes of individual scenarios including the values that describe the roadway and the operation of the vehicle.
- The last area finalizes the relevant crash scenarios and summarizes the functional characteristics of the countermeasure. These are the scenarios that become the subsets in the benefits equation as indicated by the summation of "i" (Appendix B).

Model Creation:

A key element of the NHTSA SIM is that the data about driver and system performance is generated by a computer model as shown in Figure 2. The purpose of the model is to generate the data that produces the safety benefits. The details of the model are tailored to suit the technology of the ACAT system and the

¹ The NASS Critical Crash Envelope includes six variables: Driver Distracted By (D07), Movement Prior to Critical Event (V21), Critical Event (V26), Corrective Action Attempted (V27), Pre-crash Vehicle Control (V28), Pre-crash Location (V29) and First Harmful Event (A06).

² The Crash Phase Time Line consists of five phases: Non-conflict, Conflict, Imminent crash, Crash and Post-crash. Zero time ($t = 0$) occurs at the beginning of the Crash phase.

relevant scenarios identified in the preceding activity. The model [13] is a set of equations (differential, algebraic, Boolean, etc.) with an embedded set of parameters that describe the performance of the vehicle/driver/ACAT countermeasure. The equations describe three relationships: 1) the control actions by the driver in response to all environmental stimuli, including warnings or other input from a ACAT countermeasure, 2) the motions of the vehicle in response to driver control inputs including interactions with other vehicles and the roadway, and 3) the performance of the countermeasure relative to vehicle motion and the driving environment. The data for the value of, or distributions of values of parameters [14] are obtained from the objective tests described below. The model outputs include the answer to the question of whether a crash occurred or not, and the dynamic conditions at the point of impact when a crash occurs. The model creation step also includes an iterative process of calibration and validation [15] that checks for adequacy [16] of the computer model outcome against the outcome of objective tests and baseline crash data.

Objective Testing:

Once the relevant crashes, crash data, and the basic concept of the model are established, various types of tests are used to obtain values for the embedded parameters. Testing includes Driving Simulator [8], Open loop test [9], Closed loop tests [10], Human factors test [11], and Lab tests [12] to determine distribution of values of parameters that would populate the driver, vehicle and countermeasure models. Various parameter values and distribution of values will be needed to replicate the following relationships in order to accurately account for driver, vehicle, countermeasure, and scenario interactions and obtain representative results to base the estimate of safety benefits. The relationships that need to be replicated include:

- The driver's response to the ACAT countermeasure
- The performance of the ACAT countermeasure system
- The vehicle's response to control inputs, including any direct ACAT countermeasure intervention
- The characteristics of the driver
- The system / component characteristics of the ACAT countermeasure

Data Generation:

When the model has been completed and validated, it is ready to be used for data generation. This activity uses the finished model that was validated and calibrated in the Model Creation activity. In this activity the model is executed using initial conditions and other scenario information to generate the data needed to estimate the safety benefits. Each “run” will simulate a period of time during which a driver is exposed to a critical event, including initial conditions that reflect an appropriate level of risk. The performance of the driver (as represented by the driver performance model) affects whether or not a crash will occur during each run. Each run *with* the countermeasure system active will be matched by a corresponding run *without* the countermeasure, for all of the scenarios.

The computer simulation [17] embodies the equations that replicate the driver, the vehicle, and the countermeasure and allows each of them to interact with the scenarios and each other. The model provides the environment by which the ACAT countermeasure is tested such that an estimate of how the countermeasure would perform in a real-world environment can be ascertained.

The initial conditions [18] in this activity include the relevant crash scenarios that describe the scope and range of events that the ACAT countermeasure will be tested against to determine the countermeasure effectiveness and produce the data needed to estimate the safety benefits.

Countermeasure Performance Analysis

This activity uses the data from the Data Generation activity to calculate the various ratios needed to evaluate the performance of the subject ACAT countermeasure and determine the system’s Safety Effectiveness in preventing crashes. The *Without* Countermeasure [19] function captures all the data generated by the Computer Simulation tests that are conducted when the ACAT countermeasure is not activated. The *With* Countermeasure [20] analysis captures all the data generated by the Computer Simulation tests that are conducted when the ACAT countermeasure is activated. The System Effectiveness [21] analysis uses the data sorted by *Without* Countermeasure and *With* Countermeasure to calculate the relevant countermeasure performance ratios that produce the System Safety Effectiveness ratio.

Safety Benefits:

This activity transforms the performance ratios into safety benefit estimates [22]. Ratios associated with fatalities, exposure, and prevention are transformed

into estimates of crashes, fatality and injury severity reductions. This is achieved by implementing the Benefits Equations $B = \sum_i N_{wo_i} \times E_i$ and its

extensions (Appendix B). In this equation, N_{wo_i} is the number of crashes that occur in scenario “i” when the ACAT countermeasure is not available and E_i is the effectiveness of the ACAT countermeasure in preventing crashes in scenario “i.”

ACAT PROGRAM

Given the framework of the NHTSA SIM, three approaches are discussed in the remaining part of this paper that fit into the NHTSA SIM methodology. NHTSA is currently working with four teams that have exercised the SIM methodology in the ACAT program as a means of answering how effective their technology would be in preventing crashes and reducing the severity of injuries to vehicle occupants. A summary of these approaches is given below:

Approach1

The first approach begins by defining the crash problem size by looking into public domain databases as well as naturalistic driving data to come up with technology relevant crash types. Crashes that fall into these categories are sub-sampled to obtain a technology relevant subset of crashes. These subsets are reconstructed based on their time-domain relationships and are subject to test-track testing, simulator testing, lab testing, etc. to generate parameter values that feed into the computer model. The models are validated and calibrated against the reconstructed data as well as the preliminary results obtained from simulation data. This validated model is used in the final set of simulation runs that generates data for the safety benefits estimation process.

Approach2

The second approach begins similarly by defining the crash problem size from public domain research databases to narrow down the relevant crash types. However, instead of real-world crashes, the approach builds heavily on statistical distributions for parameter values that populate the driver, vehicle, and countermeasure models. The values for these distributions are obtained from subjective simulator and human factors testing combined with driver-vehicle involved track tests. These distributions form the basis for inputs of all parameters that populate the simulation model. A random number generation using a Monte Carlo process picks data from each of these distributions that will define the initial state of the parameters as well as the dynamics of the run. Each run will be performed several times to account

for all possible range of values that is applicable to the prevailing countermeasure system. The output from these simulation runs will be used in the safety benefit estimation process.

Approach3

The third approach addresses safety benefits from the perspective of fatality and injury reduction by reduction in impact speed. This process is conducted by classification of the accident patterns for each countermeasure system; and use driver and vehicle models to estimate effectiveness of the safety system. Driver and vehicle parameters such as subjects' response time to the warning, system response time, and reduction speed are obtained from objective tests.

ACAT Implementation

The three approaches mentioned above form the basis of all SIM implementations in the ACAT program. All four teams have implemented the SIM methodology that can be expressed within the framework of these three approaches. The four teams NHTSA is working with and the details of their approach towards the SIM are as follows:

Team 1: . Advanced Collision Mitigation Braking System. (ACMBS) Countermeasure.

Dynamic Research Inc is working with Honda who developed an ACMBS. The ACMBS automatically predicts impending collisions, warns the driver, and applies braking in order to reduce the effects of an impact. Their approach (1) begins with the reconstruction of series of crashes from archival US DOT accident databases (NASS/CDS, Pedestrian Crashworthiness Data System (PCDS) and FARS) to generate a Crash Scenario Database This crash scenario database contains in-depth information and time-space reconstructions of real-world accidents based on their time-domain relationship. This data is used to classify the crash scenarios in terms of technology relevance and to create sub-samples of cases in each technology relevant crash type.

Once the technology relevant crash types defined and real world cases are selected, tests are conducted to obtain parameter values. In objective testing, relevant scenarios are subject to lab tests, driver-out-of-the-loop tests, driver-in-the loop test, and driving simulator tests to provide the necessary data that could be used to validate and calibrate the driver, vehicle, and countermeasure performance models. These tests would serve as a bridge between the reconstructed component of the analysis and the simulation runs that generate the data.

The computer simulation comprises the validated models (driver, vehicle and countermeasure) and calibration parameters. The simulation tool is used to simulate driver, vehicle, and the environment, with and without the ACAT, allowing for uncertainties in driver response to the ACAT system. The outputs from the runs are used to estimate the overall effect of the ACAT on crash involvement and fatalities for each crash type.

Team 2: Lane Departure Collision Countermeasure.

Volvo and Ford, working with the University of Michigan Transportation Research Institute (UMTRI), are researching Volvo developed Driver Alert Control (DAC), Lane Departure Warning, and Emergency Lane Assist (ELA) systems. DAC monitors lane keeping and curve taking performance over long periods of time and warns the driver to take a break from driving if performance degrades. LDW uses a camera to detect lane lines and warns the driver when the vehicle is drifting out of the lane. ELA senses when the driver is making a lane change into oncoming traffic that could result in a conflict and responds automatically to help move the vehicle back into the lane.

The Volvo/Ford/UMTRI (VFU) approach (2) uses a Monte Carlo simulation to generate the data required for estimating safety benefits. Following are the steps involved in developing the model:

A detailed investigation of crash circumstances and related factors is developed based on a nationally representative crash database (in this study GES was used). The VFU team developed a method of classifying crashes that results in mutually exclusive scenarios that are potentially relevant to ACAT countermeasures. This allowed for developing scenarios that were as closely tailored as the crash data allows to the safety technologies being evaluated .the safety technologies are assumed to be relevant for crashes in which the subject vehicle was not maneuvering prior to the initiation of the crash sequence, i.e. where the lane/road departure appears to be unintentional.

Naturalistic driving data from appropriate FOTs (Road Departure Crash Warning System Field Operational Test (RDCW-FOT)[leBlanc, 2006]) is used to assist in assigning initial conditions, and to assist in parameterize driver inattention models.

Public road tests, test track tests, and driving simulator tests are conducted to generate distributions of parameters, assess system availability, and for

characterization of vehicle, driver, and environment models.

The Monte Carlo simulation model includes a vehicle model, an ACAT system model (DAC, LDW, & ELA), and a driver model. All the components of the simulation model are validated and calibrated against available test data. This completes the model development process. Then the developed model is used to generate data in terms of when crashes are likely to occur and when there is likely to be no crash. This model is executed with and without the countermeasure active. The output from the simulation is used to generate an estimate of the effectiveness ratio for the technology, and safety benefits that given sufficient input could be calibrated to represent national statistics.

Team 3: Pre-Collision Safety System (PCS) Countermeasure.

Toyota's ACAT project develops a safety impact estimation methodology (SIM) for a pre-collision safety system (PCS) that is designed to mitigate the collision impact with obstacles in front of the subject vehicle through warning, activation of brake control systems, and occupant restraint systems prior to a collision. It addresses safety benefits from the viewpoint of fatality and injury reduction by reduction in impact speed.

Accident data from 2005 NASS-GES and 2005 FARS are categorized into major accident patterns. Accident patterns applicable to the safety system will be selected from the categorized patterns. A driver and vehicle model are used by the SIM to estimate the effectiveness of the safety system.

The parameters of the driver model, such as response time to warning, are determined from driver simulator tests while the vehicle model parameters, such as system delay and speed reduction, are determined from test track tests.

The reduction in impact speed, with the ACAT system active, is determined by overlaying effects of ACAT system from test-track tests on driver's reaction from driving simulator tests. The reduction in impact speed is then used to estimate reduction in fatalities and casualties [Yamanaka, 2006]. These effectiveness values are extrapolated to national estimates of safety benefits.

Team 4: Backing-Collision Countermeasure. General Motors, working with the Virginia Tech Transportation Institute is researching a Next-Generation Backing-Collision countermeasure that

provides levels of information, warning and automated control to avoid backing collisions.

The focus of General Motor's (GM) ACAT Backing Crash Countermeasure Program (annual report 1) is to characterize backing crashes in the U.S. and investigate a set of integrated countermeasures to mitigate them at appropriate points along the crash timeline, with the objective of estimating the potential safety benefit, or harm reduction that this countermeasure-set might provide. The primary goal of the SIM is to predict the proportion of certain crashes that might be eliminated or mitigated if a countermeasure is deployed.

GM's Safety Impact Methodology (annual report 2007) begins with estimating the crash problem size utilizing multiple sources like public domain research on backing maneuvers, existing GM research, national crash databases like GES, FARS, Special Crash Investigations (SCI), and NHTSA's report to Congress on backing maneuvers.

The analysis of the crash problem description leads to the development of a framework of ten technology relevant scenarios (6 representing pedestrian back-over crashes, 3 representing vehicle-to-vehicle crashes, and 1 for vehicle-to-fixed-object crashes).

Once the technology relevant crash types, scenarios and the countermeasure performance requirements are established, objective tests are performed. As part of the ACAT goal, a preliminary set of three classes of objective tests were designed. The three basic types or classes of objective tests are:

1. Driver out-of-the-loop Grid Test for Obstacle Response Performance,
2. Trained driver-in-the loop test for False Alarm rate
3. Naïve driver-In-The-Loop Test of Crash avoidance.

The data from these tests provides information that aids in both model construction and model validation. The validated model essentially forms the core the SIM tool which is a Matlab/Simulink programming environment that performs the necessary mathematical operations.

The core of the SIM is the Monte Carlo simulation process that will extract data from a given set of distributions. The process involves picking values from a given distribution for a given iteration, which

are obtained from objective tests and other sources of data. Each iteration is run several times for a new set of parameter values with and without countermeasure active to account for the variability in outcomes. A comprehensive set of data is produced for all situations which are used in the estimation of safety benefits. The main outcome of the safety benefits estimation process is the predicted number of crashes potentially avoided and injuries mitigated annually following the deployment of a particular crash countermeasure.

ACAT Summary

A summary comparing the three approaches for the four ACAT teams and their components are given below in Table 1

CONCLUSION AND SUMMARY

This paper develops a basic framework for Safety

Impact Methodology (SIM) to estimate potential safety benefits of pre-production advanced Driver Assistance Systems (DAS), describes three approaches for the framework, and provides a description of the implementation of the SIM by the Advanced Crash Avoidance Technologies (ACAT) program teams.

Each of the approaches by the four teams exhibits a unique and challenging opportunity to assess the effectiveness of a countermeasure system. Given the complexity of each of the systems and their subcomponents, each process brings with it numerous merits. All four of these projects are still in progress so the final step of estimating safety benefits has not been completed. The testing phase of each project is almost complete and each of the projects will be completed during 2009.

SIM Blocks	Components	Team 1: . Advanced Collision Mitigation Braking System. (ACMBS)	Team 2: Lane Departure Collision Countermeasure	Team 3: Pre-Collision Safety System (PCS) Countermeasure	Team 4: Backing-Collision Countermeasure
Data Usage	Archival Data, Real world data, Corporate body of knowledge and Technology characteristics	NASS/CDS, PCDS, VTTI data, and FARS and GES data for an <i>Advanced-Collision Mitigation Braking System</i>	GES, CDS, Highway Performance Monitoring System (HPMS), ,RDCW-FOT, and data for a <i>Lane-Departure Prevention System</i>	GES, FARS and Event data recorder (EDR) for a <i>Pre-Collisions Safety system</i>	FARS, GES, SCI, Public domain research, and VTTI data for a <i>Backing Countermeasure System</i>
Case Scenarios	Breakdown of scenarios, Crash Characteristics and Technology relevant scenarios	–vehicle-vehicle, rear-end/forward impact –vehicle-vehicle, head-on –vehicle-vehicle, intersecting paths –Single vehicle, pedestrian	Inadvertent lane or road departure	- (Lead vehicle stopped(LVS) - Lead vehicle decelerating (LVD)	10 scenarios (6 pedestrian crashes, 3 vehicle-to-vehicle crashes, and 1 vehicle-to-fixed-object crashes).
Objective Tests	Driving simulator, test track and Lab/HMI test	Driving simulator and lab tests involved. Tests include guided soft Target-vehicle impact tests using naïve and trained driver.	Driving simulator and lab tests involved. Naïve driver test conducted for LDW. Trained driver tests for system validation.	Driving simulator involved. Vehicle tests with -fixed obstacles for system performance	Track and public road tests involved. All 10 scenarios tested. Pedestrian tests using mannequins.
Model Creation	Model definition, validation and calibration	Indigenous simulation model. Cases validated against automated reconstruction and simulation	Using distribution of parameters. Model generated with Matlab/ Simulink/CarSIM	Model validated from test track.	Matlab/Simulink model. Validated based on previous corporate sponsored research
Data Generation	Digital computer simulation and simulator testing	Reconstructed crashes run with and without the DAS.	Monte Carlo simulation run with and without DAS	Simulator Testing results	Monte Carlo simulation run with and without DAS
Countermeasure Performance Analysis	Without countermeasure, With countermeasure, System effectiveness.	DeltaV, Crash, No crash, exposure ratio, prevention ratio	Crash/No, Crash, Exposure ratio, Prevention ratio	Crash/ No crash, Speed reduction Crashes avoided, Injuries reduced	Crash/No crash, Prevention ratio
Safety Benefit	Safety benefits	Crashes, fatalities, conflicts , injury severity	Crashes reduced/ mitigated	Crash reduction, fatalities and injury reduction.	Crashes reduced/ mitigated

Table 1: Comparison of SIM for the four ACAT teams

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APPENDIX A EVALUATION EXAMPLES

Estimations of the safety impact of driver assistance systems are performed for a wide range of purposes. Two of the more common purposes are as part of the regulatory analysis for a pending regulatory activity and for the evaluation of the safety impact of a prototype system as part of a field operational test.

In this Appendix, one example of each of these two types of evaluation are discussed in the context of the SIM framework.

Regulatory Evaluation [FMVSS #126, 2007]

This example discusses the Safety Benefits portion of the Final Regulatory Impact Analysis for Standard No. 126. that requires installation of electronic stability control (ESC) systems.

As with most evaluations, the evaluation begins by identifying Data that can support the analysis. In this case, the CDS and FARS crash data files were determined to be appropriate data sources.

The next step, identifying relevant Case Scenarios, is accomplished by comparing the performance characteristics of ESC systems with crash characteristics from the crash data files. This comparison led to the conclusion that there are two main types of crashes that are addressed by ESC systems: single-vehicle crashes and a subset of single-vehicle crashes where the first-harmful-event is a rollover. The system performance characteristics for this evaluation were obtained by testing commercially available systems.

ESC systems have been installed on vehicles for enough years that there is now a history of crash results with these systems. This evaluation makes use of the available crash data for vehicles that are equipped with compliant ESC systems. Availability of crash data for vehicles with the system is one feature of this evaluation that distinguishes it from the evaluation in the ACAT program. In the ACAT methodology it is necessary to have computer models, or equivalent tests, that are used to create a data base for the evaluation. In the case of this evaluation, the available crash data serves that purpose. Thus, in the framework shown in Figure 1, the Objective Test, Model Creation and Data Generation activities are replaced by the combination of crash data for vehicles with ESC systems and vehicles without ESC systems.

The Countermeasure Performance analysis consists of estimating system effectiveness through use of the

available crash data. The effectiveness estimation uses the form of the Benefits Equation described in Equation 5 of Appendix B.

In this evaluation the measure of exposure that has been selected is the number of “non-relevant crash involvements” for each group of vehicles (those without ESC and those with ESC [Dang 2007]).

The Countermeasure Performance Analysis in this evaluation concludes with values of effectiveness in preventing single-vehicle crashes and single-vehicle crashes with rollover as the first-harmful-event for passenger cars. The analysis also includes similar results for fatal crashes and for light-truck and van type vehicles. The two values of effectiveness for passenger cars are:

$$SE_{PC} = 34 \% \\ SE_{PC/Rollover} = 71 \%$$

The final step in the SIM is to combine estimates of effectiveness with the size of the problem to obtain the estimate of safety benefits. This analysis concluded that in the year 2011 when the requirement for installation of ESC goes into effect, there will be 142,000 relevant single-vehicle passenger car crashes and 33,700 relevant single-vehicle passenger car crashes with rollover as the first-harmful-event. Thus the annual safety benefits of introducing this requirement are the reductions in these numbers that will occur due to installation of ESC. The evaluation concludes that these passenger car benefits are 48,400 single-vehicle crashes and 21,100 single-vehicle passenger car crashes with rollover as the first-harmful-event.

Field Operational Test [Najm, 2006]

This evaluation uses data that was generated during a field operational test of a rear-end crash warning system [Zador, 2000]. In this analysis, the GES and CDS crash data files were determined to be appropriate crash data sources to complement the field data from the operational test.

Relevant Case Scenarios were determined by comparing the performance characteristics of the ACAS with crash characteristics from the crash data files. This comparison led to the conclusion that there are three main types of crashes addressed by the ACAS. They are:

1. Lead-vehicle stopped
2. Lead-vehicle moving at lower constant speed
3. Lead-vehicle decelerating

These three primary scenarios were subdivided further by the type of driver response and the speed at the time of the event. There are two basic driver responses: brake or steer. The speeds (V) were grouped into three ranges: $V < 25$ mph, $25 \text{ mph} < V < 35$ mph, $V > 35$ mph. Thus, there are a total 18 scenarios to be evaluated.

The evaluation uses the form of the Benefits Equation shown in Equation 7 of Appendix B. In this form, the effectiveness in each scenario is a combination of the Exposure Ratio and the Prevention Ratio. The Exposure Ratio quantifies the change in rate of exposure to conflicts that results from introduction of the ACAS; and the Prevention Ratio quantifies the change in number of crashes that occur as a consequence of the conflict. Thus, the estimation of effectiveness consists of estimating these two ratios. The data for estimating the Exposure Ratio comes directly from the FOT data. The evaluation uses two conflict types (Conflict and Near-crash) and two intensity levels (Low intensity and High intensity) as the basis for determining Exposure Ratio. However, during the test program, none of the vehicles experienced a crash; a limitation that is common to most FOTs. Therefore, it was not possible to estimate the Prevention Ratio directly from the FOT data. To circumvent this shortcoming, the evaluators utilized a model of the relative motion between vehicles during braking and overtaking scenarios. Details of the distributions of parameters in the model are discussed below. The model was used in a Monte Carlo simulation to create a database that could be used to estimate values of Prevention Ratio. The Countermeasure Performance analysis utilized the formulation of the Benefits equation that is based on values of the Exposure Ratio and the Prevention Ratio in each scenario. The list of scenarios discussed above shows that the range of the summation for estimating system effectiveness is $1 \leq i \leq 18$. In summary, the Data Generation activity included both the data gathered during the FOT and data generated by the Monte Carlo simulation.

The Countermeasure Performance Analysis in this evaluation consists of estimating the value of the Exposure Ratio and the Prevention Ratio for each of the 18 crash scenarios. The values of Exposure Ratio were calculated directly from FOT data. The model mentioned above was used in a Monte Carlo series of simulations to estimate the change in number of crashes, and hence the value of Prevention Ratio. Initial conditions for the simulations were taken from the FOT data, but distributions of parameters such as level of deceleration and time-to-collision at the time of brake application were taken from the literature.

The results of the Countermeasure Performance Analysis are summarized in the following table for the seven scenarios that showed statistically significant improvements with ACAS. These are the only scenarios that were used to estimate system effectiveness.

ACAS Effectiveness Estimation					
Scenario	Avoidance Maneuver	Speed (Mph)	E_i	N_{woi} / N_{wo}	SE Component
LVS	Brake	V>35	0.14	0.05	0.68%
LVM	Brake	V<25	0.73	0.03	2.09%
LVM	Steer	V>35	0.21	0.00	0.01%
LVD	Brake	V>35	0.18	0.26	4.60%
LVD	Steer	V>35	0.21	0.01	0.23%
LVS	Brake	25<V<35	0.29	0.03	0.99%
Net System Effectiveness =					8.60%

The final step in the SIM is to combine estimates of effectiveness with the size of the problem to obtain the estimate of Safety Benefits. From GES it is seen that there are 1,791,000 police-reported rear-end crashes annually. These are distributed between the three primary scenarios as follows:

- LVS: 28%
- LVM: 8%
- LVD: 61%

There are also approximately 2,149,000 unreported rear-end crashes annually, making a total problem size, N_{wo}, of 3,940,000 crashes. Combining this problem size with the system effectiveness of 8.6 % leads to the conclusion that the ACAS could help prevent 340,000 rear-end crashes per year. The evaluation includes additional details of confidence intervals and ranges of possible benefits that are not discussed in this short summary.

**APPENDIX B
SUMMARY OF EQUATIONS FOR
ESTIMATING SAFETY BENEFITS**

The purpose of the SIM is to implement the Benefits Equation for the estimation of number of crashes prevented by the ACAT countermeasure, and provide extensions for estimation of impact on level of injury. Although there are many formulations, they all are based on the fundamental definition of benefits [Burgett, 2008]:

$$B = N_{wo} - N_w \quad (1)$$

Where,

B = benefits, (which can be the number of crashes, number of fatalities, “harm,” or other such measures).

N_{wo} = value of this measure, (for example, number of crashes) that occurs without the system.

N_w = value of the measure with the system fully deployed.

The value of N_{wo} is usually known from crash data files, but N_w is not known for pre-production or early-production systems. Thus, it is necessary to estimate the effectiveness of a countermeasure and combine it with the known value of N_{wo} , as shown in the following equations:

$$B = N_{wo} \times SE \quad (2)$$

Where,

SE = effectiveness of the system, and

N_{wo} = size of the problem.

An extension of this idea is that the overall benefits consist of the sum of benefits across a number of specific scenarios:

$$B = \sum_i N_{wo_i} \times E_i \quad (3)$$

Where,

“i” = individual scenarios.

E_i = effectiveness of the system in reducing the number of crashes in a specific crash-related scenario

N_{wo_i} = baseline number of crashes in individual scenario “i”

B_i = the benefits in each of the individual scenarios.

From expressions (2) and (3), system effectiveness can be written as:

$$SE = \sum \left(E_i \times \frac{N_{wo_i}}{N_{wo}} \right) \quad (4)$$

An extension of Equation 4 is needed when the source of estimates of the number of crashes without the system is not the same as the source of estimates with the system. In this case the relative exposure between the two sources needs to be included. This extension is expressed in the form:

$$\tilde{E}_i = 1 - \frac{\tilde{N}_{wi} / \tilde{X}_{wi}}{\tilde{N}_{wo_i} / \tilde{X}_{wo_i}} \quad (5)$$

Where,

N_{wo_i} = baseline number of crashes in individual scenario “i”

N_{wi} = number of crashes with the system for individual scenario “i”

X_{wi} = Exposure with the system for individual scenario “i”

X_{wo_i} = Exposure without the system for individual scenario “i”

and the “~” is used to emphasize that these are estimates.

Commonly used measures of exposure include vehicle miles traveled (VMT), number of registered vehicles, or other indirect measures.

A second extension is needed if the number of conflict events varies within a scenario. A modified version of Equation 5 that accommodates non-uniform exposures is given by:

$$\tilde{E}_i = 1 - \frac{\left[\left(\frac{\tilde{S}_{wi}}{VMT_{wi}} \right) \right]}{\left[\left(\frac{\tilde{S}_{woi}}{VMT_{woi}} \right) \right]} \times \frac{\left[\left(\frac{\tilde{N}_{wi}}{\tilde{S}_{wi}} \right) \right]}{\left[\left(\frac{\tilde{N}_{woi}}{\tilde{S}_{woi}} \right) \right]} \quad (6)$$

Where,

S_{woi} = number of conflicts that occur without the system for scenario “i”

S_{wi} = number of conflicts that occur with the system for scenario “i”

VMT_{woi} = the exposure (VMT is used in this expression) that occurs without the system for scenario “i”

VMT_{wi} = exposure that occurs with the system for scenario “i”

It can be seen that this expression for the estimate of effectiveness is composed of rates of crashes per conflict (Prevention Ratio) and rates of conflicts per unit of exposure (Exposure Ratio).

In this form, the expression for effectiveness is written as:

$$\tilde{E}_i = (1 - ER_i \times PR_i) \quad (7)$$

Where,

ER_i = Exposure Ratio for the specific scenario “i”.

PR_i = Prevention Ratio for the specific scenario “i”.

This is the expression for E_i that is included in Equation 4 for system effectiveness.