

Extension of the Honda-DRI “Safety Impact Methodology” (SIM) for the NHTSA Advanced Crash Avoidance Technology (ACAT) II Program and Application to the Evaluation of a Pre-Production Head-On Crash Avoidance Assist System - Progress Report

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ABSTRACT

This paper reports on the interim progress of the Honda-DRI ACAT-II program initiated by the National Highway Traffic Safety Administration (NHTSA). 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. 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 (HCAAS). 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. 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 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 US level were also determined. Overall, this ACAT-II program was successful in extending a methodology that can be used to estimate the safety benefits and driver acceptance of frontal crash avoidance and mitigation countermeasures.

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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 [1, 2]. 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.

Honda and Dynamic Research Inc (DRI) have been developing and applying safety impact analysis methods for many years (e.g., [3, 4]) and have had Cooperative Agreements with NHTSA for both the first and second phases of the ACAT program. 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 [5, 6, 7, 8]. 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). A mid-term progress report for this study was presented in [9, 10]. More detailed results from this study are presented in [11].

Project Aims

The primary objective of the National Highway Traffic Safety Administration (NHTSA) Advanced Crash Avoidance Technologies (ACAT) II program was to further develop a formalized Safety Impact Methodology (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; 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 [1] 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 (Figure 2), and the other 11 Functions were accomplished "off-line".

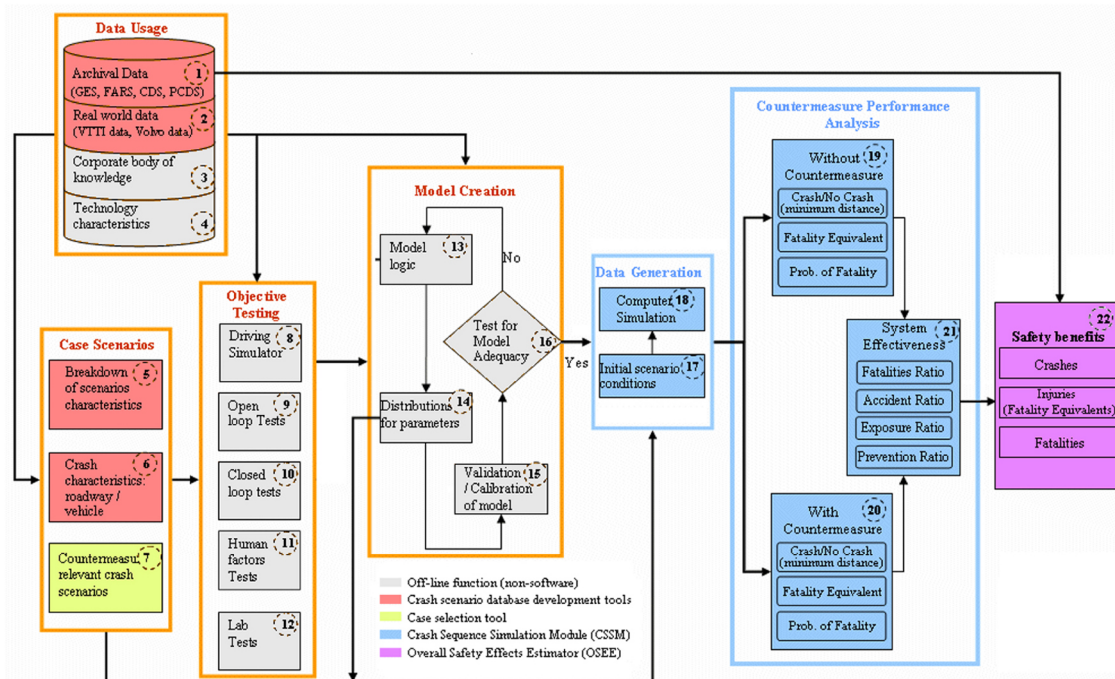


Figure 1. NHTSA ACAT SIM Framework [1].

Overview of the SIM

The Honda-DRI SIM comprises four main modules as illustrated in Figure 2. The color coding of each module in Figure 2 corresponds to the color shading of the functions in Figure 1. The main SIM modules comprise:

1. Crash scenario database development tools to accomplish NHTSA Framework Functions 1, 2, 5, and 6;
2. Technology relevant case specification and case sub-sampling tools to accomplish Function 7;
3. A Crash Sequence Simulation Module (CSSM) to accomplish Functions 17 to 21; and
4. An Overall Safety Effects Estimator (OSEE) to accomplish Function 22.

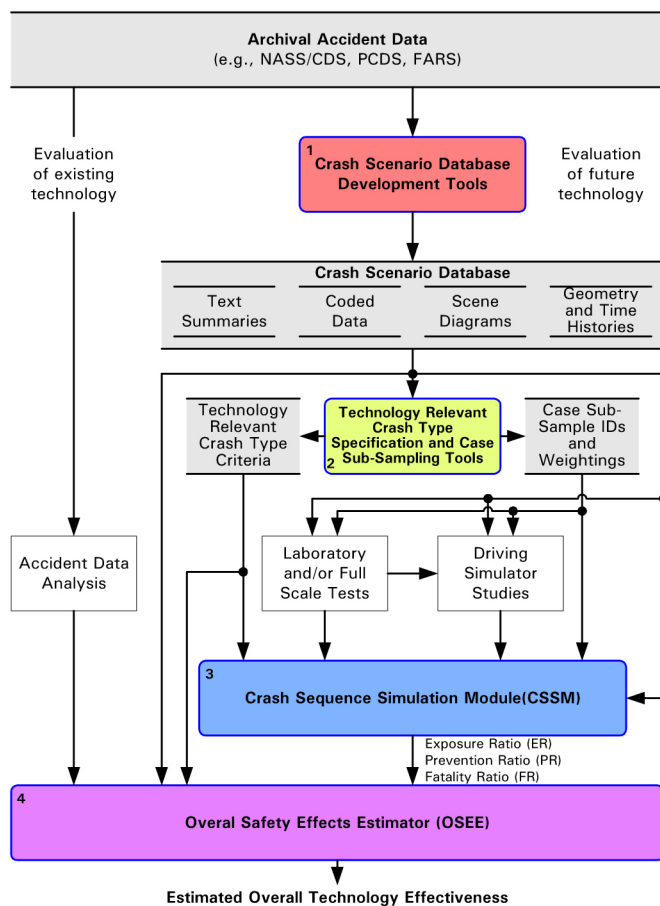


Figure 2. Honda-DRI SIM Tool Schematic.

Module 1 - Crash scenario database development Tools

The Crash Scenario Database Development tools comprise three main sub-modules as illustrated in Figure 3. Sub-module 1.1 extracts a set of coded vehicle level crash scenarios from the NASS/CDS, PCDS, and GES databases [12, 13, 14], which are used throughout the SIM tool. Sub-

module 1.2 downloads crash scene diagrams from a NHTSA website for each NASS/CDS case in the crash scenarios from Sub-module 1.1. This sub-module also downloads reports from a NHTSA website for each NASS/PCDS case and then extracts the scene diagrams in GIF format. Sub-module 1.3 is an Automated Accident Reconstruction Tool (AART), which is used to reconstruct the time-space relationships of the collision partners using physics based models of the pre-crash, crash, and post-crash phases and the available coded information and digitized information from the crash scene diagrams. The pre-crash, crash, and post-crash phases are separated in time by the point-of-impact (POI⁽⁻⁾) and separation POI⁽⁺⁾ as illustrated in Figure 4.

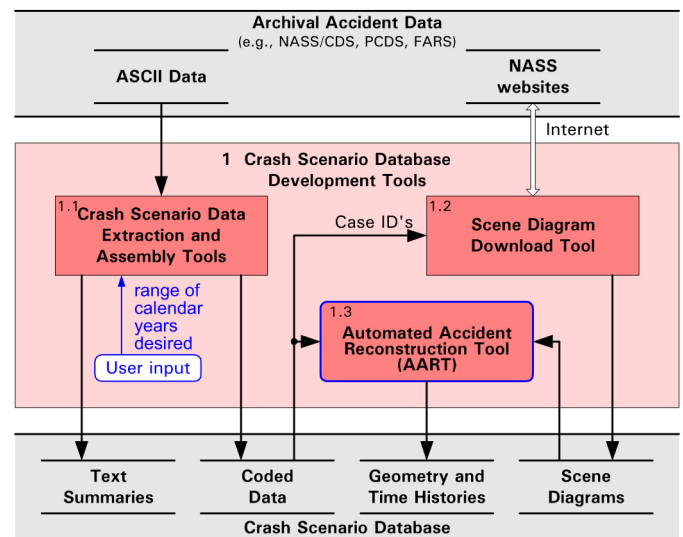


Figure 3. Crash Scenario Database Development Tools.

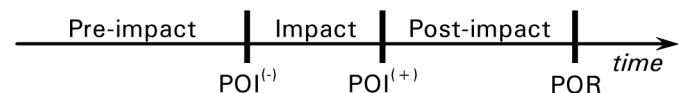


Figure 4. AART Assumed Crash Phases for Vehicle Dynamics.

Module 2 - Technology relevant case specification and case sub-sampling tools

The technology relevant case specification and case sub-sampling tools comprise three main sub-modules as illustrated in Figure 5. Sub-module 2.1 is an interactive tool which the ACAT designer can use to formalize the descriptions of the Technology Relevant Crash Types (TRCTs) in terms of coded accident database (e.g., NASS/CDS) variables. These ACAT technology specific descriptions are saved in a specially formatted file for use in subsequent SIM modules. Sub-module 2.2 is an interactive tool which the ACAT evaluator can use to select a representative sample of crash scenarios (e.g., NASS/CDS

cases) to be used in the ACAT evaluation. The resulting list of sampled cases is used in Sub-module 2.3 and in Module 3 (the Crash Sequence Simulation Module). Sub-module 2.3 is used to further sub-sample test cases to be used in the driver-in-the-loop and driver-not-in-the-loop tests.

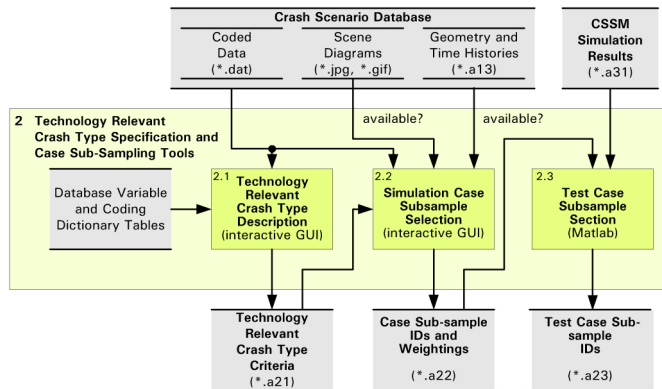


Figure 5. Technology Relevant Crash Type Specification and Case Sub-Sampling Tools.

Module 3 - Crash sequence simulation module

The Crash Sequence Simulation Module illustrated in Figure 6 is a time-domain simulation of the driver, the vehicle (with and without the ACAT) and the environment, in order to predict the relative effects of the ACAT and modeled driver behaviors on crash occurrence and injury consequences in real-world crash scenarios. Sub-module 3.5 in this figure is the driver model, which is based on NASA's APEX and MIDAS human modeling tools [15, 16]. The APEX driver model of the driver controls a Simulink model of the vehicle, environment and ACAT (Sub-module 3.6). The APEX and Simulink models are linked together with a TCP/IP communications interface; providing visual object information to the driver model and driver control outputs to the vehicle model. The simulation also has a virtual reality display output indicated by Sub-module 3.7. The results of the simulation are used to determine whether a crash occurs, and if it does occur, then an ATB simulation is used to estimate the crash Delta-V, which in turn used to estimate the probability of fatality and NHTSA's Injury Fatality Equivalents using probability functions.¹ The Technology Effectiveness Estimator (Sub-module 3.11) then estimates the Exposure Ratio, Prevention Ratio, and Fatality ratios² for each TRCT.

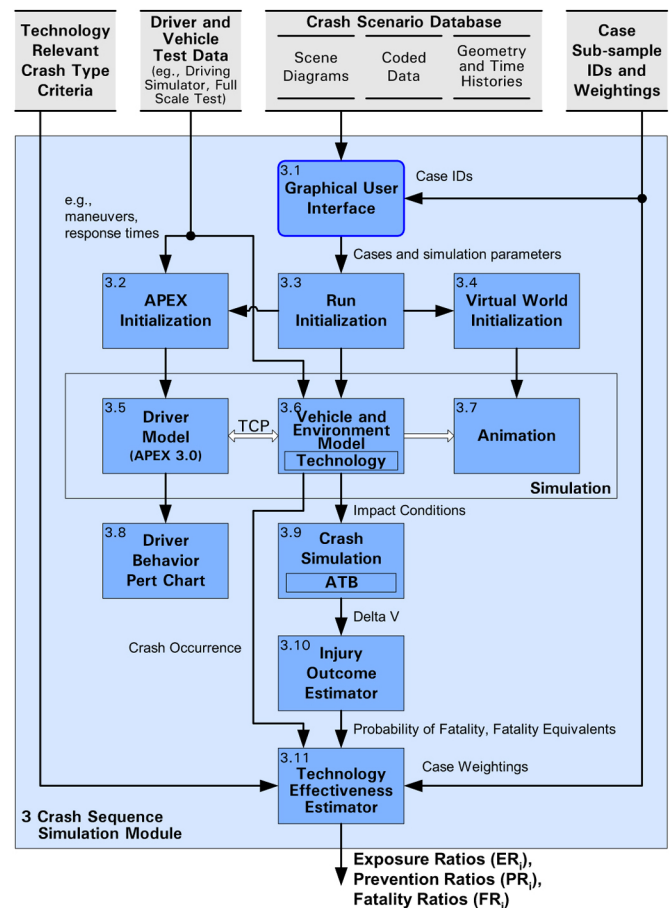


Figure 6. Crash Sequence Simulation Tool.

Module 4 - Overall safety effects estimator

The Overall Safety Effects Estimator is an integrated tool for estimating the combined effects of multiple ACATs on the number of crashes and fatalities based on technology effectiveness functions, crash scenarios, and retrospective and forecasted data [1]. The technology effectiveness functions describe the exposure, prevention, and fatality ratios (ER, PR, FR) as a function of the coded TRCT criteria. These functions are based on results from the CSSM and other a-priori knowledge (e.g., published literature and statistical accident data analyses for existing safety technologies such as side airbags [17]) expressed as mathematical functions of the relevant human, vehicle, environment and accident factors. Retrospective data sources include FARS and GES accident databases [18, 14] and R.L. Polk & Co. National Vehicle Population Profile[®] vehicle registration data [19].

¹The probability of Fatality and expected value for NHTSA's Fatality Equivalent Injury are assumed to be functions of the longitudinal and lateral change in vehicle velocity. The equations and model coefficients for these functions are described in Appendix D.4 of [8]. The Fatality Equivalent Injury is a cost weighted composite index of maximum AIS 1 through 6 injuries that has been used in previous NHTSA evaluations, as described in Appendix A of [8].

²The Exposure Ratio and Prevention Ratio are defined in [20] as "The Exposure Ratio is the ratio between rate of exposure (i.e., the rate at which drivers encounter an imminent crash) with the system and the rate of exposure without the system. Similarly, the Prevention Ratio is the ratio between the probability of having a crash with the system and the probability of having a crash without the system." This concept is also extended to Fatality Ratio, which is the ratio between the conditional probability of a fatality with the system and the conditional probability of a fatality without the system, given that a crash does occur.

The results from the OSEE are used to estimate the size of the problem, technology effectiveness, and benefits according to the equations [20]:

$$B = N_{WO} - N_W \quad (1)$$

$$B = \sum_i B_i = \sum_i N_{WO_i} \times E_i \quad (2)$$

where,

- B is the benefit, (which can be the number of crashes, number of fatalities, or other such measures);
- N_{WO} is the value of this measure (e.g., the number of crashes) that occurs without the system; and
- N_W is the value of the measure with the system fully deployed;³
- " i " is an index referring to an individual scenario;
- E_i is the effectiveness of the system in reducing the value of the measure (e.g., fatalities) in a specific crash-related scenario;
- N_{WO_i} is baseline value of the measure in individual scenario " i "; and
- B_i is the benefit in each of the individual scenario.

The SIM is described in further detail in [7,8,11].

Extensions Made During the ACAT-II Program

The Honda-DRI tools were extensively modified and refined as part of the ACAT-II program. These refinements were needed specifically for the H-CAAS evaluation and/or general SIM utility.

Module 1 refinements

The refinements that were made to the crash scenario database development tools in Module 1 (Figure 2 and Figure 3) generally included updating the supported archival databases to more recent calendar years, more stringent case reconstructability criteria, a "Delta-V constraint" so AART reconstructions of CDS cases will more closely fit the WinSMASH Damage Algorithm based Delta-V estimates [22,23], and a new Simplified AART for head-on crash scenarios, and other changes that were determined necessary for the head-on crash avoidance technology evaluation.

Refinements that were made to Module 1.1 include:

- Extending the crash scenario database to more recent calendar years in order to better represent the current and future US crash population. This involved extending the NASS/CDS crash scenario database to the 2007 calendar year (CDS data was not available in ASCII format for the 2008 calendar year); extending the NASS/GES crash scenario database to the 2008 calendar year; and extending the NASS/PCDS case weightings to the 2007 calendar year;
- Extending the ASCII FARS database to the 2008 calendar year, by means of a data format translator. The ASCII FARS data is used by the Overall Safety Effects Estimator, as well as providing additional information about fatal NASS/CDS and NASS/PCDS cases in the crash scenario database;
- Additional vehicle parameters were integrated by linking to a NHTSA-provided data file,⁴ in order to be able to reconstruct cases involving newer vehicles;
- Adding support for NHTSA's Universal Descriptors [20];
- Adding "DOCTRAJ" and other variables to the crash scenario database, as needed to support more stringent AART reconstructable case criteria for ACAT-II; and
- Calculating and adding the WinSMASH moment arm and other supporting variables to the crash scenario database, as needed for the AART "Delta-V constraint."

Refinements that were made to the AART (Module 1.3) include:

- The reconstructability criterion for the AART was expanded to include an optional requirement that the NASS/CDS crash investigator had sufficient physical evidence to know or approximate the POI and POR positions for the vehicle (i.e., the "DOCTRAJ" variable for each vehicle indicates that "there was sufficient crash induced physical evidence available to know or approximate the point of impact and final rest position for this vehicle's Highest Delta V CDC, independently of whether the WinSMASH program trajectory algorithm could be used");
- The definition of the Safety Critical Conflict (SCC) time, which is used to reconstruct the assumed timing of the attempted avoidance maneuver and pre-crash speeds as illustrated in Figure 7, was expanded to include braking and/or steering maneuvers because avoidance maneuvers involving steering may be more likely to avoid crashes in some types of conflicts (e.g., head-on crash conflicts). Therefore t_{SCC} is as defined the last time at which braking and/or steering at 0.75 g times the coefficient of friction (μ) can successfully avoid the collision;

³It is assumed herein that the ACAT is installed on only one of the crash involved vehicles. For example, if the H-CAAS were installed on one of the vehicles involved in a head-on crash, then there would be a 50% probability that the drifting vehicle has the HCAAS and 50% probability that the other vehicle has the H-CAAS. This may tend to underestimate the total benefits of the H-CAAS if it were installed on both vehicles.

⁴This file (NASS CDS specs 00-08.xls) provided the curb weight, overall length, maximum width, wheelbase, and front overhang for each vehicle listed in the 2000 through 2008 NASS/CDS database.

- The AART algorithm for NASS/CDS cases was modified to better match the WinSMASH Damage Algorithm Delta-V values recorded in the CDS data files by taking advantage of additional Damage Algorithm input and output data in the CDS files, in cases where this information is available. The vehicle damage based Delta-V information coded in the CDS files is regarded by many CDS data users as having a relatively high degree of reliability, in comparison to, for example, information in the crash scene diagram; and
- A new Simplified Head-On Drift AART which assumes the subject vehicle driver/vehicle are unintentionally drifting at a constant low lateral acceleration level, the conflict partner does not begin a crash avoidance maneuver until after the subject vehicle crosses into the opposing traffic lane, and other assumptions about data accuracy and priority. The Simplified Head-On Drift AART also has an intended path digitizer, the results of which are used in Module 3 for the simulation of the post-conflict recovery phase.

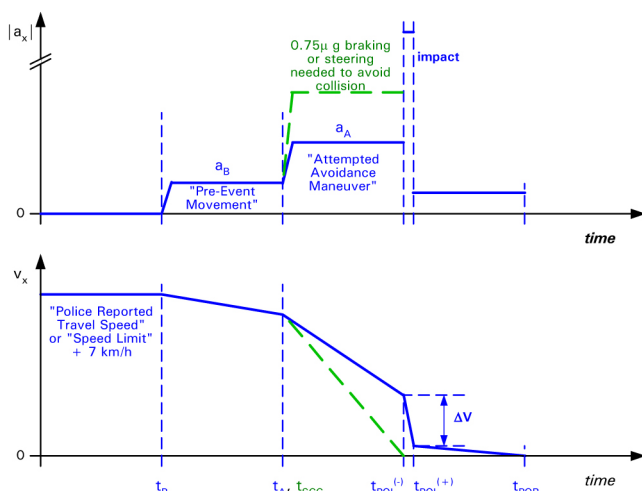


Figure 7. Assumed Vehicle Speed Profile for AART Reconstructions.

Delta-V Constraint

The AART algorithm was modified to better match the WinSMASH Damage Algorithm Delta-V values recorded in the CDS data files by taking advantage of additional Damage Algorithm input and output data in the CDS files, in cases where this information is available. The vehicle damage based Delta-V information coded in the CDS files is regarded by many CDS data users as having a relatively high degree of reliability, in comparison to, for example, information in the crash scene diagram.⁵

The “Delta-V Constraint” modification uses close-form equations to calculate the relative vehicle contact geometry (i.e., relative vehicle positions and orientation) and relative translational and angular velocities, which tend to be non-

linear and harder to solve for by numerical methods. Since the WinSMASH algorithm is based on measured vehicle damage data it cannot be used in the CSSM to predict changes in crash Delta-V due to changes in impact geometry and velocities. Therefore a predictive physics based Articulated

Total Body (ATB) model [24] is fit to the WinSMASH results by varying the energy absorption and contact friction parameters in the ATB model. This “Delta-V Constraint” is implemented as a batch pre-processing module since it does not require any digitized data or other manual input. The results are saved in an intermediate file with the “.a14” extension, for use by the reference trajectory solver and final trajectory estimator in the interactive AART module described in Sections B.3.3 and B.3.4 of App B of [11].

Given the pre-computed relative impact conditions (which tend to be non-linear), the interactive portion of the AART can then be used to estimate the absolute positions, orientations, translational, and angular velocities of the vehicles by fitting the trajectories to the digitized data using numerical optimization methods. This fitting process tends to be more robust and quickly converging because the vehicle trajectories are more linearly related to the digitized scene diagram data. Therefore the AART tends to converge to a final solution much faster and the results better match the WinSMASH computed Delta-V values.

The contact geometry at the point-of-impact is determined based on the moment arm (VDVH) and principle direction of force (VPDOF) information from the WinSMASH Damage Algorithm as illustrated in Figure 8.

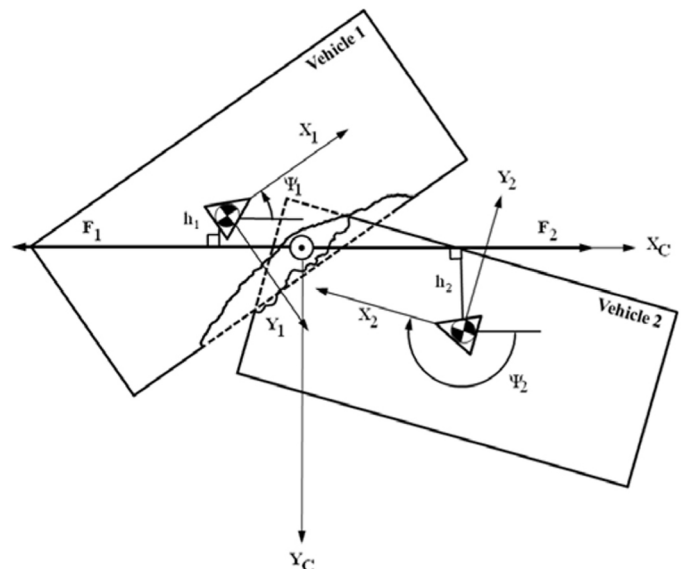


Figure 8. Vehicle Contact Geometry Derived from WinSMASH Damage Information

⁵Several studies have found that the WinSMASH damage algorithm systematically underestimates the crash Delta-V by 13 to 23% on average, e.g. [21].