POTENTIAL APPLICATION OF THE NHTSA-HONDA-DRI ACAT "SAFETY IMPACT METHODOLOGY" (SIM) TO THE EVALUATION OF AUTOMATIC EMERGENCY BRAKING SYSTEM EFFECTIVENESS IN AVOIDING AND MITIGATING COLLISIONS WITH MOTORCYCLES

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ABSTRACT

Research Question/Objective

Advanced Driver Assistance Systems (ADASs) such as Forward Collision Warning (FCW) and Automatic Emergency Braking (AEB) have been developed for light passenger vehicles (LPVs) to avoid and mitigate collisions with other road users and objects. These frontal crash avoidance and mitigation countermeasures have contributed to the reduction in the number of real-world traffic crashes, injuries, and fatalities involving LPVs. However, despite this success, the number of crashes, injuries, and fatalities in the US involving motorcycles has remained relatively constant. As a result, the relative percentage of US traffic fatalities involving a motorcycle has increased from 11% in 2006 to 14% in 2015 (Source: NHTSA 2015 Traffic Safety Facts). Therefore, there is a need for passenger vehicle FCW and AEB systems to also be effective in avoiding collisions with motorcycles. This paper describes the potential application of the Honda-DRI ACAT Safety Impact Methodology (SIM) to the evaluation of passenger vehicle FCW and AEB system effectiveness in avoiding and mitigating collisions with motorcycles, in order to further the objective of improving motorcycle safety and overall traffic safety.

Methods and Data Sources

Extensions to the NHTSA-Honda-DRI ACAT SIM needed to evaluate the effectiveness of LPV FCW and AEB systems in avoiding or mitigating collisions with motorcycles are identified. Potential extensions to the Crash Scenario Database Development Tools (SIM Module 1) to create passenger vehicle pre-crash/crash scenarios involving a motorcycle include a new Automated Motorcycle Accident Reconstruction Tool (AMART) and supporting data sources (e.g., NASS/CDS and MCCS). Potential extensions to the Crash Sequence Simulation Module (SIM Module 3) to simulate the passenger vehicle pre-crash/crash scenarios involving a motorcycle include a refined subject vehicle driver model and supporting data (e.g., driving simulator data) to model the driver glance and control response behavior specific to motorcycle conflicts, refined sensor models for the FCW and AEB systems, a passenger vehicle versus motorcycle collision model, and a motorcyclist equivalent life unit (ELU) injury model. This could also involve the development and refinement of motorcycle specific track tests for the FCW and AEB systems.

Results

Anticipated results of the extended ACAT SIM tool would include the estimated effectiveness and benefits of the LPV FCW and AEB systems in avoiding and mitigating passenger vehicle crashes involving motorcycles.

Discussion and Limitations

The results of the extended ACAT SIM tool would be 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.

Conclusion and Relevance to session submitted

The proposed extensions to the ACAT SIM methodology to evaluate passenger vehicle-motorcycle safety would provide a valuable tool to help assess the effectiveness and benefits of LPV FCW and AEB systems in avoiding and

mitigating LPV crashes involving motorcycles. This would help to further the objective of improving motorcycle safety and overall traffic safety.

The methods used are directly relevant to the test and evaluation procedures to assess the safety benefits and effectiveness of advanced driver assistance technologies.

INTRODUCTION

Advanced Driver Assistance Systems (ADASs) such as Forward Collision Warning (FCW) and Automatic Emergency Braking (AEB) have been developed for light passenger vehicles (LPVs) to avoid and mitigate collisions with other road users and objects. These frontal crash avoidance and mitigation countermeasures have contributed to the reduction in the number of real-world traffic crashes, injuries, and fatalities involving LPVs. However, despite this success the number of crashes, injuries, and fatalities in the US involving motorcycles has remained relatively constant. As a result, the relative percentage of US traffic fatalities involving a motorcycle has increased from 11% in 2006 to 14% in 2015 [1]. Therefore, there is a need for LPV FCW and AEB systems to also be effective in avoiding collisions with motorcycles.

Lenkeit and Smith [2] evaluated the ability of eight 2016 MY US LPVs equipped with FCW to detect an exemplar motorcycle and passenger car using two tests in the NHTSA FCW confirmation test procedures [3]. The results of this preliminary evaluation indicated that only two of the eight subject vehicles (SVs) tested were able to pass the NHTSA test procedure with a stationary motorcycle as the principal other vehicle (POV), compared to all SVs passing the test with a stationary passenger car POV. Therefore these preliminary results tend to confirm the hypothesis that FCW systems may not be as effective in avoiding or mitigating collisions with a motorcycle as they are with a passenger car.

Background

Dynamic Research, Inc. (DRI) has been developing and applying safety impact analysis methods for many years (e.g., [4-7][1]). This included the development of a comprehensive Safety Impact Methodology (SIM) in two NHTSA-Honda-DRI ACAT programs. The ACAT-I program refined and used this methodology to evaluate the effectiveness and benefits of a prototype Honda Advanced Collision Mitigation Braking System (A-CMBS) [5]. The ACAT-II program further refined and used this methodology to evaluate the effectiveness and benefits of pre-production Head-on Crash Avoidance Assist System (H-CAAS) [6, 7]. The comprehensive and general structure of this methodology and accompanying tools are well suited for the potential evaluation of LPV FCW and AEB system effectiveness in avoiding and/or mitigating collisions with motorcycles with the extensions summarized herein.

Project Aims

The objective if this paper is to identify the extensions of the NHTSA-Honda-DRI ACAT SIM tools that would be needed to evaluate the effectiveness and benefits of LPV FCW and AEB systems in avoiding and mitigating collisions with a motorcycle.

SAFETY IMPACT METHODOLOGY

The NHTSA-Honda-DRI ACAT SIM was developed to correspond to the general framework described in [8]. This framework comprises 22 different functions that are grouped into seven different activities.

Overview of the SIM

A top-level block diagram of the Honda-DRI SIM tool is illustrated in Figure 1. The SIM tool comprises four main modules as follows:

1. Crash scenario database development tools, comprising three submodules.

   Submodule 1.1 assembles a crash scenario dataset with a representative sample of LPVs involved in real-world crashes with a fixed object, 1 or 2 other vehicles, or a pedestrian, as illustrated by the example data in Figure 2. The cases are currently obtained from NASS/GES [9], CDS [10], PCDS [11], and naturalistic driving data [12]. The horizontal axis is the maximum Fatality Equivalents in the crash based on the coded KABCO or MAIS injury according to Appendix A of [5]. The resulting dataset comprises coded information about the accident, subject vehicle, collision partner, and persons, for use in the other SIM tool modules. This includes information for defining technology relevant crash types and effectiveness, and crash outcomes. A subset of this data (e.g., from CDS, PCDS) has more in-depth information that are used to reconstruct and simulate crash scenarios. Cases from GES provide information about

[1] Additional references are listed in [7].

crashes where the subject LPV was not towed, which tend to be less severe.

Submodule 1.2 is a tool to download or extract scene diagrams for each case in the crash scenario dataset if available.

Submodule 1.3 is an Automated Accident Reconstruction Tool (AART) to reconstruct the pre-crash and crash trajectories of the LPVs for each case in the crash scenario file, provided there is sufficient information available and the case is within the domain-of-validity of the AART (e.g., there is a scene diagram, vehicle velocity, and contact information). These reconstructable cases[2] are denoted by the dark blue symbols in Figure 2. The resulting reconstructions can be used for simulation and testing.

2. Technology relevant case specification and case sampling tools comprise three submodules. Submodule 2.1 is a tool used by the ACAT designer to define the technology relevant crash types. Submodule 2.2 is a tool to select a representative subsample of crash scenario cases for simulation. Submodule 2.3 is a tool to select a subsample of cases for testing.
3. A Crash Sequence Simulation Module (CSSM) to simulate the driver and vehicle with and without the ACAT in crash scenarios in order to estimate the effects of the ACAT in avoiding or mitigating the crash. The CSSM incorporates a Simulink model of the ACAT that was provided by the ACAT designer, and driver behavior data from driving simulator tests. The resulting integrated CSSM simulation was then validated by comparison to driving simulator and track test results.
4. An Overall Safety Effects Estimator (OSEE) to estimate the overall effectiveness and benefits of the ACAT.

The current SIM tool is described in detail in [5, 6].

One of the limitations of the current tool is that it was originally developed primarily to evaluate technologies installed on an LPV to avoid or mitigate crashes with fixed objects, other LPVs or pedestrians. It was not specifically developed to evaluate LPV crashes with motorcycles.

[2] Based on the ACAT-I reconstructable case criteria listed in Tables B-4 and B-5 of [5]. This does not include the more stringent documentation of trajectory data (DOCTRAJ) criterion added for ACAT-II.

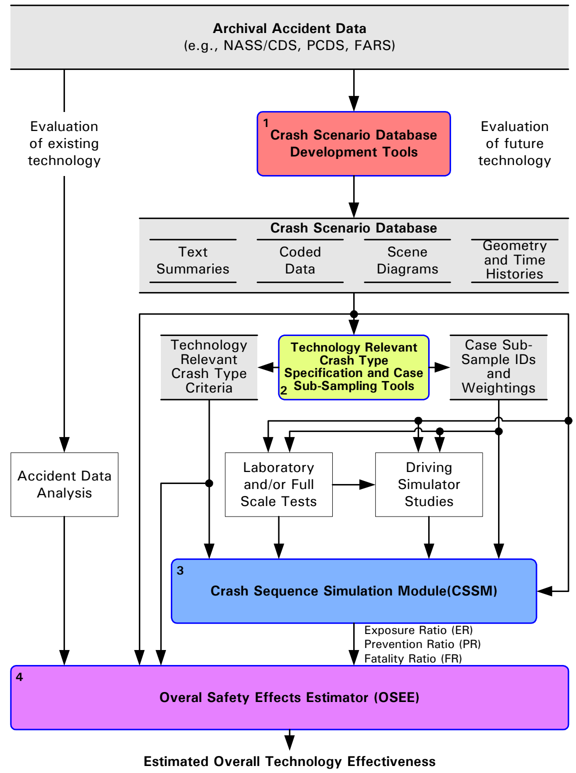

Figure 1. NHTSA-Honda-DRI ACAT SIM Tool

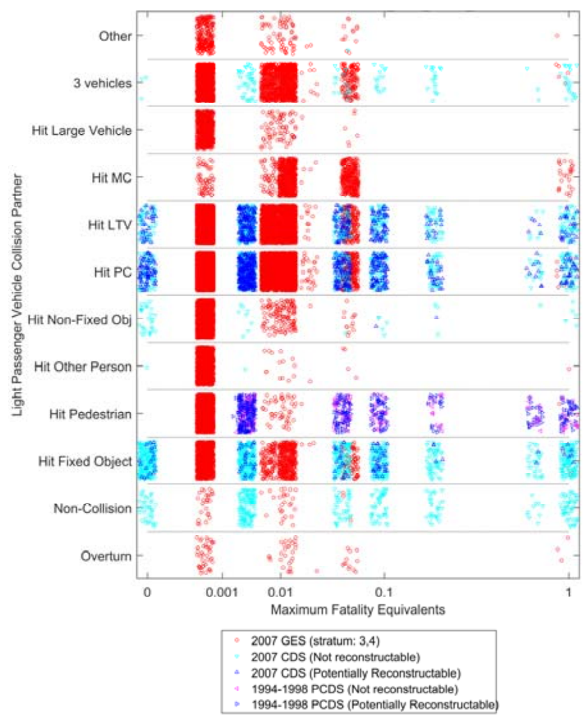

Figure 2. NHTSA-Honda-DRI ACAT SIM Crash Scenario Cases (e.g., 2007 data)

Proposed Extensions for Motorcycle Conflicts and Collisions

The following extensions or refinements to the ACAT SIM tools would be needed in order to evaluate the effectiveness and benefits of FCW and AEB systems in avoiding and mitigating crashes between an FCW/AEB equipped LPV and a motorcycle.

Module 1 Refinements

The crash scenario database and development tools would need to be extended and refined to specifically address crashes involving an LPV and a motorcycle. This would fill the data gap for motorcycles shown in Figure 2. This primarily affects the data for submodule 1.1 and the accident reconstruction in submodule 1.3.

The current SIM primarily uses CDS data for more severe and reconstructable crash scenarios involving LPVs. Therefore the first choice would be to also use LPV-MC crash scenario cases from these data as well. There are 138 LPV-MC cases in the 2000 through 2015 CDS data. The main limitation of the CDS data is that motorcycles are not CDS applicable vehicles. Consequently there are no injury outcome data for the motorcycle occupants, which are used by the Overall Safety Effect Estimator (Module 4). It may be possible to link some cases to FARS, GES, or state accident data [13] to obtain the motorcycle occupant injury information.

Another limitation of CDS data is that motorcycles are out of the scope of WinSmash Delta-V reconstructions methods used by CDS. Therefore the Delta-V information currently used by the AART to reconstruct LPV-LPV crash scenarios are not available to reconstruct LPV-MC crash scenarios. Therefore other information about the pre-crash vehicle speeds are needed for the accident reconstruction. One potential source for this information is the EDR data for the subject LPV. EDR data with pre-crash speed information are currently available for 8 of the 138 LPV-MC cases.[3] The pre-crash speeds for the motorcycle would need to be estimated from the posted speed limit (which is known for all of the 8 cases), the CDS coded travel speed, pre-event movement (prior to the critical event), and the attempted avoidance maneuver.

The distribution of potential motorcycle cases from the CDS data is illustrated in Figure 3. The format of this figure is similar to Figure 2. The crash severity in this figure does not include the MC rider and passenger injuries. Therefore this figure illustrates the limited amount of motorcycle crash scenario data potentially available from CDS.

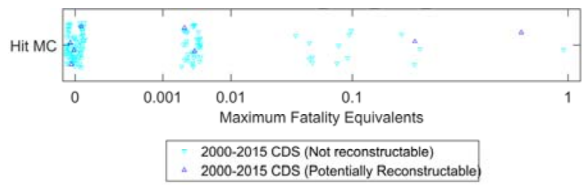

Figure 3. Potential Motorcycle Crash Scenario Cases from the CDS data (LPV injuries only)

NASS National Motor Vehicle Crash Causation Survey (NMVCCS) [14] and Crash Injury Research and Engineering Network (CIREN) [15] data were also investigated for potential LPV-MC crash scenarios. There were 30 two-vehicle cases involving an LPV and a motorcycle in the NMVCCS data. Only two of these NMVCCS cases had pre-crash EDR speed information which could be used in reconstructing the pre-crash scenario. There was only one CIREN case involving a motorcycle.

There are 224 cases in the recently completed Motorcycle Crash Causation Study (MCCS) [16] involving a single LPV and a single L1 or L3 motorcycle and no pedestrians. One potential limitation of the MCCS data is that a large percentage of the cases do not have any injuries coded for the LPV driver. It may be possible to link some fatal cases to FARS data in order to obtain any missing LPV occupant injury information. One could assume that the driver was not injured in the other cases.

It is assumed that the crash can be reconstructed based on the pre-crash travel speeds, impact speeds, and principal direction of forces of the LPV and MC, and other coded information such as the relative heading angle and the VIN or make-model-year decoded vehicle mass and size properties.

The distribution of 116 potentially reconstructable motorcycle cases from the MCCS data is illustrated in Figure 4. The format of this figure is similar to Figure 2 except the different symbol types for the CSSM data. The number of reconstructable MAIS=1 cases is underrepresented compared to the more severe crashes.

[3] EDR data were not available for any 2015 CDS case as of 2017-04-03.

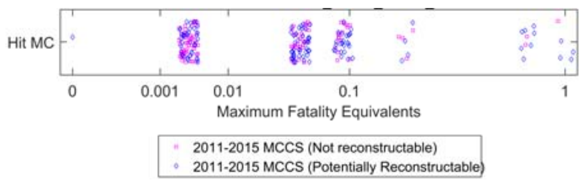

Figure 4. Potential Motorcycle Crash Scenario Cases from the MCCS data

The pre-crash trajectory for the motorcycle for the 10 sec prior to impact can be reconstructed using the vehicle dynamics model described in Weir and Zellner (1978) [17]. The LPV-MC crash scenario reconstruction process could then be implemented by a new Automated Motorcycle Accident Reconstruction Tool (AMART) that would use coded data and scene diagrams as inputs.

Module 3 Refinements

The extensions to the crash sequence simulation (CSSM) module and postprocessor would involve: 1) extending the ACAT system sensor models called by the simulation as needed to include motorcycles; 2) incorporating the reconstructed motorcycle trajectories into the CSSM simulation; 3) measuring LPV driver response behavior to motorcycle conflicts using a driving simulator tests (e.g., [18]) and incorporating the results into the CSSM driver model; and 4) adding a new LPV-MC impact simulation and injury severity estimator.

The LPV-MC impact simulation could be based on the simulation described in Kebschull et al. (1998) [19]. This simulation predicts the probability of AIS injury to the head, chest, and abdomen, as well as femur and tibia fractures and knee dislocations. The simulation was also extended to predict neck injuries in [20]. The overall simulation result is an estimated Equivalent Life Units (ELU) [21] or Fatality Equivalent (FE) injury severity index for the motorcycle rider.

Module 2 and 4 Refinements

There would not need to be any extensions to modules 2 and 4 of the ACAT SIM.

SAFETY AREA TO BE ADDRESSED BY ADVANCED TECHNOLOGIES

The objective of the ACAT SIM tool with the motorcycle extensions is to evaluate the effectiveness and benefits of LPV technologies such as FCW and AEB in avoiding or mitigating LPC-MC crashes. It is assumed that these technologies would primarily be effective in crashes where the LPV driver inattention is a contributing factor.

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 of non-technology specific crash types that have been broadly defined in terms of numbers of vehicles involved and vehicle types. Some of these crashes are not expected to be addressable by an FCW or AEB due to either the vehicle application (e.g., not an LPV), the vehicle role (e.g., struck vehicle), or other technology relevant factors. For example, the results in Table 1 include 43,000 single vehicle crashes involving a motorcycle (i.e., did not involve an LPV), with 1,997 rider and non-motorist fatalities. These results indicate that while motorcycles are involved in less than 1% of the crashes, these crashes resulted in 7.5% of the overall crash fatalities and 20% of the fatalities involving two vehicles.

Table 1.
Estimated crash problem size for the entire US motor vehicle fleet in the 2015 calendar year

Crash Category	Crash Type	Estimated Number of		
		Crashes (1000s)	Vehicles (1000s)	Fatalities[2]
1-vehicle	All[1]	1,817	1,817	19,036
2-vehicle	Involves a MC	50	51	2,636
	Other[1]	4,000	8,049	10,506
3 or more	All[1]	418	1,336	2,914
Total		6,285	11,253	35,092

Sources: GES and FARS data.
[1] Includes crashes that do not involve an LPV.
[2] Includes parked and working vehicles and non-motorists.

Advanced Technologies

Candidate technologies include FCW and AEB systems. A prototype version of the Honda A-CMBS which included these features is described in [5].

FCW systems use vehicle speed information and forward looking sensors to detect an impending forward collision with another vehicle (POV) or object and alert the driver. FCWs that satisfy the performance criteria specified in [22, 3] for conflicts with “a midsize sedan or a dummy vehicle fixture” have been a recommended by the New Car Assessment Program since the 2011 model year [23, 24].

AEB systems combine FCW with automatic braking that activates if the driver does not react to the alert in order to avoid or mitigate the forward collision. NHTSA has announced plans to add AEB as a NCAP recommended technology beginning with the 2018 model year [25]. Twenty LPV manufacturers have committed to making AEB systems standard equipment on US LPVs by September 2022 [26].

OBJECTIVE TESTS

Driving simulator and track tests based on LPV-LPV crash scenarios were conducted for the ACAT evaluation of the Honda A-CMBS [5]. The driving simulator tests were used to determine the driver responses to the conflict and system warnings for a sample of the reconstructed crash scenarios. A subsample of these crash scenarios was also track tested to measure and confirm the responses of the vehicle, sensor, and driver behavior. Similar tests could also be conducted using reconstructed LPV-MC crash scenarios (e.g., [2]).

ASSUMPTIONS AND LIMITATIONS

The results of the extended ACAT SIM tool would be based on various assumptions, approximations, and limitations, such as the representativeness and accuracy of the supporting data and reconstructed accident pre-crash scenarios. A number of these limitations are described in [5].

CONCLUSIONS

This paper has summarized the data and extensions to the Honda-DRI-ACAT SIM tool needed to evaluate the effectiveness and benefits of LPV FCW and AEB systems in avoiding or mitigating LPV-MC crashes. One of the key elements of the SIM are real world LPV-MC scenarios, for which several sources were investigated. Approximately 100 LPV-MC scenarios can potentially be reconstructed from MCCS data, with some additional cases potentially from CDS data.

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DEFINITIONS, ACRONYMS, AND ABBREVIATIONS

ACAT Advanced Crash Avoidance Technology
A-CMBS A prototype Honda Advanced Collision Mitigation Braking System
ADAS Advanced Driver Assistance System
AEB Automatic Emergency Braking system
CDS Crashworthiness Data System
ELU Equivalent Life Units (an ISO 13232-5 measure of Injury Severity)
FARS Fatality Analysis System
FE Fatality Equivalents (a NHTSA measure of Injury Severity)
FCW Forward Collision Warning system
GES General Estimates System
H-CAAS A preproduction Honda Head-on Crash Avoidance Assist System
KABCO A police reported injury severity scale
LPV Light Passenger Vehicle (passenger car or light truck or van)
MAIS Maximum Abbreviated Injury Severity
MC Motorcycle
MCCS Motorcycle Crash Causation Study
MY Model Year
NCAP New Car Assessment Program
NHTSA National Highway Traffic Safety Administration, US Department of Transportation
NMVCCS National Motor Vehicle Crash Causation Survey
PCDS Pedestrian Crashworthiness Data System
POV Principal Other Vehicle (e.g., a motorcycle)
SIM Safety Impact Methodology
SV Subject Vehicle (e.g., an LPV equipped with FCW)