U.S. Department of Transportation
National Highway Traffic Safety Administration

www.nhtsa.gov

DOT HS 811 340 June 2010

Crash Imminent Braking (CIB) First Annual Report

CAMP

Crash Imminent Braking Consortium

Ford GM Continental DELPHI Mercedes-Benz

DISCLAIMER

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipients's Catalog No.
DOT HS 811 340		

4. Title and Subtitle	5. Report Date
Crash Imminent Braking (CIB) First Annual Report	June 2010
	6. Performing Organization Code
7. Author(s) Crash Avoidance Metrics Partnership	8. Performing Organization Report No.
9. Performing Organization Name and Address National Highway Traffic Safety Administration	10. Work Unit No. (TRAIS)n code
	11. Contract of Grant No. DTNH22-05-H-01277
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration 1200 New Jersey Ave. S.E. Washington, DC 20590	13. Type of Report and Period Covered Annual Report
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report documents the work completed by the Crash Avoidance Metrics Partnership (CAMP) Crash Imminent Braking (CIB) Consortium during the first year of the project titled “Objective Tests for Imminent Crash Automatic Braking Systems.” The project is being conducted by the CIB Consortium which is comprised of Continental, Delphi Corporation, Ford Motor Company, General Motors Corporation and Mercedes-Benz. The purpose of the project is to define minimum performance requirements and objective tests for crash imminent braking systems and to assess the harm reduction potential of various system configurations and performance capabilities. The project is sponsored by the National Highway Traffic Safety Administration (NHTSA).

This report presents a summary of the work performed during the first year of the project.

17. Key Words	18. Distribution Statement
Crash Imminent Braking, CIB, active safety, pre-crash safety, autonomous braking	Document is available to the public from the National Technical Information Service www.ntis.gov

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No of Pages	22. Price
Unclassified	Unclassified	40	

Form DOT F1700.7 (8-72) **Reproduction of completed page authorized**

List of Acronyms

AAAM	Association for the Advancement of Automotive Medicine
AIS	Abbreviated Injury Scale
ACAS-FOT	Automotive Collision Avoidance System Field Operation Test
CAMP	Crash Avoidance Metrics Partnership
CAN	Controller Area Network
CDS	Crashworthiness Data System
CI	Cut-In
CIB	Crash Imminent Braking
CIBC	Crash Imminent Braking Consortium
ECU	Electronic Control Unit
EDR	Event Data Recorder
FARS	Fatality Analysis Reporting System
FOT	Field Operational Test
FoV	Field of View
FYL	Functional Years Lost
GES	General Estimates System
GIDAS	German In-depth Accident Study
GPS	Global Positioning System
HLE	Horizontal Line Estimator
HRL	Hughes Research Laboratory
IP	In Path
LIDAR	Light Detection and Ranging
LTAP-LD	Left Turn Across Path – Lateral Direction
LTAP-OD	Left Turn Across Path – Opposite Direction
LVD	Lead Vehicle Decelerating
LVM	Lead Vehicle Moving
LVS	Lead Vehicle Stopped

MAIS	Maximum Abbreviated Injury Scale
NASS	National Automotive Sampling System
NHTSA	National Highway Traffic Safety Administration
OD	Opposite Direction
PCDS	Pedestrian Crash Data Study
PIP	Performance Improvement Prototype
PVC	Polyvinyl Chloride
RE	Rear End
ROAD	Real-world Operational Assessment Data
RWUP	Real-World User Profile
SIM	Simulated
SCP	Straight Crossing Path
TMT	Technical Management Team
TRK	Track
TTC	Time to Collision
VRTC	Vehicle Research and Test Center
USDOT	United States Department of Transportation

Executive Summary

This report documents the work completed by the Crash Avoidance Metrics Partnership (CAMP) Crash Imminent Braking (CIB) Consortium during the first year of the project titled “Objective Tests for Imminent Crash Automatic Braking Systems.” The project is being conducted by the CIB Consortium which is comprised of Continental, Delphi Corporation, Ford Motor Company, General Motors Corporation and Mercedes-Benz. The purpose of the project is to define minimum performance requirements and objective tests for crash imminent braking systems and to assess the harm reduction potential of various system configurations and performance capabilities. The project is sponsored by the National Highway Traffic Safety Administration (NHTSA).

The project consists of ten tasks. Seven of the tasks were active during the first year of the project. Task 1 is the project management task and runs throughout the duration of the project. The activities in this task focused on the project oversight needed to ensure that the project achieves its objectives within the resources allocated.

Task 2, initiated and completed during the first year of the project, centered on the identification of the crash scenarios and predominant crash factors from historical databases for maximum injury/harm reduction and the development of preliminary functional requirements for CIB systems. This work was conducted jointly with NHTSA and the Volpe National Transportation Systems Center (Volpe).

The priority crash scenarios identified in Task 2 for vehicle-to-vehicle crashes include opposite direction, rear end, left turn across path from the opposite direction, straight crossing path and turning impacts. Priority scenarios for vehicle-to-object crashes include pedestrian, pole, tree, ground and structure impacts. The pole, tree, ground and structure impact scenarios are all preceded by road departure. These priorities were based upon a Top-down statistical analysis of fatalities found in the National Automotive Sampling System (NASS) Fatality Analysis Reporting System (FARS) as well as of the Functional Years Lost calculated for Maximum Abbreviated Injury Scale (MAIS) 2+ injuries from the NASS Crashworthiness Data System (CDS) and General Estimates System (GES) databases for crashes involving light vehicles newer than 1998 model year involving frontal damage during the first impact and included all persons involved.

Also in Task 2, a Bottom-up analysis was conducted that included the review of individual cases identified in the Top-down analysis to study the events leading up to the crash scenarios and provide the detailed information needed for establishing test methods capable of simulating these events. While NASS-CDS data provided the initial information for the Bottom-up analysis, it contained insufficient data for many of the cases to complete a thorough analysis. Therefore, Volpe and the CIB team supplemented these studies with Event Data Recorder (EDR) information, German In-Depth Accident Study (GIDAS) data, and Field Operational Test (FOT) data as appropriate. For additional data on pedestrian impacts, case review studies were conducted using the Pedestrian Crash Data Study (PCDS) database.

Task 3, “Technology Survey and Synthesis of Countermeasure Candidates,” provided the first step in selecting the CIB system configurations that will later become part of the

Performance Improvement Prototype (PIP) vehicles used for test method development. As part of this task, a survey document was distributed to key automotive forward-looking sensor suppliers requesting assessment of the potential performance capabilities of their sensing technologies in regards to the priority crash modes identified in Task 2. This survey document included a page for high-level system configuration, performance and constraint descriptions plus pages for specific sensor system characteristics. A cover letter accompanied the survey form and described the objectives of the CIB project and the purpose of the survey. Completed surveys were compiled and analyzed with viable brake actuator options added by the CIB consortium participants to form a list of potential CIB system candidates. The list of candidate CIB systems was used to develop a more detailed set of initial system and component specifications in Task 4. Task 3 was also completed during the reporting period.

Task 4 was undertaken to fuse the data and information from the preceding tasks to determine the initial minimum performance specifications of a crash imminent braking system. Task 4 then combined, or fused, the information to arrive at an overall set of initial minimum performance specifications based upon both the collision scenarios and the available sensing and braking technologies. An important aspect of the Task 4 work was determining candidate CIB systems to be used in future tasks for developing test methods based upon the CIB performance specifications determined in Task 4. As a result of the work in Task 4, twenty candidate CIB sensing systems and 12 candidate CIB braking systems were identified. The candidate sensing and braking systems will be evaluated and ranked during Task 5.

Tasks 5, 6 and 7 were initiated as the Year 1 reporting period closed. These tasks will continue into Year 2 of the project and will be summarized in future reports as work in these tasks is completed. Task 5, titled “Preliminary Evaluation and Ranking of Technology Candidates,” will focus on use of a technology selection methodology to rank and select the CIB systems that will later be built into the PIP vehicles. This process will involve defining the criteria and weighting factors for system ranking, performing computer simulations to generate data for evaluating the candidate systems, conducting the ranking process to select appropriate systems to build, and obtaining agreement with NHTSA on the selected systems. In Year 1 of the project, Pugh Analysis was selected as the tool for conducting the assessment of the candidate systems. Pugh Analysis (Pugh, 1996; Taguchi et al., 2004) is a tool from the Design for Six Sigma process used for rank ordering potential design options. This tool provides a method of collectively evaluating subjective and objective assessment criteria as objectively as possible. Evaluation criteria and weighting factors for rank ordering the candidate CIB systems were also identified.

The objective of Task 6 is to build the test systems that will be used for developing and validating the CIB test procedures. PIP vehicles will be used for evaluating the objective test procedures and potential benefits calculations. This will ensure that the objective tests are capable of differentiating the relative performance and potential benefits of various systems. The work completed during Year 1 includes the identification of the basic test types needed based on the Task 2 priority crash scenarios. Test vehicles were also selected and initial target system requirements were identified. Final requirements for the target systems will be set following completion of initial baseline vehicle testing beginning early September, 2008.

Task 7, conducted in parallel with Task 6, focuses on the development of the objective CIB test procedures. During Year 1, a detailed list of the verification tests needed for this work was created for each of the selected crash scenarios identified in Task 2. Baseline vehicle testing will start in September, 2008. As the testing progresses, it is anticipated that the verification test matrix will be refined as new information is learned from the test results. A preliminary list of verification tests for expected false positive and negative scenarios was also created. The final list of verification tests will be set following the Real-world Operational Assessment Data (ROAD) Trip in Summer 2009. The purpose of the ROAD Trip is to collect data for use in assessing CIB system reliability. This will be done by collecting data about real-world conditions with the potential to cause CIB sensors to incorrectly identify the driving situation which, in turn, may lead to unintended actions by the CIB system. Operational test methods for assessing CIB systems will be developed based on the most frequently recorded false activation conditions observed during the ROAD Trip. This will provide a balanced assessment of overall CIB system performance.

Table of Contents

List of Figures

List of Tables

1 Introduction

The Crash Imminent Braking (CIB) project was initiated in September 2007. The project is being conducted by the Crash Avoidance Metrics Partnership (CAMP) CIB Consortium, which consists of Continental, Delphi Corporation, Ford Motor Company, General Motors Corporation and Mercedes-Benz. The project is sponsored by the National Highway Traffic Safety Administration (NHTSA) through NHTSA Cooperative Agreement No. DTNH22-05-H-01277, Project Order 0002. From inception to completion, the project is scheduled to run 32 months.

This report presents a summary of the work performed during the first year of the project. The objective of the CIB project is to develop test methods for evaluating crash imminent braking systems and to establish benefits estimation methods for assessing their effectiveness at reducing the severity of potential injuries in vehicle crashes.

1.1 Project Background

Numerous crash avoidance systems now appearing within the U.S. fleet claim the opportunity to improve the crashworthiness of vehicles. Vehicle crashworthiness may be improved by activating pre-crash protection systems when a crash becomes unavoidable and before impact based on environmental data provided by external sensors. Such protections may include full-authority last-second braking to dissipate energy from the crash, pre-tensioning belts to improve coupling of occupants to the vehicle, and pre-arming airbags to reduce firing times, among others.

The purpose of the project is to develop and validate performance requirements and objective test procedures for CIB systems and to assess the harm reduction potential of various system configurations with differing performance capabilities. CIB systems with adjustable characteristics will be integrated into test vehicles in order to develop minimum performance requirements and further characterize the vehicle system performance sensitivity to the pre-crash sensor specifications. These results will be augmented with the final tests exercised on a limited number of system configurations. Data obtained during testing will be used to develop preliminary estimates of potential benefits of these prototype systems. In addition, this project will use the restraints performance data and results from the NHTSA-sponsored project titled “Objective Tests for Advanced Restraint Systems” to estimate the injury distribution for the occupants. The Advanced Restraint Systems project is being conducted concurrently with the CIB project by the CAMP Advanced Restraints Systems Consortium under Project Order 0003 of the NHTSA cooperative agreement discussed above.

The CIB project consists of ten tasks. Task 1 involves the project management activities needed to oversee the project. This task will run throughout the project. Tasks 2-5 feature the work needed to identify both the pre-crash events that lead to severe injuries and the near-term technologies that could potentially be used to address the selected crash events. Task 6 involves building three Performance Improvement Prototype (PIP) vehicles that can support the data collection needed to establish comprehensive test procedures in this project. It is anticipated that these test vehicles will feature an array of multiple sensors that can detect combinations of pre-crash events, brake controllers with adjustable parameters and system controls capable of supporting multiple configurations. The actual testing activities in the project are contained in Tasks 7-9. Work in these tasks will focus on defining and subsequently performing functional and operational tests that will emulate the selected pre-crash events, assess levels of CIB system performance and identify potential unintended consequences. Finally, estimates of the effectiveness and the benefits of the tested CIB PIP system configurations will be developed in Task 10.

2 Summary of First Year Activities

2.1 Task 1 – Project Management

The Crash Imminent Braking (CIB) project was initiated in September 2007 with a formal kickoff meeting between the CIB team and the U.S. Department of Transportation (USDOT) held in Washington, D.C. The main agenda of the kickoff meeting was to cover contractual issues governing the project and to provide a project overview to the members of the USDOT team, including members from the Volpe National Transportation Systems Center (Volpe) and the Vehicle Research and Test Center (VRTC). The Technical Management Team (TMT) members' weekly meetings, as well as face-to-face workshops, were organized to ensure adequate work progress is being achieved.

To help achieve the objectives of the project, the CIB activities were divided into ten tasks, and where appropriate sub-tasks, as listed in Table 1. The tasks define a structure for the work to be done in the program. Figure 1 contains the overall project timeline for these tasks.

Table 1 – CIB Task Breakdown

Task No.	Task Title	Sub-Task(s)
1	Program Management	NA
2	Target Crash Scenarios and Development of Preliminary Functional Requirements	2.1 Identify Crash Field Database(s) 2.2 Analyze Crash Types and Crash Time Sequence of Events 2.3 Apply severe injury scale filter to the selected database(s) 2.4 Apply additional filters to determine predominant crash scenarios/crash elements 2.5 Identify predominant crash factors for maximum harm reduction from crash database(s) 2.6 Establish performance metrics for crash severity and injury/harm reduction 2.7 Develop preliminary functional requirements for crash imminent braking systems based on performance metrics
3	Technology Survey and Synthesis of Countermeasure Candidates	3.1 Prepare Supplier technology survey document 3.2 Prepare list of suppliers and send technology survey document 3.3 Identify Suppliers and Schedule Supplier Meetings 3.4 Conduct Supplier Meetings 3.5 Compile comprehensive list of technology ideas for development and integration

Task No.	Task Title	Sub-Task(s)
4	Determine the Initial Minimum Performance Specifications	4.1 Set initial minimum performance specifications for preferred pre-crash safety systems 4.2 Select technology candidates to form preferred safety systems 4.3 Set initial performance specifications for components in each preferred safety system 4.4 Gather proto-type cost, timing and other relevant information from suppliers for each of the preferred safety systems 4.5 Prepare a matrix of preferred safety systems with cost, timing, and other pertinent information
5	Preliminary Evaluation and Ranking of Candidates	5.1 Establish criteria and weighting factors 5.2 Perform Computer Simulations for Objective Data Analysis 5.3 Review Sensor Component Test Data from Supplier 5.4 Develop a Ranking method to rank system proposals 5.5 Obtain Ranking method approval and perform initial ranking 5.6 Schedule joint meeting with CAMP/NHTSA 5.7 Select system and obtain buy-in 5.8 Notify suppliers and establish working agreements
6	Development and Fabrication of Prototype Systems Suitable for Testing	6.1 Identify basic test types needed 6.2 Identify test vehicle requirements 6.3 Identify target system/vehicle requirements 6.4 Identify System Hardware Requirements 6.5 Identify Data Acquisition / Ground Truth Measurement Requirements 6.6 Identify & Quote System Suppliers 6.7 Define Workload Balance 6.8 Fabricate Systems 6.9 Modify systems based upon test method requirements
7	Development of Objective Test Plans	7.1 Create detailed list of all verification tests for each selected crash scenario 7.2 Create list of verification tests for expected false positive/negative scenarios 7.2.1 Determine a Real World User Profile 7.2.2 Determine a Real-World system verification plan 7.3 Determine List of Signals to be Gathered for Data Analysis 7.4 Coordinate with the Advanced Restraints Team 7.5 Initial proveout of verification tests with current production systems 7.6 Proveout of verification tests with project prototype systems 7.7 Gather initial real-world data locally with project prototype systems 7.8 Develop analysis and reporting tools for use with real world data 7.9 Refine and finalize test procedures and plans

Task No.	Task Title	Sub-Task(s)
8	Demonstration and Validation of the Objective Tests	8.1 Determine a suitable test site for controlled verification tests 8.2 Prepare and Send prototype test vehicles for formal testing 8.3 Conduct Controlled tests as per test plan 8.4 Gather Real-World data with project prototype systems 8.5 Analyze test data and results after each test or series of tests 8.6 Make adjustments to test procedures and/or systems components and adjust test plan/components 8.6.1. Obtain NHTSA/USDOT approval for modified test plan 8.7 Record results from all tests 8.8 Prepare a report consolidating all results and record conclusions 8.9 Present and review the test results and conclusions with NHTSA/USDOT
9	Finalization of the Performance and Test Specifications	9.1 Finalize Performance Specifications for Desired Function 9.2 Finalize Requirements for Severity and Occurrence of Negative Effects 9.3 Finalize Test Procedures and Methods for Controlled testing 9.4 Finalize Procedures for Gathering Real-World data 9.5 Prepare a report on Performance and Testing Specifications for the selected safety system and review with USDOT/NHTSA
10	Finalization of the Benefits	10.1 Gather final test results (Crash Severity & Occupant Injuries) for pre-crash and baseline safety systems from Task 8 10.2 Identify a method to compute injury risk theoretically from reductions in crash severity 10.3 Identify a Benefits estimation method for estimating harm reduction 10.4 Estimate effectiveness of candidate crash imminent braking system performance characteristics using the adopted Benefits estimation method 10.5 effectiveness and performance results of pre-crash safety system(s)

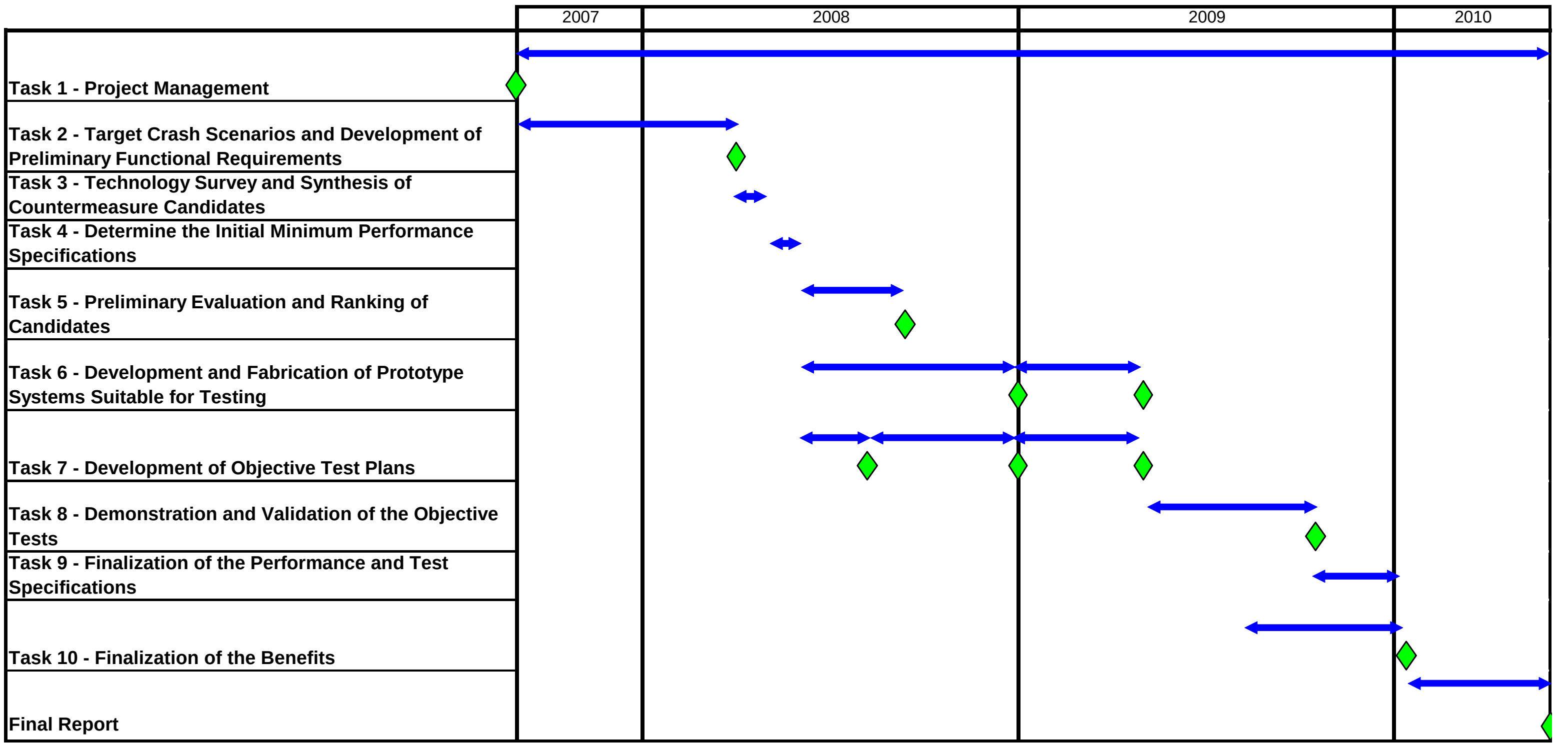

Figure 1 - CIB Project Timeline

Task 1 provides the overall project oversight to ensure that the project achieves its technical objectives within the timeframe and resources allocated for the effort. This task will run throughout the entire project.

The major activities undertaken as part of Task 1 included:

- Leadership over all work within the CIB Project
- Preparation of the project's Research Management Plan
- Preparation for and execution of the Progress Briefings for NHTSA
- Addition of Mercedes-Benz to the CIB Consortium effective June 1, 2008
- Maintenance of the project schedule
- Coordination with other programs such as NHTSA's Advanced Restraint Systems project
- Preparation of project reports, including quarterly status and interim technical reports

2.2 Task 2 - Identification of Target Crash Scenarios and Development of Preliminary Functional Requirements

Task 2, "Target Crash Scenarios and Development of Preliminary Functional Requirements," provided the foundation for the remainder of the CIB project by delivering two important initial requirements. First, the priority crash scenarios established in this task provided the basis against which objective test methods and benefits estimation methods will be developed later in the project. Second, the preliminary functional requirements established in Task 2 provided the starting point for defining the CIB system combinations that the project team will need to build into test vehicles for evaluating, developing and validating the objective test methods.

2.2.1 Identification of Crash Field Databases (Subtask 2.1)

The priority crash scenarios derived in this task for vehicle-to-vehicle crashes included opposite direction, rear end, left turn across path from the opposite direction, straight crossing path and turning impacts. Priority scenarios for vehicle-to-object crashes included pole, tree, ground and structure impacts. Pedestrian scenarios indentified in this work involved the Pedestrian Cut-In and Pedestrian In-Path scenarios. The pole, tree, ground and structure impact scenarios were all preceded by road departure.

These priorities were based upon the analysis of fatalities found in the National Automotive Sampling System (NASS) and Fatality Analysis Reporting System (FARS). Functional Years Lost (FYL), calculated for Maximum Abbreviated Injury Scale (MAIS) 2+ injuries from the NASS Crashworthiness Data System (CDS) and General Estimates Survey (GES) databases, was used to prioritize the data. The analysis focused on crashes involving light vehicles newer than 1998 model year involving frontal damage during the first impact and included all persons involved. FYL is a non-economic indicator of the harm caused by crashes. The metric is the sum of the years of lost functional productivity resulting from non-fatal crashes and the years of life lost from fatal crashes. The Abbreviated Injury Scale (AIS) is a classification system for assessing impact injury severity developed and published by the Association for the Advancement of Automotive

Medicine (AAAM) and is used for coding single injuries, assessing multiple injuries or for assessing cumulative effects of more than one injury. Maximum AIS (MAIS) refers to the highest single AIS for a person with one or more injuries.

For additional data on pedestrian impacts, case review studies were conducted using the Pedestrian Crash Data Study (PCDS) database. This work was conducted in collaboration with NHTSA and Volpe and was broken into two phases. The first phase involved a statistical evaluation, or Top-down analysis, of crash data to identify the most prominent crash scenarios occurring within the scope selected for the analysis and to determine national trends. The second phase, or Bottom-up analysis, included the review of individual cases identified in the Top-down analysis to study the events leading up to the crash scenarios and provide the detailed information needed for establishing test methods capable of simulating these events. Figure 2, below, provides a visual representation of the process flow used within this analysis and the steps used for the two phases.

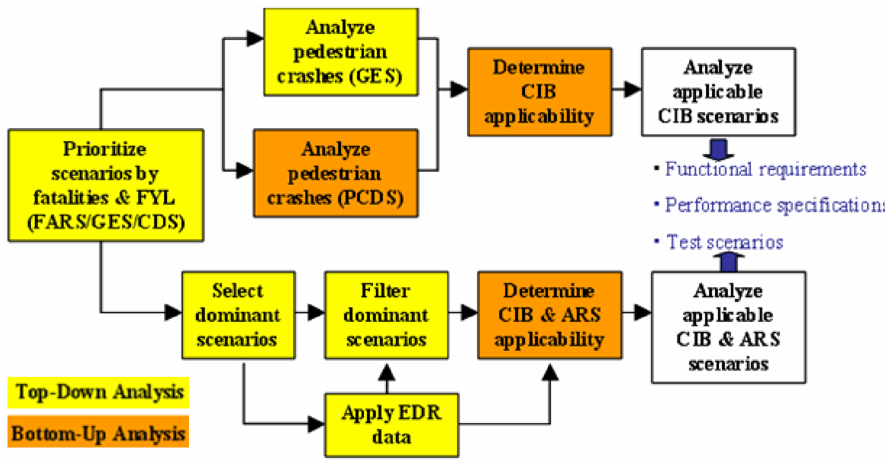

Figure 2 - Analysis Flow of Crash Data

2.2.2 Analyze Crash Types and Crash Time Sequence of Events (Subtask 2.2)

The term Top-down analysis refers to the statistical analysis of available crash data to define the scope of the overall crash problem to be addressed by this project. This step allowed the identification of priority crash events for additional analysis. Analysis of the FARS database ensured that prioritization of crash modes paid particular attention to fatal crashes. FARS, however, contained very little detailed data of the individual events. The NASS-GES database had a similar issue. This database contained the largest number of cases and was useful for determining national trends and statistics for prioritization of crash types, but did not contain sufficient case detail for establishing test methods capable of simulating these events. In contrast, NASS-CDS contained many fewer cases than NASS-GES since it only includes crashes involving towed passenger vehicles. However, this system contained more detail for each of the cases entered. NASS-CDS data, therefore, provided the initial data for the second phase analysis, referred to as Bottom-up analysis.

The results from the three data sources were compared to demonstrate that the priorities derived from each database largely agree with each other. Based on results from the Top-down analysis, the following crash priority rankings were selected:

Vehicle-to-Vehicle Crashes

1. Opposite Direction – Front to Front
2. Rear End – Front to Back
3. Left Turn Across Path / Opposite Direction (Front to Front and Front to Right Side)
4. Straight Crossing Path (Front to Left Side and Front to Right Side)
5. Turning – Front to Left Side

Vehicle-to-Object Crashes

1. Pedestrian
2. Road Departure – Pole
3. Road Departure – Tree
4. Road Departure – Ground
5. Road Departure – Structure

2.2.3 Apply Injury Severity Scale Filter to the Selected Databases (Subtask 2.3)

As previously noted, the FYL measurement used for ranking the crash types is based upon MAIS 2+ injuries of all persons involved in the crash with no age restriction placed on the initial data. These filters were selected based upon the key attributes of CIB system functionality. These systems mitigate crash energy severity by reducing the initial impact speed of the equipped vehicle. By dropping the initial impact speed, the severity of the entire crash sequence is reduced. Therefore, opportunities exist to reduce potential injuries for any persons involved in the crash, regardless of whether they are a passenger of the equipped vehicle or not. Finally, the potential of CIB systems to reduce overall crash energy through a reduction in the impact speed could mitigate some of the less severe, but higher frequency injury levels. These could include injuries associated with upper and lower extremities that can be difficult for existing restraint technologies to address.

2.2.4 Apply Additional Filters to Determine Predominant Crash Scenarios/Crash Elements (Subtask 2.4)

Bottom-up analysis is a detailed review of individual crash cases for the purpose of identifying the events leading up to the crash for the scenarios selected for study. The NASS-CDS database alone still contained insufficient data for many of the cases to complete a thorough Bottom-up analysis. Therefore, Volpe and the CIB team supplemented these studies with Event Data Recorder (EDR) information, German In-Depth Accident Study (GIDAS) data provided by the Advanced Restraints Systems Consortium, and Field Operational Test (FOT) data as appropriate and publicly available. Additionally, during the Top-down analysis, Volpe and the CIB TMT noted a relatively high percentage of cases involving pedestrians. Since the aforementioned databases contained little detail for assessing the applicability of these pedestrian cases to CIB systems, Volpe and the CIB TMT conducted additional case review studies using the Pedestrian Crash Data Study (PCDS) database.

The analysis conducted in this subtask started by applying a series of additional filters on the NASS-CDS priority crash scenarios for the cases involving target vehicles that were light vehicles 1998 model year and later that suffered front damage from the first impact. CIB for heavy trucks was considered beyond the scope of this program so only light vehicles were considered. The target vehicles were limited to model years 1998 and later to insure modern vehicles with current safety equipment. The target vehicle must also have front damage (from the first impact in case of multiple impact crashes) for CIB to be applicable. When these filters were applied to the vehicle-to-vehicle crash data, a significant reduction in the number of cases available for analysis resulted. In fact, the filtering process removed almost 96% of the vehicle-to-vehicle priority crash scenarios from the NASS-CDS data, leaving just over 4% for subsequent analysis. Limiting the cases to those with moderate or worse injury and to those in which no braking maneuver was made eliminated about 95% of the cases. The remaining filters had only minor effects on the cases selected. However, these cases represented the cases where opportunity exists to potentially reduce the severity of injury to the vehicle's occupants.

Filters similar to those applied to the vehicle-to-vehicle data were also applied to the vehicle-to-object data and to the vehicle-to-pedestrian data. Again, a significant number of cases were removed from further analysis. Similar to what occurred for the vehicle-to-vehicle data, limiting the vehicle-to-object cases to those with moderate or worse injury and to those in which no braking maneuver was made eliminated about 92% of the cases. For the vehicle-to-object crash scenarios, 98% of the cases were ultimately eliminated from further consideration while approximately 85% of the vehicle-to-pedestrian cases were eliminated from the PCDS database.

2.2.5 Identify Predominant Crash Factors for Maximum Harm Reduction from Crash Databases (Subtask 2.5)

The filtered cases used for the CIB project were provided by Volpe. There were three spreadsheets prepared, one for each major crash category, i.e., vehicle-to-vehicle crashes, vehicle-to-object crashes and vehicle-to-pedestrian crashes. Within each spreadsheet there were separate worksheets that contain detailed crash data decoded by Volpe for every priority crash scenario.

One of the key determinations in the Bottom-up analysis was whether or not a CIB system could address a given case by affecting the crash outcome. The term used for capturing this system functionality was "CIB applicability," meaning the CIB system could potentially be effective at reducing impact speed and have a positive impact on injury outcome in the crash. First, Volpe analyzed each case to determine if a CIB system could affect the outcome of a crash case using a developed decision algorithm. Second, the CIB team also examined data from one priority crash scenario, Vehicle-to-Vehicle Rear End crashes, to determine CIB system effectiveness. The CIB team used a "CIB Tracker" spreadsheet to capture the review of every case in the Rear End crash scenario category. Third, a comparison was made between the Volpe results and the CIB team results to determine whether or not the two analyses matched. A difference was noted between each group's analyses and adjustments were made to the Volpe decision algorithm to increase consistency. The final decision algorithm was then applied to the remaining crash scenario cases for the other Vehicle-to-Vehicle crash types such as: Opposite Direction – Front to Front, Left Turn Across Path / Opposite Direction (Front to Front and Front to Right Side), Straight Crossing Path (Front to Left Side and Front to Right Side), Turning – Front to Left Side. In addition, this logic was used for determining CIB applicability to the pedestrian and vehicle-to-object crash cases.

The Bottom-up analysis provided a more thorough understanding of the factors associated with each of the crash types. Examples of crash factors used to analyze the case analysis were crash mode (frontal, side, rollover, etc.), timing factors of crash sequence, vehicle type and mass (mid size sedan, SUV, etc.), occupant type (driver, passenger, etc.), delta impact speed, object impacted (car, concrete wall, pole, vehicle type, pedestrian, etc.) and crash scene topography and environment.

To summarize, the important crash factors determined and to be used in the CIB Project are as follows:

- Topography of crash scenes, object impacted, delta impact speed (ΔIS),
- Pre-crash braking of vehicles less than 10,000 pounds,
- Timing factors of crash sequence (i.e., time to collision, or TTC),
- Vehicle trajectory (pre-event maneuver) and frontal crash mode.

The above summary of predominant crash factors will influence the selection of the appropriate pre-crash sensors and crash imminent braking functions in this project. These factors were being taken into account when establishing performance metrics and functional requirements.

2.2.6 Establish Performance Metrics for Crash Severity and Injury/Harm Reduction (Subtask 2.6)

The CIB team established preliminary performance metrics for crash severity and injury reduction under the identified crash conditions from the filtered NASS-CDS database. As part of this effort, the team elected to use the TNO PreScan Simulation[1] tool to conduct crash scenario re-creation. The simulation results were then used to analyze the effectiveness of multiple pre-crash sensor types. The PreScan tool provided an objective means to assess crash scenario dynamics and parameter limitations needed for test method development and initial system performance specifications. In later tasks, the PreScan tool will be used to re-create and analyze test methods. However, the PreScan tool will not be used for system validation.

Case simulations were completed for the priority scenarios identified in the major crash categories such as vehicle-to-vehicle, vehicle-to-object, and vehicle-to-pedestrian crashes. There were a total of 14 priority crash scenarios identified for the simulation work. One representative case for each priority crash scenario was selected from the filtered NASS-CDS spreadsheet. Cases selected were screened for reliable impact speed values (EDR data), well constructed scene diagram with accurate scaling factor, clear scene photos, and representative but not overcrowded scene environment. The CIB team

[1] PreScan is a registered trade mark of TNO. Additional information regarding PreScan is available from: TNO Science and Industry, Automotive, Steenovenweg 1, 5708 HN Helmond, The Netherlands.

managed to reduce the simulation models by adapting certain models to fit others by adjusting the input parameters. For example, the simulation model for the Rear End Lead Vehicle Stopped was found to be easily modified to fit Rear End Lead Vehicle Moving and Rear End Lead Vehicle Decelerating scenarios. The same logic applied to Vehicle-to-Object and Pedestrian scenarios. Therefore, a total of eight simulations were required to cover all 14 priority crash scenarios.

The key inputs for each model were the striking and struck vehicle pre-impact speeds, and the external sensor parameters (i.e., automotive radar sensor). The Automotive Collision Avoidance System Field Operation Test (ACAS-FOT) radar was used as baseline in this preliminary set of simulations. For every run within a simulation, the sensor detection range was kept constant while the field of view (FoV) was varied until the desired detection of the struck vehicle was achieved. The ACAS-FOT sensor detection range of 200m was clipped to 50m to narrow down simulation output to the range of interest for further CIB analysis. The trajectory of the vehicles, ground objects, and approach angle were reconstructed on PreScan based on NASS-CDS case scene diagram and scene photos.

The majority of the models were run more than once in order to converge to a radar detection range and field of view (FoV) that appropriately detected the struck vehicle or object for each crash scenario. The less complicated models were run only once simply to confirm the radar parameters prescribed. Based on the runs, the team can conclude whether the radar FoV resulted in an undetectable, marginal, desired, or excessive radar detection condition.

One of the key metrics in CIB systems is determining when an application of the brakes is warranted. The actuation of the brakes will be based upon an algorithm decision from the pre-crash sensing system after sensing a valid target in the vehicle path of motion. Autonomous braking will take place without any driver intervention in order to reduce impact speed and crash energy in the imminent crash. The time before impact at which to apply the brakes is dependent upon the time to collision (TTC) and the amount of impact speed reduction to be achieved. TTC is defined here as the range to the target divided by the range rate (Sultan and McDonald, 2003).

Based on equations of motion calculations and literature research, the computation of TTC for lead vehicle stopped, lead vehicle moving, and lead vehicle decelerating scenarios were identified. The equations derived for these three scenarios were applicable and, therefore, selectively assigned to the rest of the priority crash scenarios in order to provide preliminary TTC estimations.

For a Crash Imminent Braking system, application of the brakes autonomously occurs after a point is reached where either braking or steering to avoid the collision would not be possible for the vehicle operator. This point is referred to as the "time to crash imminent" (T_{CI}). T_{CI}, therefore, is the time at which the crash unavoidable state is reached. The CIB project assumed that the driver has steering and braking available to avoid the crash. T_{CI} included the driver reaction time to recognize the target and take evasive action by braking or steering.

The minimum time to avoid a crash will be a function of the range to the target and the closing speed or range rate. Based upon work by Takeshi Fujii (2005), the minimum steering distance and minimum braking distance to avoid collisions were plotted. See Figure 3. Steer-to-avoid is best in driving situations with high relative velocity (closing speed) and high relative distance. In driving situations with low relative velocity and low relative distance, a decelerate-to-avoid approach would be more advantageous. In either case, the calculation for the minimum steer and minimum brake distance or TTC must be calculated in order to determine when the autonomous braking system should be triggered.

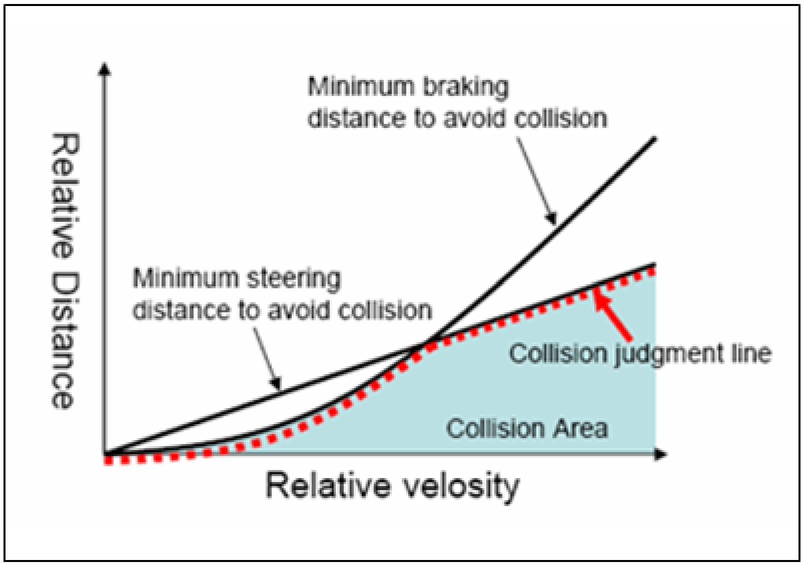

Figure 3 - Time Steer-to-Avoid and Decelerate-to-Avoid Usage Areas (Fujii, 2005)

The Crash Imminent Braking system must take into account the minimum braking distance or time and the minimum steering time to avoid a collision before application of autonomous braking. Within these calculations are the human reaction times, system response time (e.g., for braking this is deceleration build time), and the period over which the deceleration occurs once the system reaches roughly a steady state. Depending upon the change in impact speed required, the autonomous brake system can be applied at times between T_{CI} and at deceleration levels below or at maximum vehicle deceleration.

2.2.7 Develop Preliminary Functional Requirements for Crash Imminent Braking Systems Based on Performance Metrics (Subtask 2.7)

Preliminary functional requirements for CIB systems were established in this task. The preliminary functional requirements were based upon a combination of statistical analysis of the crash data from the Top-down analysis, the detailed case review data generated during the Bottom-up analysis, and computer simulations of the most typical pre-crash events leading to the priority crash scenarios. Consequently, a range of kinematic values that represented at least 90% of each of the different scenarios surveyed were proposed based on the information the team had collected thus far. These preliminary requirements were intended to be used as a starting point for discussion of proposed system specifications and will be further refined as more information becomes available from the subsequent tasks.

In Task 3, this information will be used to generate a survey form which will be used to canvas the sensor supplier landscape and identify the available sensing technologies and capabilities.

This initial set of requirements identifies minimum sensor/system performance thought to be required in order for the CIB system to perform its intended functions. The resulting specification is not sufficient to prevent unintended system activations (false events) or to define the system reliability. These requirements will be determined later in Task 6.

2.3 Task 3 - Summary: Technology Survey and Synthesis of Countermeasure Candidates

Task 3, "Technology Survey and Synthesis of Countermeasure Candidates," provided the first step in selecting the CIB system configurations that will later become part of the PIP vehicles used for test method development. As part of this task, a survey document was distributed to key automotive suppliers of forward-looking sensors requesting assessment of the potential performance capabilities of their sensing technologies in regards to the priority crash modes identified in Task 2. This survey document included a page for high-level system configuration, performance and constraint descriptions plus pages for specific sensor system characteristics. A cover letter accompanied the survey form and described the objectives of the CIB project and the purpose of the survey. Completed surveys were compiled and analyzed with viable brake actuator options added by the CIB consortium participants to form a list of potential CIB system candidates.

2.3.1 Prepare Supplier Technology Survey Document (Subtask 3.1)

In the first step of the Technology Survey development, documents were prepared that described the project objectives, the target crash scenarios/crash elements and the sensor performance metrics developed from Task 2. These materials, used during interactions with the suppliers, provided a clear understanding of the project and types of brake and pre-crash sensor technologies of interest.

An introduction letter was created that introduced the basic project background and reasons for conducting this survey. Sensor suppliers were encouraged to provide non-proprietary information that would assist the CIB Consortium (CIBC) in the definition of performance requirements and objective test procedures. Technology Survey spreadsheets were also developed that requested the suppliers to provide a brief overview of the mechanical and electrical design, performance and limitations of proposed sensors available today or in the near term.

The survey specifically asked suppliers if the particular scenarios defined in Task 2 could be detected by their sensor(s) and at what maximum delta closing speed. Information for the minimum Pedestrian height and weight and the Pole/tree minimum diameter information were requested. In addition, a column for Sensor Set/Comments was included for additional clarification of any unique features or constraints of the proposed sensors.

2.3.2 Prepare a List of Suppliers and Send Technology Survey Document (Subtask 3.2)

Each participating company in the CIBC provided a list of potential sensor suppliers. A master list of all the potential suppliers was created and the cover letter and technology survey document was sent to each. Eight potential suppliers worldwide were identified and contacted.

2.3.3 Identify Suppliers and Schedule Meetings (Subtask 3.3)

Of the eight suppliers contacted, six provided Technology Survey responses. After the responses were reviewed, follow-up meetings were scheduled to discuss the material provided by the respondents and obtain additional information about the sensors. The follow-up meetings were conducted either by telephone or by face-to-face meeting for those suppliers based in the Detroit metropolitan area.

2.3.4 Conduct Supplier Meetings (Subtask 3.4)

Separate meetings were conducted for each of the three pre-crash sensor suppliers within a two week time window from April 10, 2008 to April 24, 2008. Collaborating brake system suppliers were asked to present at the same time.

General discussions took place regarding the survey spreadsheets, vehicle performance testing and builds, and some details of the common data collection parameters. It was also explained that the spreadsheets are to be used as a guideline for their proposed sensors and sensor sets and could be modified as needed.

Intellectual Property concerns were addressed by the “black box” concept for all vehicle builds. “Black box” refers to systems that provide input and output interface capabilities for data collection and connection to the brake controller and other test equipment without revealing the internal workings of the sensors and/or sensing algorithm.

As a result of these meetings, additional information was obtained about potential sensors that would not have been available from the survey responses alone. This is because the follow-up meetings allowed supplier concerns regarding intellectual property protection to be addressed and the additional information released to the project. The new information was subsequently combined with the tabulated survey responses. With the addition of this new information, potential sensors and sensor sets are judged to be representative of what is available now or in the near term.

2.3.5 Compile Comprehensive List of Technology Ideas for Development and Integration (Subtask 3.5)

From the overall technology data compilation, a comprehensive list of potential countermeasure technology ideas that are hardware-ready and capable of vehicle integration was generated. This comprehensive list of technology ideas were used as a databank of countermeasure candidates. The Component Technical Specifications for these technology ideas were developed and listed as part of Task 4. This information will be used to rank order and select countermeasure candidates for implementation in this project in Task 5.

Table 2 presents a summary of the first dimension, Crash Scenarios, of the six supplier surveys. This chart indicates detection capability for the defined Vehicle-to-Object and Vehicle-to-Vehicle crash modes.

Table 2 - Crash Modes Potentially Detected by Technology Identified

		Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5	Supplier 6
Vehicle-to-Object Crashes:							
	Pedestrian	yes	yes	Yes	yes	yes	no
	Pole/Tree	unknown	yes	Yes	no	yes	yes
	Road Side Structure	yes	yes	unknown	no	yes	yes
Vehicle-to-Vehicle Crashes:							
	Opposite Direction – Front-to-Front	yes	yes	yes	yes	yes	yes
	Rear End – Front-to-Back	yes	yes	yes	yes	yes	yes
	Left Turn Across Path / Opposite Direction	yes	yes	yes	yes	yes	unknown
	Straight Crossing Path	yes	yes	yes	unknown	yes	yes

Details for the sensors were further broken down, as shown in Table 3 below, where an overview of the survey response is presented. The table shows the number of unique systems proposed by each responding supplier. For the Radar and LIDAR sensors, this breakdown is based upon the sensors maximum distance specification as reported in the survey. For the camera data, either a single or dual camera element is defined. In total, 13 sensors from six suppliers were identified.

Table 3 - Summary of Technology Survey Responses

Shown are the number of unique systems proposed by each responding supplier.

	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5	Supplier 6
Radar Data (#)						
Short Range (<10m)	0	1	0	0	0	0
Mid Range (<60m)	0	0	1	0	0	0
Long Range (>100m)	0	1	1	0	0	1
Combination	0	1	0	0	0	0
LIDAR data (#)						
Short Range (<10m)	0	1	0	0	0	0
Mid Range (<60m)	0	0	0	0	0	0
Long Range (>100m)	0	0	0	0	0	0
Combination	0	0	0	0	0	0
Camera Data (#)						
Mono	0	1	1	2	0	0
Stereo	1	0	0	0	1	0
Fusion of Technologies	0	0	1	0	0	0

Various brake actuation devices or technologies shared during the working meetings conducted during Task 3 are shown in Table 4. When the CIB system determines that brake activation is required, the proper signal will be sent to the electronic brake controller. The latency between activation decision and the vehicle braking response is a major component affecting the timing of the CIB-requested deceleration. Various technologies exist today to perform this task, each with a unique brake system activation response time. The typical response time for each of the braking technologies is also shown in Table 4, generically characterized from short response time to long response time. In this context, response time means the ability of the brake technology to build brake line pressure and vehicle deceleration in an amount of time (pressure per unit time).

Table 4 - Braking Technologies and Their Relative Response Times

Braking Technology	Relative Response Time
Active Vacuum Booster	Medium to High
Hydraulic Accumulator	Low
Hydraulic Pump	Medium
Other (e.g., Electric Booster, Electro-mechanical brakes, etc.)	Low to High

2.4 Task 4 - Determine the Initial Minimum Performance Specifications

Task 4 was undertaken to fuse the data and information from Tasks 2 and 3 in order to determine the initial minimum performance specifications of a crash imminent braking system. The specifications were developed to facilitate the selection of the candidate CIB systems that will be incorporated into the PIP vehicles used for test method development later in the project. To summarize, Task 2 identified the CIB system performance parameters based on collision scenarios and Task 3 identified system performance parameters based upon available technology. Task 4 then combined, or fused, the information to arrive at an overall set of initial minimum performance specifications based upon both the collision scenarios and the available sensing and braking technologies. The final performance requirements will be refined and documented following the completion of Task 10 using the test results and the developed benefits evaluation methodology.

2.4.1 Set Initial Minimum Performance Specifications for Candidate Crash Imminent Braking Systems (Subtask 4.1)

The objective of a crash imminent braking system is to reduce the collision speed and the total crash energy. Total crash energy reduction correlates directly to crash injury mitigation. Given the Task 2 preliminary functional requirements and the performance metrics from potential countermeasures identified in Task 3, a set of initial minimum performance specifications for the candidate crash imminent braking systems was established.

In Subtask 4.1, a set of preliminary performance specifications for the CIB PIP vehicles was defined. This selection enabled the work in Task 4 to move forward so that candidate systems for the build of the PIP vehicles could be identified. The initial CIB PIP vehicle minimum performance specifications addressed the following:

- Vehicle-to-vehicle crash scenarios (see section 2.2.2)
- Vehicle-to-object crash scenarios (see section 2.2.2)
- Vehicle impact speed reduction
- Wheel slip control
- Yaw control
- Road surface conditions

Once the vehicle testing in Task 5 is completed, a reassessment of these preliminary specifications will be possible. The final performance requirements will be documented and presented in the final project report. In the future work, a more comprehensive assessment of the performance specifications will be conducted that will include consideration of the estimated benefits, costs and reliability of the CIB systems.

2.4.2 Select Technologies to Form Candidate Crash Imminent Braking Systems (Subtask 4.2)

From the list of technology candidates generated under Task 3, combinations of pre-crash sensor and brake actuator components were selected to form potential candidate CIB systems. These systems are designated as System A, System B, etc., as shown in the tables throughout this chapter. Since there were minimal hardware interfaces between the pre-crash sensing and braking actuators, the technology was divided into pre-crash sensing and braking technology and analyzed separately. All interfacing will be via serial data messages, so this was a natural place to separate the hardware pieces and electrical components. In terms of combinations, a detailed matrix of both braking and pre-crash sensing was not required.

2.4.3 Pre-crash Sensing Technology Candidate Systems

From the technology survey details, suppliers are currently using three pre-crash sensing technologies: radar, vision (camera), and light detection and ranging (LIDAR). Of the six suppliers that responded to the survey, three submitted 77 GHz radar-based candidate systems. One of the three suppliers also included a 24 GHz system as part of their survey response. One of the six responding suppliers submitted a LIDAR-based system as a candidate. Further, four suppliers submitted camera- or vision-based systems for consideration. Two of the four suppliers submitted stereo vision systems and two submitted monocular vision systems. The monocular vision systems were suggested and are to work in concert with a radar system through fusion of vision and radar. No suppliers responded with pre-crash sensors containing ultrasonic or infrared sensing technology. A complete listing of the candidate systems is shown in Table 5.

Systems A, B, C, D, E, M and P include radar-sensor-only-based systems. Systems G, N, Q, R and S contain a camera or vision system only – either monocular or stereo vision. System F consists of a single LIDAR sensor acting alone. Systems H, I, J, K, L, O and T include combinations of technology such as radar/LIDAR, radar/vision, or LIDAR/vision designed to provide additional information on potential targets. In these systems, fusion between technologies is possible to bring target data together from each system to determine target threat assessment. Representative sensors from each technology area were examined (i.e., radar, LIDAR and vision) and combined to create systems that would address a wider range of crash types and increase the reliability of target detection. The tables that follow represent the culmination of the efforts to combine the sensors. Not all combinations of sensors are represented in the tables. The systems presented represent logical combinations of technologies based on the CIB technical team's experience with these sensors and inputs received from the sensor suppliers regarding how they might be combined in future applications.

Survey respondents' systems are listed in Table 5 and designated with an alphanumeric identification to aid in understanding the technology available. The check marks presented in Table 5 indicate the types of sensors used in each system.

Table 5 - Matrix of Candidate Pre-crash Sensing Systems

System	Radar				LIDAR	Camera		Sensor Fusion Required?	Sensor Fusion Available?
	Short-Range	Mid-Range	Long-Range	Mid- & Long-Range Combo Sensor		Mono Vision	Stereo Vision		
A	✓								
B			✓						
C	✓		✓					Yes	No
D		✓	✓	Yes					
E	✓	✓	✓	Yes				Yes	No
F									
G						✓			
H				Yes				Yes	No
I		✓	✓	Yes		✓		Yes	Yes
J								Yes	Yes
K		✓	✓	Yes	✓	✓		Yes	No
L				Yes				Yes	No
M		✓	✓	Yes					
N									
O		✓	✓	Yes		✓		Yes	Yes
P									
Q						✓			
R									
S							✓		
T				Yes				Yes	No

2.4.4 Pre-crash Braking Technology Candidate Systems

Based upon the braking technology available from two of the suppliers, Table 6 was developed. Both organizations contacted are major suppliers of electronic braking systems to the automotive industry. Both have various braking actuators in production today in the U.S. automotive fleet and have supplied millions of braking systems, including antilock braking, electronic stability control systems and adaptive cruise control systems. Braking actuator technology available for near-term production consists of four groups: active vacuum booster, hydraulic accumulator, hydraulic pump and a category identified as "Other," which includes braking systems such as electro-hydraulic braking, electro-magnetic braking and electric booster. The "Other" category is a catch-all category for braking actuators that are not in production or considered to be available for production in the near-term. An appropriate combination of pre-fill, pre-brake and auto braking algorithms will be implemented with one of the braking technologies discussed below. A complete listing of the candidate systems is shown in Table 6.

Table 6 - Matrix of Candidate Pre-crash Braking Systems

Task 4.2 - Braking System	
System	**Brake System Description**
A	Active Vacuum Booster w/ auto braking algorithm
B	Hydraulic Accumulator w/ auto braking algorithm
C	Hydraulic Pump w/ auto braking algorithm
D	EHB, EMB, Electric Booster w/ auto braking algorithm
E	Active Vacuum Booster w/ pre-fill & auto braking algorithm
F	Hydraulic Accumulator w/ pre-fill & auto braking algorithm
G	Hydraulic Pump w/ pre-fill & auto braking algorithm
H	EHB, EMB, Electric Booster w/ pre-fill & auto braking algorithm
I	Active Vacuum Booster w/ pre-brake & auto braking algorithm
J	Hydraulic Accumulator w/ pre-brake & auto braking algorithm
K	Hydraulic Pump w/ pre-brake & auto braking algorithm
L	EHB, EMB, Electric Booster w/ pre-fill & auto braking algorithm

2.4.5 Set Initial Performance Specifications for Components in Each Candidate Crash Imminent Braking System (Subtask 4.3)

From the system performance specifications in Subtask 4.2, a layout of initial performance specifications for the sensing and braking system components was compiled. The specifications for the components were set based upon Task 2 crash scenario analyses and Task 3 supplier surveys. Typical crash imminent braking systems are comprised of brake components, brake functions and required external sensors.

One of the main challenges for the pre-crash sensing system is to identify and classify a potential threat in a minimum amount of time. Threat is defined as an in-path vehicle or object that potentially can collide with the subject vehicle. Detecting a target, classifying the target, tracking the motion of the target and assessing the potential threat must also be completed quickly to allow autonomous braking to occur and be effective. In the specification list below, target acquisition time quantifies the need to quickly assess a threat to the vehicle. Another important parameter for the CIB Project is that of lateral closing speed. In the CIB Project, the technical team included crash scenarios from straight crossing path and turning-type collisions. These types of collisions require sensing systems to have a much wider field of view than car following crash scenarios.

2.4.6 Collect Information from Suppliers for Each of the Candidate Crash Imminent Braking Systems (Subtask 4.4)

Work in the project has focused only on sensor and brake systems that would be available for the PIP build timeline established in Task 1. From the list of identified suppliers, information was gathered regarding prototype component relative costs, integration complexity, component availability lead time and other relevant information for each of the candidate CIB systems in the list. The description of the cost, integration complexity and lead time risk ratings is described in the material below and summarized in Table 7. The results of this effort are presented in Table 10 and Table 11 found in the next section of the report. This information will be used as part of the sourcing decisions for building performance improvement prototypes for evaluating the objective test procedures and potential benefits calculation in future tasks. The CIB technical team worked with suppliers to populate these tables with information to assess the characteristics of varying systems and technologies.

Table 7 - Summary of Cost, Integration Complexity and Lead Time Ratings Used

Risk Rating	Relative Cost	Integration Complexity	Component Lead Time
Low	Available in mass production	Mature and stable hardware and software	Component available in production today
Medium	Low volume production	Moderate hardware and software development needed	Component available by Dec. 31, 2008
High	Limited quantities available	Complex hardware and software development needed	Component not available until early 2009

It should be noted that the information contained in Table 10 and Table 11 represents a snapshot in time of the industry's capability in terms of pre-crash sensing and braking components. While the technology is improving and developing rapidly, the information in the tables will be applicable for near term project sourcing decisions. As the systems improve over time, the information in the tables may become outdated.

2.4.7 Prepare a Matrix of Candidate Crash Imminent Braking Systems (Subtask 4.5)

A matrix of candidate CIB systems was assembled using the information obtained from the technology survey conducted during Task 3. The results of this effort are presented below, broken into two parts – one for the sensing system and one for the braking system. Table 8 identifies the sensing systems available for the CIB Project. These are the candidates from the sensing technology available from industry participants. The ability for each system to detect the various crash scenarios is also listed in the table. Table 9 identifies the braking systems available from the industry participants who responded to the survey. The ability of the braking systems to meet the performance specifications is captured in this table. The ranking for the candidate braking systems (low, medium and high) corresponds to the relative performance of the system. For example, high performance reflects a short response time to build brake line pressure and vehicle deceleration, while low performance equates to a long system response time. This is based on the analyses conducted during Tasks 3 and 4.

Table 8 – Candidate Sensing Systems for the CIB Project
Task 4.5 - Sensing System

System	Sensor System Description	Detectable/Classifiable Crash Scenario[1] (D=detectable only, X=detectable & classifiable)							Supplier
		Pedestrain	Pole/Tree	Side Structure	Opposite Direction	Rear End	LTAP/OD	Straight Crossing Path	
A	Short Range Radar	D[2]	D[2]	D[2]		x	x	x	2
B	Long Range Radar	D	D	D	x	x		x	2
C	Short + Long Range Radar	D	D	D	x	x	x	x	2
D	Mid & Long Range Radar	D	D	D	x	x	x	x	2
E	Short + Mid & Long Range Radar	D	D	D	x	x	x	x	2
F	Lidar	D	D			x			2
G	Mono Camera	x	x	x	x	x			2
H	Mid & Long Range Radar + Lidar	x	x	x	x	x	x	x	2
I	Mid & Long Range Radar + Mono Camera	x	x	x	x	x	x	x	2
J	Lidar + Mono Camera	x	x		x	x			2
K	Mid & Long Range Radar + Lidar + Mono Camera	x	x	x	x	x	x	x	2
L	Short + Mid & Long Range Radar + Lidar + Mono Camera	x	x	x	x	x	x	x	2
M	Mid & Long Range Radar	D	D	D	x	x	x	x	3
N	Mono Camera	x	x[3]		x	x	x		3
O	Mid & Long Range Radar + Mono Camera	x	x[3]	D	x	x	x	x	3
P	Long Range Radar		D	x	x	x		x	6
Q	Mono Camera	x	x[3]		x	x	x		4
R	Stereo Camera	x		x	x	x	x	x	1
S	Stereo Camera	x	x	x	x	x	x	x	5
T	Mid & Long Range Radar + Stereo Camera	x	x	x	x	x	x	x	1, 2, 3, 5

Note 1: System capabilities shown are based upon the survey responses from Task 3. Actual performance can vary due to environmental conditions, vehicle speed and other factors. Detectable is defined as sensing of the object. Classifiable is defined as sensing of the object plus determining if the object is a positive threat, i.e., pole, tree, structure, pedestrian, etc.
Note 2: two short range radars required
Note 3: capability will be added to future software versions

Table 9 – Candidate Braking Systems for the CIB Project

Task 4.5 - Braking System

System	Brake System Description	Relative Performance
A	Active Vacuum Booster w/ auto braking algorithm	Mid
B	Hydraulic Accumulator w/ auto braking algorithm	High
C	Hydraulic Pump w/ auto braking algorithm	Low
D	EHB, EMB, Electric Booster w/ auto braking algorithm	Mid
E	Active Vacuum Booster w/ pre-fill & auto braking algorithm	Mid
F	Hydraulic Accumulator w/ pre-fill & auto braking algorithm	High
G	Hydraulic Pump w/ pre-fill & auto braking algorithm	Mid
H	EHB, EMB, Electric Booster w/ pre-fill & auto braking algorithm	Mid
I	Active Vacuum Booster w/ pre-brake & auto braking algorithm	High
J	Hydraulic Accumulator w/ pre-brake & auto braking algorithm	High
K	Hydraulic Pump w/ pre-brake & auto braking algorithm	High
L	EHB, EMB, Electric Booster w/ pre-brake & auto braking algorithm	Mid

Table 10 - Sensing Systems Cost and Complexity Assessment

Task 4.4 - Sensing System

System	Sensor System Description	Relative Cost	Integration Complexity	Component Lead Time
A	Short Range Radar	Low	Low	Low
B	Long Range Radar	Low	Low	Low
C	Short + Long Range Radar	Mid	Mid	Low
D	Mid & Long Range Radar	Mid	Low	Mid
E	Short + Mid & Long Range Radar	Mid	Mid	Mid
F	Lidar	Low	Low	Low
G	Mono Camera	Mid	Low	Low
H	Mid & Long Range Radar + Lidar	Mid	Mid	Mid
I	Mid & Long Range Radar + Mono Camera	High	Mid	Mid
J	Lidar + Mono Camera	Mid	Mid	Low
K	Mid & Long Range Radar + Lidar + Mono Camera	High	High	Mid
L	Short + Mid & Long Range Radar + Lidar + Mono Camera	High	High	Mid
M	Mid & Long Range Radar	Mid	Low	Mid
N	Mono Camera	Mid	Low	Low
O	Mid & Long Range Radar + Mono Camera	High	Mid	Mid
P	Long Range Radar	Low	Low	Mid
Q	Mono Camera	Mid	Low	Mid
R	Stereo Camera	Mid	Low	Mid
S	Stereo Camera	Mid	Low	Mid
T	Mid & Long Range Radar + Stereo Camera	High	High	Mid

Table 11 - Braking Systems Cost and Complexity Assessment

Task 4.4 - Braking System

System	Brake System Description	Relative Cost	Integration Complexity	Component Lead Time
A	Active Vacuum Booster w/ auto braking algorithm	Low	Low	Low
B	Hydraulic Accumulator w/ auto braking algorithm	High	Mid	High
C	Hydraulic Pump w/ auto braking algorithm	Low	Low	Low
D	EHB, EMB, Electric Booster w/ auto braking algorithm	High	High	High
E	Active Vacuum Booster w/ pre-fill & auto braking algorithm	Low	Low	Low
F	Hydraulic Accumulator w/ pre-fill & auto braking algorithm	High	Mid	High
G	Hydraulic Pump w/ pre-fill & auto braking algorithm	Low	Low	Low
H	EHB, EMB, Electric Booster w/ pre-fill & auto braking algorithm	High	High	High
I	Active Vacuum Booster w/ pre-brake & auto braking algorithm	Low	Low	Low
J	Hydraulic Accumulator w/ pre-brake & auto braking algorithm	High	Mid	High
K	Hydraulic Pump w/ pre-brake & auto braking algorithm	Low	Low	Low
L	EHB, EMB, Electric Booster w/ pre-fill & auto braking algorithm	High	High	High

2.5 Task 5 - Preliminary Evaluation & Ranking of Technology Candidates

Principal activities completed during Year 1 include the initial steps required for selecting candidate CIB systems for building the PIP vehicles. This involved the establishment of evaluation criteria and weighting factors for rank ordering the candidate CIB systems. Evaluations of predicted candidate system performance under the priority crash scenario conditions are currently being conducted using the PreScan simulation software. This data will also be combined with supplier test data evaluations during the rank-ordering process. The selected rank ordering tool for the CIB project was Pugh Analysis (Pugh, 1996; Taguchi et al., 2004), which is a tool from the Design for Six Sigma process used to assess design options from a combination of objective and subjective data. Task 5 will continue into Year 2 of the project and will be summarized in future reports as work in Task 5 is completed.

2.6 Task 6 - Development and Fabrication of Prototype Systems Suitable for Testing

The main objective of Task 6 is to build the test systems that will be used for developing and validating the CIB test procedures. PIP vehicles will be used for evaluating the objective test procedures and potential benefits calculations. This will ensure that the objective tests are capable of differentiating the relative performance and potential benefits of various systems. The work completed during Year 1 includes the identification of the basic test types needed based on the Task 2 priority crash scenarios. Test vehicles were also selected and initial target system requirements were identified. Final requirements for the target systems will be set following completion of initial baseline vehicle testing beginning early September 2008. The accomplishments of Task 6 will be summarized in future reports as work in this task is completed.

2.7 Task 7 - Development of Objective Test Plans

Task 7, conducted in parallel with Task 6, focuses on the development of the objective CIB test procedures. A detailed list of the verification tests was created for each of the selected crash scenarios identified in Task 2. The initial test matrix will be evaluated with baseline vehicle testing beginning in early September 2008. The matrix will then be refined as testing continues with the PIP vehicles. A preliminary list of verification tests for expected false positive and negative scenarios was also created. The final list of verification tests will be set following the Real-world Operational Assessment Data (ROAD) Trip in Summer 2009. The purpose of the ROAD Trip is to collect data for use in assessing CIB system reliability. This will be done by collecting data about real-world conditions with the potential to cause CIB sensors to incorrectly identify the driving situation which, in turn, may lead to unintended actions by the CIB systems. Operational test methods for assessing CIB systems will be developed based on the most frequently recorded false activation conditions observed during the ROAD Trip. This will provide a balanced assessment of overall CIB system performance. Work in Task 7 will continue into the next reporting period.

3 References

Fujii, Takeshi (2005). *Forward Collision Damage Mitigation Braking Systems on ASV*. Japan Automobile Research Institute, The 10th ITS Informal Meeting; Informal document No. WP.29-136-17(136th WP.29, 21-24 March 2005, agenda item 2.4.); pg 6.<http://www.unece.org/trans/doc/2005/wp29/WP29-136-17e.pdf>.

Kiefer, R. J., Cassar, M. T., Flannagan, C. A., Jerome, C. J., and Palmer, M. D. (2005). *"Forward collision warning requirements project—Tasks 2 and 3a final report: Surprise braking trials, time-to-collision judgments, and 'first look' maneuvers under realistic rear-end crash scenarios"*, (Final Report DOT HS 809 902). Washington, DC: National Highway Traffic Safety Administration.

Nagari, S., Amano, Y., Fukui, K., and Doi, S. (2003). *"A Study of a Personally Adaptive Driving Support System Using a Driving Simulator." Proceedings of the Driving Simulation Conference North America 2003 (DSC-NA-2003)*, Dearborn, MI. <http://www.dsc-na.org>.

Pugh, S., (1996). *Creating Innovating Products Using Total Design*. Reading, MA: Addison-Wesley.

Sultan, B. and McDonald, M. (2003). *"Assessing the Safety Benefit of Automatic Collision Avoidance Systems (During Emergency Braking Situations)." Proceedings of the 18th International Technical Conference on the Enhanced Safety of Vehicle.* (DOT HS 809 543). Washington, DC: National Highway Traffic Safety Administration. <http://www-nrd.nhtsa.dot.gov/departments/nrd-01/esv/18th/esv18th.htm>.

Taguchi, G., Chowdhury, S. and Wu, Y. (2004). *Taguchi's Quality Engineering Handbook.* Hoboken, NJ: Wiley.

Zhang, Yizhen (2006). *"Engineering Design Synthesis of Sensor and Control Systems for Intelligent Vehicles."* Doctoral Thesis. California Institute of Technology; May 2006. <http://etd.caltech.edu/etd/available/etd-05252006-221412>.

DOT HS 811 340
June 2010

U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

www.nhtsa.gov