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

NHTSA
www.nhtsa.gov

DOT HS 811 341 **June 2010**

Crash Imminent Braking (CIB) Second Annual Report

CAMP

Crash Imminent Braking Consortium

Ford
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DELPHI
Mercedes-Benz

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Technical Report Documentation Page

1. Report No.
DOT HS 811 341

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Crash Imminent Braking (CIB) Second Annual Report

5. Report Date
June 2010

6. Performing Organization

7. Author(s)
Crash Avoidance Metrics Partnership

8. Performing Organization

9. Performing Organization Name and Address
Crash Avoidance Metrics Partnership

39255 Country Club Drive, Suite B-40
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10. Work Unit No. (TRAIS)

11. Contract or Grant No.
DTNH22-05-H-01277

12. Sponsoring Agency Name and Address
National Highway Traffic Safety Administration
Vehicle Safety Research

1200 New Jersey Avenue SE.
Washington, DC 20590

13. Type of Report and Period
Annual Report

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

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 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 for 32 months.

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

17. Key Words
Crash Imminent Braking, CIB, active safety, pre-crash safety, autonomous braking

18. Distribution Statement
Document is available to the public from the National Technical Information Service www.ntis.gov

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)

21. No. of Pages
47

22

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

List of Acronyms

ABS	Antilock Braking System
CAMP	Crash Avoidance Metrics Partnership
CAN	Controller Area Network
CI	Cut In
CIB	Crash Imminent Braking
DRP	Dynamic Rear Proportioning
EHB	Electro-hydraulic Brakes
EMB	Electro-mechanical Brakes
ESC	Electronic Stability Control
FOV	Field of View
GPS	Global Positioning System
IP	In Path
LIDAR	Light Detection and Ranging
LTAP	Left Turn Across Path
LTAP-OD	Left Turn Across Path - Opposite Direction
LTAP-LD	Left Turn Across Path – Lateral Direction
LTIP	Left Turn in Path
LVD	Lead Vehicle Decelerating
LVM	Lead Vehicle Moving
LVS	Lead Vehicle Stopped
NCAP	New Car Assessment Program
NHTSA	National Highway Traffic Safety Administration
OD	Opposite Direction
PIP	Performance Improvement Prototype
P-CP	Pedestrian – Crossing Path
P-IP	Pedestrian – In Path
RE	Rear End
RE-CI	Rear End – Cut In
RE-LTIP	Rear End – Left Turn in Path
RE-LVD	Rear End – Lead Vehicle Decelerating
RE-LVM	Rear End – Lead Vehicle Moving
ROAD	Real-world Operational Assessment Data
RTIP	Right Turn in Path
SCP	Straight Crossing Path
TTC	Time to Contact
TMT	Technical Management Team
USDOT	United States Department of Transportation
V-O	Vehicle-to-Object
V-V	Vehicle-to-Vehicle
VRTC	Vehicle Research and Test Center

Executive Summary

This report documents the work completed by the Crash Avoidance Metrics Partnership (CAMP) Crash Imminent Braking (CIB) Consortium during the second 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 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. Four of the tasks were active during the second 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 timeframe and resources allocated to the project.

Tasks 2-4 feature the work needed to identify the pre-crash events that lead to severe injuries and the near-term technologies that could potentially be used to address these events. The tasks were documented in the CIB First Annual Report.

Tasks 5, 6 and 7 were initiated as the Year 1 reporting period closed and completed during Year 2. Task 5, titled “Preliminary Evaluation and Ranking of Technology Candidates,” focused on use of a technology selection methodology to rank and select the CIB systems which were later built into the Performance Improvement Prototype (PIP) vehicles. This process involved 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.

The objective of Task 6 was to build the test systems, which were later used for developing and validating the CIB test procedures. PIP vehicles are also being 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.

Task 7, conducted in parallel with Task 6, focused on the development of the objective CIB test procedures. 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 then started in September 2008. As the testing progressed, the verification test matrix was refined based on information obtained from the tests conducted. A preliminary list of verification tests for expected false positive and false negative scenarios was also created. The final list of verification tests will be finalized following the Real-world Operational Assessment Data (ROAD) Trip, which will be completed early in Year 3. The purpose of the ROAD Trip is to collect data about real world conditions that could be used to assess the potential for unintended actions that may be taken by CIB systems.

Task 8, entitled “Demonstration and Validation of Objective Tests,” was initiated late in Year 2. Track tests demonstrating the functional test procedures were conducted, and the analysis of the data collected during these tests is ongoing. Results from these tests will be reported in the CIB Final Report. Preparations were also made late in Year 2 for the ROAD Trip, which is scheduled for completion early in Year 3. Results of the data collected from the ROAD Trip, including any operational test procedures developed based on the data, will also be reported in the CIB Final Report.

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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 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 for 32 months.

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

1.1 Project Background

Numerous crash avoidance systems that are now emerging within the U.S. fleet have the potential to improve the crashworthiness of vehicles. Vehicle crashworthiness may be improved by activating prior to impact, pre-crash protection systems when a crash becomes unavoidable. These systems are activated based on environmental data provided by external sensors. These systems may perform a variety of actions, including limited- or 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.

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. A subset of these system configurations will be examined during the execution of the final tests. Data obtained during testing will be used to develop preliminary estimates of the potential harm reduction benefits of these prototype systems.

The CIB Project consists of ten tasks. Task 1 involves the project management activities needed to oversee the project. Tasks 2-5 feature the work needed to identify the pre-crash events that lead to severe injuries and the near-term technologies that could be used to potentially address these events. Task 6 involves building three Performance Improvement Prototype (PIP) vehicles to support the data collection needed to establish comprehensive test procedures in this project. These test vehicles 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 focuses on defining and subsequently performing functional and operational tests that emulate the selected pre-crash events, assessing levels of CIB system performance, and identifying potential unintended consequences. Finally, estimates of the potential effectiveness and the benefits of the tested CIB PIP system configurations will be developed in Task 10.

2 Summary of Second 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 Consortium and the U.S. Department of Transportation (USDOT) held in Washington, D.C. Throughout the first and second years of the project, quarterly briefings were held with the USDOT, including representatives from the Volpe National Transportation Systems Center (Volpe) and the NHTSA Vehicle Research and Test Center (VRTC). To accommodate the various tasks in process, these meetings were held either in Washington, D.C., the CAMP office in Farmington Hills, MI, the VRTC facility in East Liberty, OH, or via conference call. These briefings provided a status update to the USDOT and allowed the CIB Consortium to demonstrate progress in developing the objective test methodologies. The Technical Management Team (TMT) members' weekly meetings, as well as workshops with the USDOT, 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 prove out of verification tests with current production systems 7.6 Prove out 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)

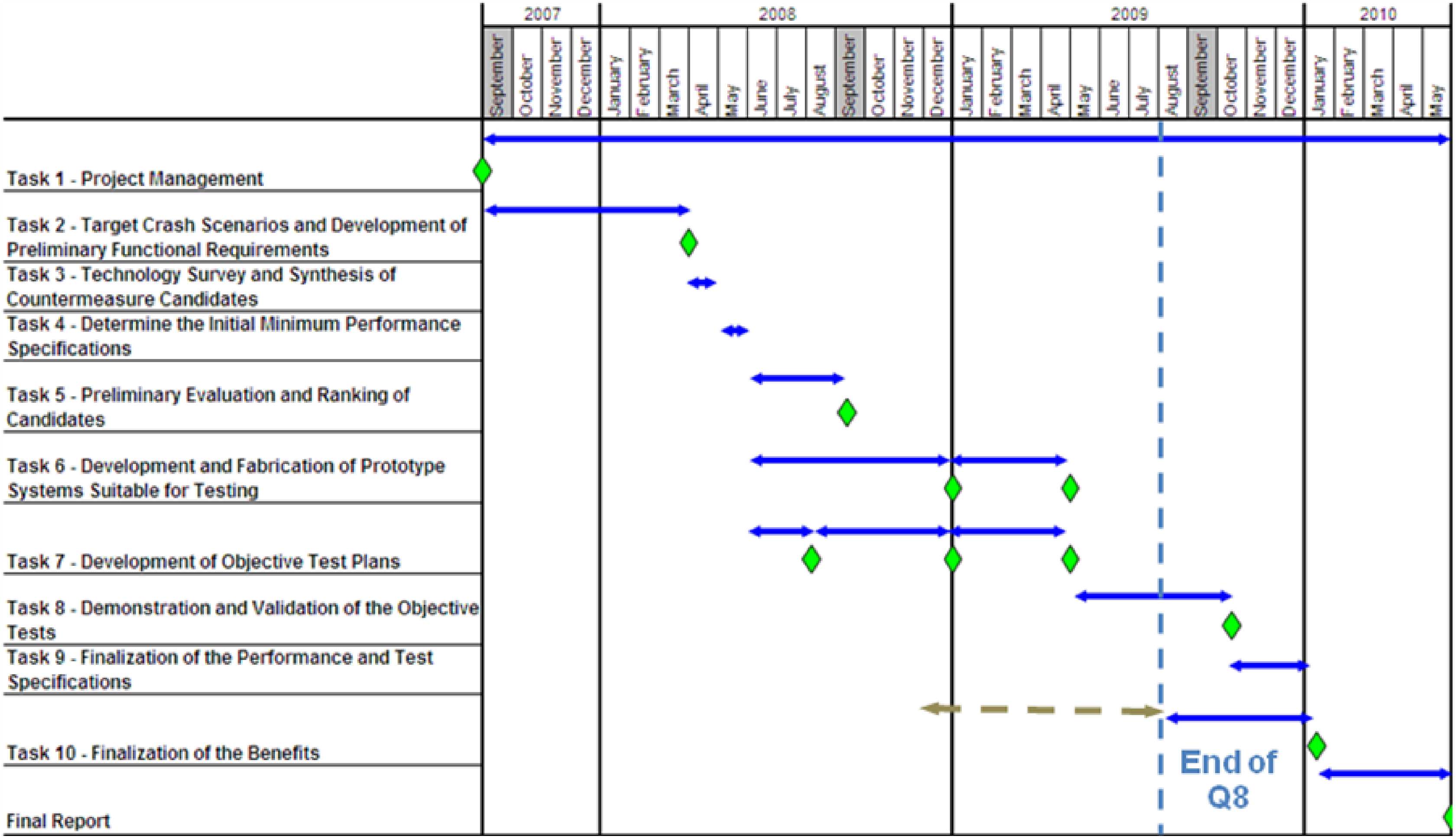


Figure 1 - CIB Project Timeline

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 during the second year included:

- Leadership over all work within the CIB project
- Execution of the project's Research Management Plan
- Preparation for and execution of the Progress Briefings for NHTSA
- Maintenance of the project schedule
- Preparation of project reports, including quarterly status and task 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 CIB consortium later built into test vehicles for evaluating, developing, and validating the objective test methods. This task was completed in the Third Quarter of the project and documented in the First Annual Report. The report summarized the work performed to identify the crash scenarios relevant to the CIB systems and the predominant crash factors from historical databases that provide potential injury/harm reduction opportunities (Eigen and Najm; 2009a; Eigen and Najm; 2009b). The 14 priority crash scenarios identified in this task include:

Vehicle-to-Vehicle Crashes

1. Opposite Direction – Front to Front
2. Rear End (RE) – Front to Back, that is, Lead Vehicle Stopped (LVS), Lead Vehicle Decelerating (LVD), Lead Vehicle Moving (LVM) and Cut In (CI)
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 (In Path and Cut In)
2. Road Departure – Pole
3. Road Departure – Tree
4. Road Departure – Ground
5. Road Departure – Structure

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 were later incorporated into 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 sensor requesting assessment of the potential performance capabilities of their sensing technologies in the priority crash modes identified in Task 2. The survey requested information on the high-level system configuration, performance and constraint descriptions, and specific sensor system characteristics. 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. This task was completed in the Fourth Quarter of the project and documented in the First Annual Report. This report presents the results of the survey of automotive technology suppliers to identify forward-looking sensors and systems that could be used in future CIB systems.

2.4 Task 4 – Determine the Initial Minimum Performance Specifications

Task 4 was aimed at determining the initial minimum performance specifications of a crash imminent braking system based upon the collision scenarios identified in Task 2 and the available sensing and braking technologies identified in Task 3. The specifications were developed to facilitate the selection of the candidate CIB systems that would be incorporated into the PIP vehicles used for test method development in later tasks. 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. This task was completed during the Fourth Quarter of the project and documented in the First Annual Report. The First Annual Report details the following:

- The initial CIB system performance specifications for the PIP vehicles to be used in objective test development
- Selected technologies and the identified candidate crash imminent braking systems grouped into CIB pre-crash sensing subsystems (20 examined) and autonomous braking subsystems (12 examined)
- Braking and forward sensing component specifications
- The matrix of candidate crash imminent braking systems

2.5 Task 5 – Preliminary Evaluation & Ranking of Technology Candidates

The work in Task 5 forms the basis for selecting the CIB systems for building the PIP test development vehicles. This task was initiated late in Year 1 and concluded early in Year 2. Principal activities completed as part of this task included establishing evaluation criteria and weighting factors for rank ordering the candidate CIB systems, and then selecting which combination of CIB system hardware and software to build into each test vehicle. This process was aided by the use of computer simulation software, which was used to predict candidate system performance under the priority crash scenario conditions identified in Task 2. This data was then 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. The proposed process was reviewed and approved by USDOT/NHTSA during a conference call conducted on July 16, 2008. A follow-up conference call was held on September 17, 2008 for the purpose of reviewing the results of the initial system ranking process and to select the systems for the PIP development vehicles.

2.5.1 CIB System Evaluation Criteria

Table 2 and Table 3 contain the sets of criteria selected for evaluating candidate CIB sensing systems and brake controllers, respectively. Assessment criteria for evaluating the candidate CIB sensing systems were grouped based upon:

1) overall system assessment
2) predicted performance in detecting the priority crash scenarios based on simulation results
3) predicted performance in classifying the priority crash events based on the data provided by the sensing suppliers

The distinction made between detection and classification is discussed further below. Note that in Table 2, V-to-O refers to the vehicle-to-object scenarios, while V-to-V refers to vehicle-to-vehicle scenarios. Similarly, brake controller candidate assessment criteria were grouped based upon overall system assessment and system functional performance. The assessment criteria for the sensing and braking systems were established based on the experience and engineering expertise of the CIB Technical Management Team (TMT) in working with similar systems. Overall, the assessment criterion groupings proved to be useful during the ranking process for helping to clearly understand the strengths and weaknesses of each of the systems.

Table 2 - CIB Sensing Systems Evaluation Assessment Criteria

	Assessment Criteria
Overall	Relative affordability
	Package size
	Electrical/communication interface
	Compatibility with data acquisition system
	Technical support from supplier
	Mechanical interface with vehicle
	Fusion algorithm risk
	Production field expertise/technical maturity
	Component lead time
	Variation in range measurement
	Variation in range rate measurement
	Variation in field of view (FOV) measurement
	Environmental performance
	Working relationship w/CIB TMT
Ability to DETECT (based upon computer simulations)	V-to-O: Pedestrian cut in
	V-to-O: Pedestrian in-path
	V-to-O: Tree
	V-to-O: Pole
	V-to-O: Roadside structure
	V-to-V: Rear end, lead vehicle stopped
	V-to-V: Rear end, lead vehicle moving
	V-to-V: Rear end, lead vehicle decelerating
	V-to-V: Rear end, cut in
	V-to-V: Left turn across path (LTAP), opposite direction
	V-to-V: Left turn in path (LTIP), Right turn in path (RTIP), Left turn across path (LTAP), lateral direction (turning)
	V-to-V: Straight crossing path
	V-to-V: Opposite direction
Ability to CLASSIFY (based upon surveys)	V-to-O: Pedestrian cut in
	V-to-O: Pedestrian in-path
	V-to-O: Tree
	V-to-O: Pole
	V-to-O: Roadside structure
	V-to-V: Rear end, lead vehicle stopped
	V-to-V: Rear end, lead vehicle moving
	V-to-V: Rear end, lead vehicle decelerating
	V-to-V: Rear end, cut in
	V-to-V: Left turn across path (LTAP), opposite direction
	V-to-V: LTIP/RTIP/LTAP, lateral direction (turning)
	V-to-V: Straight crossing path
	V-to-V: Opposite direction (OD)

Table 3 - CIB Braking Systems Evaluation Criteria

	Assessment
Overall	Relative cost
	Integration complexity
	Component lead time
	Electrical/communication interface
	Mechanical interface with vehicle
	Production field expertise/technical maturity
Functional Performance	Ability to self-apply up to 0.9 g's
	Ability to apply ~0.1 g gradients of deceleration up to 0.9 g's
	Ability to achieve 1.5 g/sec deceleration build rate
	Ability to maintain control brake functions: Antilock Braking System (ABS), Dynamic Rear Proportioning (DRP), etc.
	Ability to provide multi-tiered braking gradients

As shown in Table 2 and Table 3, the overall assessment criteria groupings included the factors associated with integrating these systems into the PIP development vehicles. These factors include the cost, integration complexity, interface factors, and timing required. Also included in the sensing system criteria is an assessment of fusion algorithm risk. This assessment refers to the availability of fusion algorithms required when employing multiple sensing technologies. For example, if a candidate sensing system does not require a fusion algorithm or a fusion algorithm is required but readily available from the supplier, then the fusion algorithm risk would be low. If, however, a fusion algorithm is required but has not yet been developed, the fusion algorithm risk would be high. This distinction is important since the scope of the CIB Project does not allow for the development of fusion algorithms or new CIB technologies.

The remaining assessment groupings for evaluating sensing system candidates shown in Table 2 represent “Ability to Detect” and “Ability to Classify”. These priority crash modes identified in Task 2 were then listed within each of these groupings. “Ability to Detect” refers to the candidate systems’ abilities to identify that a potential target is present. “Ability to Classify” refers to the candidate systems’ capabilities to correctly categorize a specific target type and condition in order to take an appropriate response action. The distinction between the two categories is important in determining the reliability that a candidate sensing system is likely to demonstrate in responding to the priority crash events. A system that is incapable of detecting a priority event, for example, will not be capable of responding to that event. A system that is capable of detecting an event but has difficulty classifying it may be able to respond to that event under some conditions. However, its reliability under those types of events may be limited. A sensing system that is capable of both detecting and correctly classifying a potential target and event has the highest probability of responding appropriately to that event.

The “Functional Performance” section of the assessment criteria for braking systems, shown in Table 3, includes factors identified within the minimum performance specifications defined in Task 4. These factors include the brake controller capabilities needed within the PIP development vehicle systems for developing and validating functional performance tests for CIB systems. Brake controllers and algorithms with these capabilities on the PIP vehicles will allow adjustable automatic braking performance characteristics which should provide the ability to evaluate a test method's abilities to detect differences in CIB system performance.

2.5.2 Predicting Candidate CIB System Performance

Objective data analysis for the pre-crash sensing systems was completed in two key areas of pre-crash sensing, including the ability of a sensing system to "detect" a target and the capability of the sensing system to "classify" a target. To analyze the former ability, a computer simulation tool used in Task 2 was employed. For analyzing classification abilities, component data from Task 4 was used.

The Task 2 crash scenario analysis used computer simulations to provide an objective data analysis of the pre-crash sensing system capabilities. The analyses consisted of simulating the high priority crash scenarios determined in Task 2. In Task 5, based upon supplier feedback, specific parameters from the candidate CIB systems were used to conduct the simulations. The results from the Task 4 supplier sensing survey suggested that Light Detection and Ranging (LIDAR), radio detection and ranging (radar), and vision technologies are near-term technologies available for potentially addressing the priority crash scenarios. A system matrix was created using stand-alone versions and various combinations of these three technologies. This matrix addressed various possible implementations within a given technology category, as well as technology-specific implementations (e.g., different implementation of a monocular cameras). As shown in Table 4 and Table 5, 22 candidate CIB sensing systems and 12 candidate CIB braking systems were identified, respectively.

Table 4 - Candidate CIB Sensing Systems

System	Supplier #	Sensor System Description
A	2	Short range radar
B	2	Long range radar
C	2	Short + long range radar
D	2	Mid & long range radar
E	2	Short + mid & long range radar
F	2	LIDAR
G	2	Mono camera
H	2	Mid & long range radar + LIDAR
I	2	Mid & long range radar + mono camera
J	2	LIDAR + mono camera
K	2	Mid & long range radar + LIDAR + mono camera
L	2	Short + mid & long range radar + LIDAR + mono camera
M	3	Mid & long range radar
N	3	Mono camera
O	3	Mid & long range radar + mono camera
P	6	Long range radar
Q	4	Mono camera
R	1	Stereo camera
S	5	Stereo camera
T	1,2,3,5	Mid & long range radar + stereo camera
U	5	Short range radar + stereo camera
V	5	Mid range radar + stereo camera

Table 5 - Candidate CIB Braking Systems

System	Brake System Description
A	Active vacuum booster with auto braking algorithm
B	Hydraulic accumulator with auto braking algorithm
C	Hydraulic pump with auto braking algorithm
D	Electro-hydraulic brakes (EHB), Electro-mechanical brakes (EMB), electric booster with auto braking algorithm
E	Active vacuum booster with pre-fill and auto braking algorithm
F	Hydraulic accumulator with pre-fill and auto braking algorithm
G	Hydraulic pump with pre-fill and auto braking algorithm
H	EHB, EMB, electric booster with pre-fill and auto braking algorithm
I	Active vacuum booster with pre-brake and auto braking algorithm
J	Hydraulic accumulator with pre-brake and auto braking algorithm
K	Hydraulic pump with pre-brake and auto braking algorithm
L	EHB, EMB, electric booster with pre-fill and auto braking algorithm

A quantitative method of grading and ranking these systems was needed to determine the relative effectiveness of these systems in addressing the high priority crash scenarios. Consequently, simulation software was used to analyze the crash scenarios in Task 5. This was similar to the approach used in Task 2, except the various specific pre-crash sensor system types listed in Table 4 were used instead of the "technology-independent" sensor approach utilized in Task 2.

The analysis consisted of running each system listed in Table 4 (i.e., System A, B, …, V) through the following six vehicle-to-vehicle and three vehicle-to-object crash scenario simulations:

Vehicle-to-Vehicle Crash Scenarios

1. Straight crossing path at 65 km/h longitudinal velocity striking vehicle
2. Rear end lead vehicle stopped at closing speed 65 km/h longitudinal velocity striking vehicle
3. Left turn across path – opposite direction at 80 km/h longitudinal velocity striking vehicle
4. Turning case such as left turn into path 90 km/h longitudinal velocity striking vehicle
5. Opposite direction – both vehicles at 75 km/h longitudinal velocity striking / struck vehicle
6. Rear end cut in case at 65 km/h longitudinal velocity striking vehicle

Vehicle-to-Object Crash Scenarios

1. Pedestrian cut in case at 72 km/h longitudinal velocity striking vehicle
2. Tree case at 80 km/h longitudinal velocity striking vehicle
3. Roadside structure at 57 km/h longitudinal velocity striking vehicle

The pre-crash sensing system parameters obtained in the industry survey from Task 4 were used in the simulations. Sensing system properties for both radar and LIDAR consisted of field of view, sensing range, and system scan frequency. Camera / vision sensing properties consisted of field of view and sensing range. The output data from the simulation software was then used to complete the "detection" matrix contained in the center section of Table 2, as shown earlier.

Once a target has been detected, a pre-crash sensing system must correctly classify a target (i.e., discriminating between threatening and non-threatening targets). Ideally, the pre-crash system should always activate in response to threatening targets and never activate in response to non-threatening targets. Following the computer simulation analysis for predicting pre-crash system performance, supplier data was used to assess a pre-crash sensing systems' ability to correctly classify a target. Each supplier that completed the technology survey indicated their sensing systems' ability to classify a target in terms of several object groupings: tree, pole, roadside structure, or vehicle. Table 6 contains the matrix used to identify the candidate systems' abilities to classify targets as a function of assumed pre-crash sensing system components.

Table 6 - Candidate Sensing Systems with Survey Performance Estimates

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

Notes. [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. [2] Two sensors required. [3] According to supplier, capability will be added to future software versions.

2.5.3 Ranking CIB System Candidates

The Pugh Analysis tool was then used for rank ordering candidate CIB systems. Pugh Analysis involves a number of different steps. First, as shown in Tables 4 and 5, candidate system configurations and potential combinations are compiled. Next, assessment criteria were established and agreed upon as described in Section 2.5.1.

After defining the assessment criteria for selecting candidate sensing systems for the PIP vehicles, subjectively-determined weighting factors were assigned to the sensing system assessment criteria using the following scale: 5 = Very Significant, 3 = Significant, and 1 = Neutral. Due to the limited number of associated evaluation criteria, weighting factors were not employed during the evaluation of candidate brake systems. For the “Overall” assessment factor group for the candidate sensing systems, weighting factors were applied based upon the effect each factor would have on implementation of the potential systems within the PIP vehicles. The weighting factors for the candidate sensing systems’ abilities to detect and classify priority crash events were assigned differently. The “Very Significant” weighting factor was assigned to the priority crash scenarios from Task 2 which yielded the highest functional years lost and fatalities. The “Neutral” weighting factor was assigned to the priority crash scenarios with the lowest functional years lost and fatalities. All other (medium) priority crash scenarios were assigned the “Significant” weighting factor. It should be noted that the above described weighting factors were used strictly to aid in the assessment of systems which ranked very closely to each other to help select the most appropriate systems for the PIP vehicles.

As part of the Pugh Analysis, one candidate sensing system and one candidate brake system were designated as the “DATUM” systems. The datum is a baseline (reference) candidate system selected either as an existing design or as a potential “best case” design (in this case based upon engineering judgment). This datum system is used as a comparison reference system for other systems during the Pugh Analysis process. Systems which are expected to perform significantly better than the datum for a given assessment criteria are given a “+,” systems which are expected to perform significantly worse than the datum receive a “-,” and systems which are expected to perform about the same as the datum receive a “S.” Once each system has been compared against the datum for each assessment criteria, the cell entries (corresponding to each of the factors considered) are summed (where “+”=1, “S”=0, and “-”=-1) to determine the highest ranking candidate systems.

As previously noted, weighting factors are not typically used during a Pugh Analysis in order to avoid skewing the assessment to a predetermined preferred system. Instead, weighting factors are only employed to help differentiate systems with similar rankings. In the CIB Pugh Analysis, weighting factors are listed for the sensing system candidates, but were not employed during the initial comparison process to remain consistent with a typical Pugh Analysis. Instead, the weighting factors were used as tie-breakers between CIB sensor combinations and brake systems that resulted in similar scores.

The final step of Pugh Analysis involves conducting a confirmation run to verify the results of the initial selection process. For the confirmation run, the highest ranking system is selected as the new datum (i.e., reference system). Any low-ranking systems may be eliminated from this step since they will not affect the results and to simplify the confirmation evaluation. The Pugh Analysis is then repeated with the highest ranking system selected as the new datum. If no other candidate system arises as a higher ranking system than the new datum, then this new datum is confirmed as the preferred system choice.

Table 7 provided the results of the initial analysis for the candidate CIB sensing systems. System I, consisting of a mid- and long-range radar sensor plus a mono-vision camera, was selected as the datum. As shown in Table 7, there were no candidate systems that outperformed the datum. Based on these result, systems A, B, E, F, J, K, L, M, P, Q, R, U, and V were all eliminated from further evaluation. These 13 systems included more negative rankings than positive. In addition, Systems G and N, both employing mono-vision cameras only, were eliminated due their comparable number of positive and negative ratings with few “same” ratings.

System C was also eliminated from consideration for the PIP development vehicles, since in the revised CIB statement of work (submitted April 14, 2008) Mercedes-Benz added a development vehicle with a system similar to System C. Therefore, this combination will already be represented and evaluated within this vehicle.

The remaining six systems include D (mid- and long-range radar combination sensor from supplier 2), H (mid- and long-range radar combination sensor plus LIDAR, both from supplier 2), I (datum- mid- and long-range radar sensor plus a mono-vision camera from supplier 2), O (mid- and long-range radar combination sensor plus mono vision from supplier 3), S (stereo vision camera from supplier 5), and T (mid- and long-range radar combination sensor from supplier 2 plus stereo vision camera from supplier 5). Of these remaining systems, the highest ranking system compared to the datum was system S, which includes a stereo vision camera sensor from supplier 5. However, this system also includes a few negative ratings including “Production Field Expertise/Technical Maturity” with a “Moderately Significant” weighting factor, plus “Variation in Range,” “Variation in Range Rate” and “Environmental Performance,” all with “Neutral” weighting factors. Systems T, O and H were also ranked very closely to the datum System I. System T includes a mid- and long-range radar combination sensor from supplier 2 plus stereo vision camera from supplier 5. This system had three negative ratings, however, including “Fusion Algorithm Risk” with a “Very Significant” weighting factor. System O, which included mid- and long-range radar plus a mono vision camera, had similar scores to System T. System H, which includes a mid- and long-range radar combination sensor plus LIDAR, rated very closely to the datum, but also received a negative rating for “Fusion Algorithm Risk” with a “Very Significant” weighting factor. The six systems remaining under consideration were included in the confirmation analysis shown in Table 8.

Table 7 - Completed Pugh Analysis for Candidate CIB Sensing Systems

			System																					
	Assessment	**Weight**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**	**U**	**V**
Overall	Relative cost	3	+	+	+	+	+	+	+	+	DATUM	+	S	S	+	+	S	+	+	+	+	S	S	S
	Package size	1	+	+	S	+	+	+	+	S		S	-	-	+	+	S	+	+	+	+	S	S	S
	Electrical/communication interface	3	+	+	S	+	S	+	+	S		S	-	-	+	+	S	+	+	+	+	S	S	S
	Compatibility with data acquisition system	5	S	S	S	S	S	S	S	S		S	S	S	S	S	S	S	S	S	S	S	S	S
	Technical support from supplier	3	S	S	S	S	S	S	S	S		S	S	S	S	S	S	S	-	-	S	-	-	-
	Mechanical interface with vehicle	1	+	+	S	+	S	+	+	S		S	-	-	+	+	S	+	+	+	+	S	S	S
	Fusion algorithm risk	5	+	+	-	+	-	+	+	-		S	-	-	+	+	S	+	+	+	+	-	S	S
	Production field expertise/technical maturity	3	-	+	-	S	-	+	S	S		S	-	-	S	+	S	S	-	-	-	-	-	-
	Component lead time	3	+	+	+	S	S	+	+	S		+	S	S	S	+	S	S	S	S	S	S	S	S
	Variation in range measurement	1	-	S	S	S	S	-	-	S		S	+	+	S	-	S	S	-	-	-	S	S	S
	Variation in range rate measurement	1	S	S	S	S	S	-	-	S		-	S	S	S	-	S	S	-	-	-	S	S	S
	Variation in field of view (FOV) measurement	1	-	-	-	-	-	S	S	S		S	S	S	-	S	S	-	S	S	S	S	S	S
	Environmental performance	1	S	S	S	S	S	-	-	S		-	S	S	S	-	S	-	-	-	-	S	S	S
	Working relationship w/CIB Technical Team	3	S	S	S	S	S	S	S	S		S	S	S	S	S	S	-	-	-	S	S	S	S
	Σ +		6	7	2	5	2	7	6	1		2	1	1	5	7	0	5	5	5	5	0	0	0
	Σ -		3	1	3	1	3	3	3	1		2	5	5	1	3	0	3	6	6	4	3	2	2
	Σ S		5	6	9	8	9	4	5	12		10	8	8	8	4	14	6	3	3	5	11	12	12
Ability to DETECT (based upon PreScan)	V-to-O: Pedestrian cut-in	3	S	-	S	S	S	-	S	S		S	S	S	S	S	S	S	S	-	S	S	-	-
	V-to-O: Pedestrian in-path	3	S	S	S	S	S	-	S	S		S	S	S	S	S	S	S	S	-	S	S	-	-
	V-to-O: Tree	1	S	S	S	S	S	-	S	S		S	S	S	S	S	S	S	S	-	S	S	-	-
	V-to-O: Pole	1	S	S	S	S	S	-	S	S		S	S	S	S	S	S	S	S	-	S	S	-	-
	V-to-O: Roadside structure	1	S	S	S	S	S	-	S	S		S	S	S	S	S	S	S	S	-	S	S	-	-
	V-to-V: Rear end, lead vehicle stopped	5	S	S	S	S	S	-	S	S		S	S	S	S	S	S	S	S	-	S	S	-	-
	V-to-V: Rear end, lead vehicle moving	5	S	S	S	S	S	-	S	S		S	S	S	S	S	S	S	S	-	S	S	-	-
	V-to-V: Rear end, lead vehicle decelerating	5	S	S	S	S	S	-	S	S		S	S	S	S	S	S	S	S	-	S	S	-	-
	V-to-V: Rear end, cut-in	5	S	-	S	S	S	-	S	S		S	S	S	S	S	S	S	S	-	S	S	-	-
	V-to-V: Left turn across path (LTAP), opposite direction	3	-	-	-	S	S	-	S	S		S	S	S	S	S	S	S	S	-	S	S	-	-
	V-to-V: LTIP/RTIP/LTAP, lateral direction (turning)	3	-	-	-	S	S	-	S	S		S	S	S	S	S	S	S	S	-	S	S	-	-
	V-to-V: Straight crossing path	5	S	S	S	S	S	S	S	S		S	S	S	+	S	+	S	S	-	S	S	-	-
	V-to-V: Opposite direction	5	-	-	-	S	S	-	S	S		S	S	S	S	S	S	S	S	-	S	S	-	-
	Σ +		0	0	0	0	0	0	0	0		0	0	0	1	0	1	0	0	0	0	0	0	0
	Σ -		3	5	3	0	0	12	0	0		0	0	0	0	0	0	0	0	13	0	0	13	13
	Σ S		10	8	10	13	13	1	13	13		13	13	13	12	13	12	13	13	0	13	13	0	0
Ability to CLASSIFY (based upon surveys)	V-to-O: Pedestrian cut-in	3	-	-	-	-	-	-	S	S		S	S	S	-	S	S	-	S	-	S	S	-	-
	V-to-O: Pedestrian in-path	3	-	-	-	-	-	-	S	S		S	S	S	-	S	S	-	S	-	S	S	-	-
	V-to-O: Tree	1	-	-	-	-	-	-	S	S		S	S	S	-	-	-	-	-	-	S	S	-	-
	V-to-O: Pole	1	-	-	-	-	-	-	S	S		S	S	S	-	-	-	-	-	-	S	S	-	-
	V-to-O: Roadside structure	1	-	-	-	-	-	-	S	S		S	S	S	-	-	-	S	-	-	S	S	-	-
	V-to-V: Rear end, lead vehicle stopped	5	S	S	S	S	S	S	S	S		S	S	S	S	S	S	S	S	-	S	S	-	-
	V-to-V: Rear end, lead vehicle moving	5	S	S	S	S	S	S	S	S		S	S	S	S	S	S	S	S	-	S	S	-	-
	V-to-V: Rear end, lead vehicle decelerating	5	S	S	S	S	S	S	S	S		S	S	S	S	S	S	S	S	-	S	S	-	-
	V-to-V: Rear end, cut-in	5	S	S	S	S	S	S	S	S		S	S	S	S	S	S	S	S	-	S	S	-	-
	V-to-V: Left turn across path (LTAP), opposite direction	3	S	-	S	S	S	-	-	S		-	S	S	S	S	S	-	S	-	S	S	-	-
	V-to-V: LTIP/RTIP/LTAP, lateral direction (turning)	3	S	-	S	S	S	-	-	S		-	S	S	S	S	S	S	S	-	S	S	-	-
	V-to-V: Straight crossing path	5	S	S	S	S	S	-	-	S		-	S	S	S	S	S	S	S	-	S	S	-	-
	V-to-V: Opposite direction	5	-	S	S	S	S	-	S	S		S	S	S	S	S	S	S	S	-	S	S	-	-
	Σ +		0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
	Σ -		6	7	5	5	5	9	3	0		3	0	0	5	3	3	5	3	13	0	0	13	13
	Σ S		7	6	8	8	8	4	10	13		10	13	13	8	10	10	8	10	0	13	13	0	0
	TOTAL: Σ +		6	7	2	5	2	7	6	1		2	1	1	6	7	1	5	5	5	5	0	0	0
	TOTAL: Σ -		12	13	11	6	8	24	6	1		5	5	5	6	6	3	8	9	32	4	3	28	28
	TOTAL: Σ S		22	20	27	29	30	9	28	38		33	34	34	28	27	36	27	26	3	31	37	12	12

Pugh Analysis Key

- = Much Worse than Datum
S = About the Same as Datum
+ = Much Better than Datum

Table 8 - Completed Pugh Analysis for Candidate CIB Sensing Systems Following Confirmation

		System																					
Assessment	**Weight**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**	**U**	**V**
Relative cost	3			+	+				+	S						S				+	DATUM 2		
Package size	1			S	+				S	S						S				+			
Electrical/communication interface	3			S	+				S	S						S				+			
Compatibility with data acquisition system	5			S	S				S	S						S				S			
Technical support from supplier	3			S	S				S	S						S				S			
Mechanical interface with vehicle	1			S	+				S	S						S				+			
Fusion algorithm risk	5			S	+				S	+						+				+			
Production field expertise/technical maturity	3			S	+				+	+						+				S			
Component lead time	3			+	S				S	S						S				S			
Variation in range measurement	1			S	S				S	S						S				-			
Variation in range rate measurement	1			S	S				S	S						S				-			
Variation in field of view (FOV) measurement	1			-	-				S	S						S				S			
Environmental performance	1			S	S				S	S						S				-			
Working relationship w/CIB Technical Team	3			S	S				S	S						S				S			
Σ +				2	6				2	2						2				5			
Σ -				1	1				0	0						0				3			
Σ S				11	7				12	12						12				6			
V-to-O: Pedestrian cut-in	3			S	S				S	S						S				S			
V-to-O: Pedestrian in-path	3			S	S				S	S						S				S			
V-to-O: Tree	1			S	S				S	S						S				S			
V-to-O: Pole	1			S	S				S	S						S				S			
V-to-O: Roadside structure	1			S	S				S	S						S				S			
V-to-V: Rear end, lead vehicle stopped	5			S	S				S	S						S				S			
V-to-V: Rear end, lead vehicle moving	5			S	S				S	S						S				S			
V-to-V: Rear end, lead vehicle decelerating	5			S	S				S	S						S				S			
V-to-V: Rear end, cut-in	5			S	S				S	S						S				S			
V-to-V: Left turn across path (LTAP), opposite direction	3			-	S				S	S						S				S			
V-to-V: LTIP/RTIP/LTAP, lateral direction (turning)	3			-	S				S	S						S				S			
V-to-V: Straight crossing path	5			S	S				S	S						+				S			
V-to-V: Opposite direction	5			-	S				S	S						S				S			
Σ +				0	0				0	0						1				0			
Σ -				3	0				0	0						0				0			
Σ S				10	13				13	13						12				13			
V-to-O: Pedestrian cut-in	3			-	-				S	S						S				S			
V-to-O: Pedestrian in-path	3			-	-				S	S						S				S			
V-to-O: Tree	1			-	-				S	S						-				S			
V-to-O: Pole	1			-	-				S	S						-				S			
V-to-O: Roadside structure	1			-	-				S	S						S				S			
V-to-V: Rear end, lead vehicle stopped	5			S	S				S	S						S				S			
V-to-V: Rear end, lead vehicle moving	5			S	S				S	S						S				S			
V-to-V: Rear end, lead vehicle decelerating	5			S	S				S	S						S				S			
V-to-V: Rear end, cut-in	5			S	S				S	S						S				S			
V-to-V: Left turn across path (LTAP), opposite direction	3			S	S				S	S						S				S			
V-to-V: LTIP/RTIP/LTAP, lateral direction (turning)	3			S	S				S	S						S				S			
V-to-V: Straight crossing path	5			S	S				S	S						S				S			
V-to-V: Opposite direction	5			S	S				S	S						S				S			
Σ +				0	0				0	0						0				0			
Σ -				5	5				0	0						2				0			
Σ S				8	8				13	13						11				13			
TOTAL: Σ +				2	6				2	2						3				5			
TOTAL: Σ -				9	6				0	0						2				3			
TOTAL: Σ S				29	28				38	38						35				32			

<u>Pugh Analysis Key</u>
- = Much Worse than Datum
S = About the Same as Datum
\+ = Much Better than Datum

Once the Pugh Analysis for the sensing system was completed, the same process was used for analyzing the candidate brake systems. Table 9 contains the Pugh Analysis results for these systems. For this analysis, System E, which consists of an active vacuum booster with pre-fill and auto braking algorithm, was selected as the datum.

Table 9 - Completed Pugh Analysis for Candidate CIB Braking Systems

		System											
	Assessment	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**
Overall	Relative cost	S	-	S	-	DATUM	-	S	-	S	-	S	-
	Integration complexity	S	-	S	-		-	S	-	S	-	S	-
	Component lead time	S	-	S	-		-	S	-	S	-	S	-
	Electrical/communication interface	S	S	S	S		S	S	S	S	S	S	S
	Mechanical interface with vehicle	S	S	+	-		S	+	-	S	S	+	-
	Production field expertise/technical maturity	S	S	S	-		S	S	-	S	S	S	-
	Σ +	0	0	1	0		0	1	0	0	0	1	0
	Σ -	0	3	0	5		3	0	5	0	3	0	5
	Σ S	6	3	5	1		3	5	1	6	3	5	1
Functional Performance	Ability to self-apply up to 0.9 g's	S	S	S	S		S	S	S	S	S	S	S
	Ability to apply ~0.1 g gradients of decel up to 0.9 g's	S	S	S	S		S	S	S	S	S	S	S
	Ability to achieve 1.5 g/sec decel build rate	S	S	S	S		S	S	S	S	S	S	S
	Ability to maintain control brake functions: ABS, DRP, etc	S	S	S	S		S	S	S	S	S	S	S
	Ability to provide multi-tiered braking gradients	S	S	S	S		S	S	S	S	S	S	S
	Σ +	0	0	0	0		0	0	0	0	0	0	0
	Σ -	0	0	0	0		0	0	0	0	0	0	0
	Σ S	5	5	5	5		5	5	5	5	5	5	5
	TOTAL: Σ +	0	0	1	0		0	1	0	0	0	1	0
	TOTAL: Σ -	0	3	0	5		3	0	5	0	3	0	5
	TOTAL: Σ S	11	8	10	6		8	10	6	11	8	10	6

<u>Pugh Analysis Key</u>
- = Much Worse than Datum
S = About the Same as Datum
+ = Much Better than Datum

As shown in Table 9, the detailed Pugh evaluation resulted in all systems being the same as the datum. This indicates that the performance criteria can be met by all defined systems when compared to an Active Vacuum Booster with pre-fill and auto braking algorithm. This outcome was expected, since all the candidate brake system hardware is based on current production brake systems. Production systems normally respond equally well to a requested vehicle deceleration initiated by the driver or by an external electrical command.

The majority of the current production systems that can create brake pressure by an external electrical command consists of an Active booster (electrically activated vacuum booster) and the activation of the hydraulic brake pump motor. The main difference in braking performance of these two systems is only relevant at lower ambient temperatures and at vehicle start up, where the viscosity of the brake fluid is high (i.e., -30 degrees F). Performance of the brake system at these lower temperatures is a production vehicle requirement and is not considered for the PIP vehicles.

2.5.4 CIB System Selection for PIP Vehicles

As a result of the Pugh Analysis, two systems were selected for build into the PIP development vehicles in addition to the Mercedes-Benz test vehicle. System O, which includes a combination mid- and long-range radar sensor plus a mono-vision camera, was selected for the following reasons. First, the system was ranked similar to the datum I system. Second, since System O is an existing candidate system from one of the suppliers that provided survey responses in Task 3, selecting this system reduced the risk associated with developing a sensor combination independently. Third, System O included a combination of sensor technologies rather than relying on a single sensor type. This difference in sensor types is expected to aid in test method development in later tasks to ensure that the methods developed were applicable to the various sensing system technologies, including stand-alone technology approaches. Fourth, System O enabled a larger number of suppliers' technology to be utilized in the project, which would not be the case if the datum System I were used.

System T was selected for the second PIP vehicle. This system includes a combination mid- and long-range radar sensor plus a stereo vision camera sensor. System T also showed generally very similar ranking results relative to datum System I. However, this system had three negative ratings, including one for “Fusion Algorithm Risk” (with a “Very Significant” weighting factor) and one for “Production Field Expertise/Technical Maturity” (with a “Moderately Significant” weighting factor). The primary benefit of selecting System T is that it allowed for the potential flexibility of acting as multiple different sensing systems, depending on whether or not a fusion algorithm is available from the supplier(s). If one is available, the system could potentially represent not only a combination of radar and stereo vision together but separate radar and stereo vision systems, such as Systems S and D. Without the fusion algorithm, Systems S and D would still be represented by this selection. It should be noted that the radar from System T is the same mid- and long-range radar as in System I, the datum. As with the first system selected above (System O), System T also includes a combination of sensor technologies rather than relying on a single sensor type. This difference in sensor types is expected to aid in test method development in later tasks to ensure that the methods developed are applicable to the various sensing system technologies. At the same time, these two selected systems, plus the sensor set on the Mercedes-Benz test vehicle, all include a common sensor technology with radar. Each of these three radar systems, however, is produced by different suppliers and use different algorithms, which should further aid in the development of the test methods. In addition, a mono-vision camera will be added to the second system (System T) because a fusion algorithm for the radars and mono-vision camera recently became available from the suppler that can be used without significant refinements.

The USDOT/NHTSA staff concurred with the selection of systems during the conference call held on September 17, 2008.

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

The objective of Task 6 was to build the selected CIB system combinations into the PIP vehicles and develop test target systems for evaluating these systems. This task involved identifying the basic test types needed and the requirements for test vehicles, target systems, system hardware, data acquisition, and ground truth measurements. Finally, based upon results from initial testing, the test systems were modified as needed to meet the project requirements.

2.6.1 Development of Test Target System Requirements

This work involved the development of a preliminary set of requirements for the target systems used for evaluating the CIB systems during testing. Target types were identified and initially developed that would be required during the various testing phases conducted in Task 7 with the PIP vehicles. Undesirable test-to-test variation data associated with different target types during the baseline tests can be used later in the program to further refine target requirements. Using the data from the baseline CIB system tests, a smaller number of targets were then selected for use in PIP vehicle testing. These targets are intended to provide test repeatability and flexibility in replicating each of the priority crash scenarios.

2.6.1.1 Initial Target Evaluations for CIB System Activation – Baseline CIB System Testing

Seven types of targets were used during the baseline CIB system testing. The target types are identified as follows:

- Balloon Cars - Several types of balloon cars were utilized for static testing targets. These targets were selected for initial evaluation based on their ease of use and their ability to replicate vehicle characteristics in all orientations. These targets replicated the general vehicle visual characteristics and provided appropriate radar reflective characteristics as metallic reflective material is affixed to the balloon car. These targets are designed to translate forward and upward when struck by the test vehicle.
- Vehicle Foam Pillows - Foam pillows were selected as static testing targets for the same reasons as described above for balloon cars. However, unlike balloon cars, these targets are currently only available as two-dimensional representations of the back of a vehicle. The static foam pillows are held together by hook and loop closures and are designed to break apart when struck by the test vehicle.
- Flip-down Target – This system, also employed for static testing, utilizes a radar corner reflector mounted through a pivot to a stationary base. The target is activated by a light beam located at a defined distance from the radar corner reflector. An electromagnet in the main unit is connected to the power source. While under current, the electromagnet keeps the reflector upright. As soon as a vehicle moves through the light barrier, the electromagnet is disconnected from power, the reflector flips down, and the test vehicle drives over the target.

- Hanging Target Testing Simulator - This target, which can be employed either for static testing or for tests when the lead vehicle is moving, utilizes a boom mechanism to hold a radar corner reflector in an adjacent lane for testing. The radar corner reflector is mounted to a soft structure which is capable of being hit by an oncoming vehicle at closing speeds up to 35 mph. The mechanism that holds the corner reflector is capable of flipping up out of the way as the vehicle under test contacts it at impact, thus, allowing the test vehicle to pass underneath. The boom mechanism can be connected to the front or rear of the vehicle so that "oncoming vehicle" tests can be performed as well as the "following vehicle" cases. Test capability includes all Rear-End and Opposite Direction test scenarios. Initial evaluations of pole and tree targets could also be evaluated by replacing the target insert with various diameter foam targets wrapped with metallic reflective material which provides appropriate radar reflective characteristics corresponding to actual pole, tree, and other obstacles.
- Crash Simulator – This system, which can be employed either for static testing or for tests where the lead vehicle is moving, was originally developed for the demonstration of a collision mitigation or crash avoidance system. When contact is about to occur with the simulator dummy, which simulates the rear of a small car, the dummy is released and moves very quickly out of the vehicle path. The simulator utilizes compressed springs on a main shaft that are held in place by electromagnets. When the power to the magnets is switched off, the spring force is released and the dummy swings up and out of the way of the approaching test vehicle.
- Balloon Car Carrier - For this target system, a specially constructed balloon car is attached to a cantilevered truss which is suspended from a second vehicle driving in the adjacent lane. Thus, this approach can be employed either for static testing or for tests when the lead vehicle is moving. A quick release clamping mechanism holds the balloon in place and releases it when the balloon is struck by the test vehicle. The clamping mechanism can be reversed to allow testing in opposite direction scenarios. The maximum velocity for this test apparatus is approximately 35 to 40 mph.
- Towed Balloon Car - A static balloon car, previously described, was placed on a tarp and pulled by a secondary vehicle at the defined test speed. This approach can be employed for tests in which the lead vehicle is moving. In order to maintain the correct heading, the tarp was guided by cables secured to the test track.

2.6.1.2 Preliminary Non-Activation Test Targets - Baseline CIB System Testing

Along with test scenarios that are intended to activate the CIB system, it is important to develop "non-activation" test scenarios, and the related test equipment, that examine the ability of the system to ignore a non-threatening target. These test scenarios are intended to assess false positive activation conditions, which can potentially lead to unintended consequences for the driver and other traffic users. The Real-world Operational Assessment Data (ROAD) Trip planned for Task 8 testing, which involves gathering a large amount of naturalistic driving data under a myriad of traffic, roadway, and environments conditions, will be used as a tool to more fully assess the presence and nature of non-activation scenarios. This naturalistic data will serve as a tool to refine the development tests to address non-activation scenarios for a broad range of sensing systems.

The targets identified below are a preliminary set of targets that were used to develop baseline CIB system non-activation test data. In preparation for the Task 8 ROAD Trip, this test data was used as an early assessment of potential test methods. Whenever possible, the natural features of available test tracks were utilized for the non-activation tests. Targets used in the evaluations included the following:

- Corner Reflector (simulation of a worst case man-hole cover)
- Additional Vehicles, as required
- Concrete Barriers and Steel Guardrails
- Signs and Signposts
- Tunnels and Bridges
- Buildings

2.6.1.3 Targets for PIP Vehicle Testing

The following material presents the target types selected for further test evaluation and development during the "prove-out" of verification tests with PIP systems in Subtask 7.5. Target system considerations identified in this phase of testing were the following. First, representative vehicle surrogates were needed for vehicle-to-vehicle tests. Second, a system was needed for safely conveying and choreographing the presentation of these targets in a manner representative of the priority crash scenarios. Third, a target system was needed for duplicating as many of the vehicle-to-object tests as possible, including pedestrian impacts.

2.6.1.3.1 Representative Vehicle-to-Vehicle Surrogates

For vehicle-to-vehicle targets, several different targeting systems were evaluated. First, in order to better accommodate CIB vision system sensing capabilities, inflatable balloon car targets were selected which were more visually representative of small passenger cars than alternative balloon car targets. These targets also offered provisions for installing radar-reflective materials to accommodate radar and LIDAR sensing systems. However, during Task 7 testing of the PIP vehicles, target durability proved to be problematic. Therefore, testing continued using the previous balloon car design described in Section 2.6.1.1.

Second, two sets of foam targets were used as targets in the vehicle-to-vehicle testing. The first foam target was similar to the Vehicle Foam Pillows described in Section 2.6.1.1 A new second foam target system was also tested that included several corner reflectors to compare the performance of tests made with balloon cars with this obstacle.

For moving balloon car tests, the balloon car carrier described in Section 2.6.1.1 was used. This system was used for initial testing of Lead Vehicle Moving and Lead Vehicle Decelerating scenarios.

2.6.1.3.2 Representative Vehicle- to-Object Surrogates

For vehicle-to-object scenarios, preliminary targets representing tree and pole objects were developed. Correlation of these targets to real world objects will be described in Section 2.7. These targets were suspended statically from the ropes employed in the conveyance system, as described below. In addition, the conveyance system was setup to accommodate the pedestrian targets. However, further study is needed to identify and correlate a representative pedestrian target suitable for CIB testing. This work will be completed in Task 8.

2.6.1.3.3 Target Conveyance System

To facilitate the development of the test methods, a conveyance system was developed to present and choreograph the inflatable car and pedestrian (mannequin) targets in a manner representative of the priority crash scenarios. The conveyance system consisted of a computer-controlled electric motor that drives pulleys and a system of ropes that transports the target. For vehicle-to-vehicle testing, the conveyance system was mounted to the roadway. For pedestrian testing, the system was suspended from support booms positioned along the roadway. This latter arrangement permitted the test vehicle to move perpendicular to or parallel with the target being transported by the conveyance system. Feedback on target position was provided to the computer in the system design so that test repeatability and efficiency could be maintained.

2.6.2 CIB PIP Vehicle System Hardware Requirements

Based on the results from Task 5, the following CIB system hardware was required for the PIP test vehicles. The PIP vehicles were outfitted with automotive-grade sensing systems and algorithms for processing the sensor inputs and controlling the brake system. The crash imminent braking system on each vehicle consisted of the components described below.

<u>2008 Chevrolet Equinox</u>

- Sensing
  - Continental Long- and Mid-Range Combination Radar
  - Continental Mono Camera
  - Continental Long- and Mid-Range Radar, and Mono Camera Fusion
  - Stereo Vision System
- Braking - The braking system in the Equinox is based upon the standard production system with a modified Continental development brake controller. The system is capable of ABS, traction control, and electronic stability control (ESC), as well as adding crash imminent braking functionality. Crash imminent braking uses the existing hydraulic brake system to apply brakes and provide deceleration to the vehicle. The brake system in the Equinox provides auto-braking with

selectable deceleration levels from 0.1 g up to full ABS braking in 0.1 g increments.

2005 Volvo XC90

- Sensing
  - Delphi Long- and Mid-Range Combination Radar
  - Delphi Mono Camera with a Third Party Machine Vision Processor
  - Delphi Long- and Mid-Range Radar, and Mono Camera Fusion
- Braking - The braking system in the Volvo was based upon the standard production system. The system is capable of ABS, traction control and ESC, as well as adding crash imminent braking functionality. Crash imminent braking uses the existing hydraulic brake system to apply brakes and provide deceleration to the vehicle. The brake system in the Volvo was capable of varying the amount of brake pressure and deceleration.

2007 Mercedes-Benz S550

- Sensors - The equipment used for this vehicle consists of three radar sensors with different ranges and employs a fusion algorithm. The sensors are located in the grille (long- and mid-range combination radar) and behind the front bumper (two short- range radar sensors) on the left and right side.
- Braking - The Mercedes-Benz S550 has an autonomous braking-capable next generation electronic brake control system with integrated traction control and dynamic handling control systems.

2.6.3 Data Acquisition and Ground Truth Measurement Requirements

In order to capture data for the CIB tests that were conducted, a suitable data acquisition system and “ground-truthing” system for each vehicle was developed. In this content, a ground truthing system refers to an accurate reference system to which sensor data can be compared to during CIB testing. Three critical areas of data needs exist for the project:

1) Recording and processing of identified data signals
2) Storage of large quantities of signal data
3) Post-processing data format requirements for re-simulation

Earlier in the project, a CIB data acquisition signal list was developed for CIB vehicle-level testing. This signal list identified critical parameters that would need to be recorded during testing with the PIP vehicles. The signals included primarily vehicle dynamics and position measurements for the test vehicles (e.g., vehicle accelerations, velocities, ranges and range rates). A suitable data acquisition system capable of measuring these signals, as well as ground-truthing data, was required. Complicating the data acquisition was the requirement to capture data in both of the vehicle-to-vehicle (non “fixed point” test cases) and vehicle-to-object (primarily “fixed point” test cases) crash scenario test modes.

A ground-truthing system was also required as part of the testing equipment to act as an accurate reference for acquired data from the CIB sensor set and Controller Area

Network (CAN) bus vehicle dynamics data. A Global Positioning System (GPS) based measurement system was used to accomplish measurement of both vehicle dynamics and vehicle positioning data. Additionally, the GPS system could meet the requirement for high measurement accuracy. Current generation GPS systems are able to increase their accuracy by using a fixed mount "base station" to perform differential GPS corrections and are accurate to less than 2 cm for distance measurements. Additionally, the selected GPS system is capable of reporting information regarding the relative positions of two or more targets with regard to the host vehicle in real time with an accuracy of 3 cm. Given this accuracy, the GPS system was also used as the ground-truthing system for the project. As vehicle data such as vehicle dynamics state (yaw, lateral acceleration, etc.) and CIB sensor data (radar and vision) was captured in the data acquisition system via the vehicle CAN bus, it could be compared to the ground truth system data available in the GPS system. Finally, the GPS system was able to capture data in both the vehicle-to-vehicle (non "fixed point" test cases) and vehicle-to-object (primarily "fixed point" test cases) crash scenarios. In the case of the baseline CIB system vehicles tested, access to vehicle CAN was not possible and signal measurement data relied heavily on the GPS ground-truthing system for data acquisition purposes.

2.6.4 Data Storage and Post Processing Requirements for Re-simulation

A critical requirement of the data acquisition system is the ability to store and process large quantities of data during testing. To address this need, a suitable data storage and processing system was developed to accommodate both the test track and ROAD Trip datasets. In addition, several terabytes of data storage capacity were included in the facility.

Once data was gathered from the on-track or ROAD Trip testing, the data was played back on the computing system for the purposes of re-simulating events. Figure 2 identifies the algorithm simulation setup and process for the CIB signal data acquired from the on-track and ROAD test sequences. The figure (with flow from top to bottom) also shows the re-simulation process employed. The data collection block contains the data files acquired from the data acquisition system during the on-track scenario testing and ROAD testing. The data files containing vehicle data and CIB sensor data were used as inputs to the algorithm block to rerun CIB algorithms with "adjusted" parameters for re-simulating test scenarios. After running a simulation, a new data set was created containing new CAN logs which contain the data in CAN format that show the effects of the parameter changes in the algorithm.

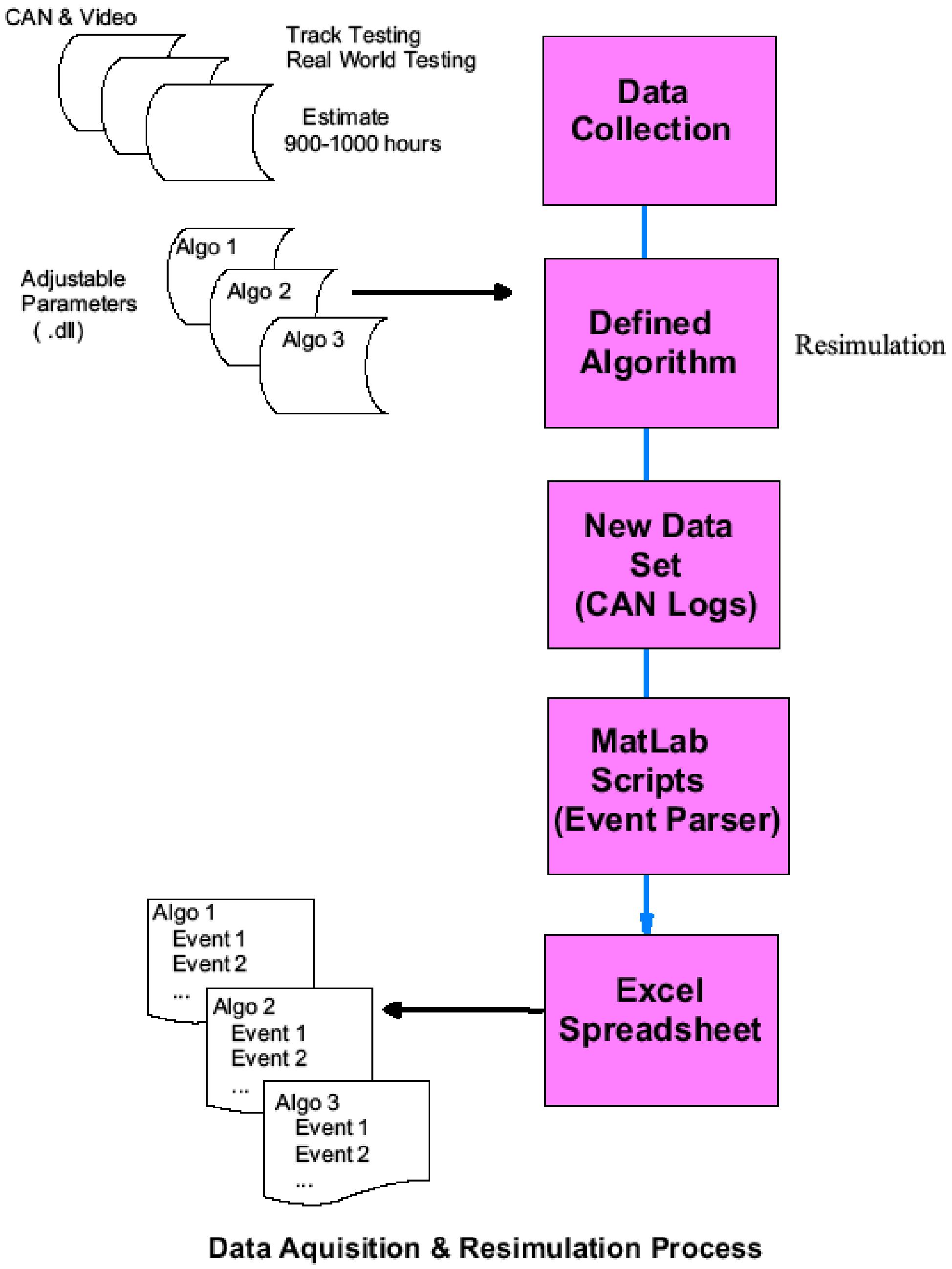


Figure 2 - Simulation Process for On-Track and ROAD Test Data

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. Task 7 involved developing a list of proposed verification test methods for each of the high priority crash scenarios and operational scenarios and conducting "prove-outs" of the verification tests with representative baseline systems.

In Task 2, the high priority crash scenarios were selected from a list of scenarios based upon the estimated societal harm associated with a particular scenario and the potential applicability and benefit opportunities provided by CIB systems. In total, 14 crash scenarios were selected for the project. Table 10 below provides a list of the major crash scenario categories scenarios, where V-V and V-O correspond to the "vehicle to vehicle" and "vehicle to object" categories, respectively.

Under this task, the test methods developed for the 14 crash scenarios were reduced to nine test methods (shown in Table 11), based on the rationale described below:

- The Left Turn Across Path Lateral Direction (Turning, LTAP-LD) was judged to be very similar to the straight crossing path (SCP) method.
- The Rear End Cut In (RE-CI) cases were found to be very difficult to choreograph in a repeated fashion on the test track. In addition, the cut in case typically resulted in LVM, LVD or LVS scenarios after the cut in occurred. (Note that, unlike the PIP testing, the baseline testing included the RE-CI scenario.)
- Since the tree and pole test method were equivalent in test speed, vehicle trajectory and object diameters, these methods were combined.
- As indicated in the last entry in Table 10, "Ground" scenario was already chosen for elimination in Task 2.
- "Structure" was eliminated based on the large number of potential objects, sizes, and shapes that would need to be simulated.

The Task 7 test method development work, therefore, consisted of developing test methods for the nine crash scenario categories which comprehended all 14 crash scenarios identified in Task 2 (with the exception of ground and structure). The conditions contemplated for the tests were expected to limit the relative velocity between the test vehicle and a target to 45 mph or less. This test condition would result in an impact speed that was roughly equivalent to the New Car Assessment Program (NCAP) barrier test speed of 35 mph, assuming a 10 mph speed reduction occurred during a test. The NCAP barrier test is considered to be a high-severity crash. Development of the test methods was then divided into two phases of testing, as shown below:

1. *Baseline testing* that focused on the initial prove-out tests using representative baseline CIB systems in current production vehicles
2. *PIP* vehicle testing to further "prove-out" test methods using the PIP test vehicles developed during Task 6

Table 10- Crash Scenarios Defined from Task 2

Scenario	Archetypal Model		
	Category	**Abbreviation**	**Description**
1	V-V	RE-LVS	Rear End Lead Vehicle Stopped
2	V-V	RE-LVM	Rear End Lead Vehicle Moving
3	V-V	RE-LVD	Rear End Lead Vehicle Decelerating
4	V-V	RE-CI	Rear End Cut In
5	V-V	LTAP-OD	Left Turn Across Path Opposite Direction
6	V-V	SCP	Straight Crossing Path
7	V-V	LTAP-LD	Left Turn Across Path Lateral Direction (Turning)
8	V-V	OD	Opposite Direction
9	V-P	P-IP	Pedestrian In Path
10	V-P	P-CP	Pedestrian Cross Path
11	V-O	N/A	Pole
12	V-O	N/A	Structure
13	V-O	N/A	Tree
14	V-O	N/A	Ground

Table 11 - Test Methods Used in Task 7 to Represent the CIB Crash Modes

	Test Method	Category	Comment
1	LVS	V-V	
2	LVM	V-V	Comprehends rear end cut in scenario
3	LVD	V-V	
4	LTAP-OD	V-V	
5	SCP	V-V	Comprehends LTAP-LD scenario
6	OD	V-V	
7	Pedestrian IP	V-O	
8	Pedestrian CI	V-O	
9	Pole / Tree	V-O	Combined Tree and Pole into one test method

2.7.1 Data Collected for Analyses

The test data signals collected address two primary project objectives: 1) Validate the crash imminent braking test methods covering the high priority crash scenarios; and

2) Assess crash imminent braking performance of the three PIP vehicles during CIB test method validation. The signal sources include the following:

- GPS-based ground-truth instrumentation, including vehicle dynamics data
- Vehicle CAN data
- Crash imminent braking sensor (vision, radar, etc.) data

The GPS-based, ground-truthing equipment is described in detail under Task 6 in Section 2.6.3. This system records dynamic measurements between the test vehicle and target, as well as test vehicle dynamics data, in a stand-alone set of instrumentation independent of the vehicle CAN data. Recorded test vehicle dynamics data includes:

- Longitudinal and Lateral Accelerations
- Velocity(s)
- Yaw
- Yaw Rate

Ground-truthing measurements and measurements between the test vehicle and target include the following:

- GPS Position
- Range
- Range Rate (closing speed)
- Target Impact Point

The additional signal data from the vehicle and forward looking sensor(s) was collected in order to aid in the development of the test methods and targets. This additional data was available in the PIP vehicles but was not available in the production baseline vehicles. Signal data from these three areas includes radar sensor data, stereo or mono vision system data, vehicle state information (vehicle speed, driver inputs, inertial sensor data, etc.), and ground truth information (GPS, additional cameras, etc.).

2.7.2 Targets Used for Testing

Task 6, documented in Section 2.6, includes a section identifying the target system requirements established to address the CIB testing needs. As explained in Section 2.6, a larger number of targets were identified for the baseline production vehicle tests to allow evaluation of potential test methods and target configurations. These choices were then down-sized for subsequent testing with the PIP vehicles based on a balance between unwanted test-to-test variation attributable to a given target type and the desire to have a flexible, common targets that could be used across multiple test modes.

After the number of potential targets was down-sized for PIP testing purposes, the targets were further correlated using the PIP vehicles. Within each of the three PIP vehicles, measurements of radar power return for tracked targets were recorded and target visual characteristics were also assessed for mono- and stereo-based camera-based systems. In addition, a general methodology was developed to aid in conducting the target system correlations.

2.7.3 Baseline Vehicle Testing

The first iteration of development and evaluation of these test methods included conducting initial prove-out tests using representative baseline CIB systems. The goals of this activity were to:

- Assess and develop preliminary test methods based on the nine priority crash scenarios that were identified. This allows early analysis of the practicality of the procedures, verifies that the instrumentation and ground truth measurement method is acceptable, determines if the maneuvers are executable, and that the objective performance criteria are reasonable and verifiable.
- Develop baseline data to assist with the test method development during the CIB PIP vehicle testing phase. This ensures that the PIP vehicles are capable of adequately representing the selected systems.
- Evaluate the variation and performance characteristics associated with various test target types. Early test method development includes different combinations of potential surrogate targets. Evaluating these different target types with the baseline systems provides data for assessing the test repeatability and functionality of each of the candidate options.

The baseline tests were performed independently by the USDOT/NHTSA, with assistance (as requested) from the CIB TMT. Three current production vehicles equipped with representative CIB systems were used for these tests. The USDOT/NHTSA selected and obtained vehicles to perform these testing. The characteristics of the CIB systems installed in the baseline vehicles are summarized below.

<u>Vehicle A</u>

- Long-range radar mounted behind the front grill with a range of 200 meters
- Mono-camera mounted at the upper part of windshield with a range of approximately 60 meters
- Forward Collision Warning, including audible alerts and visual alert
- 1-stage braking with maximum deceleration of 5 m/s^2*
- CIB system brake activation above 7 km/h**

<u>Vehicle B</u>

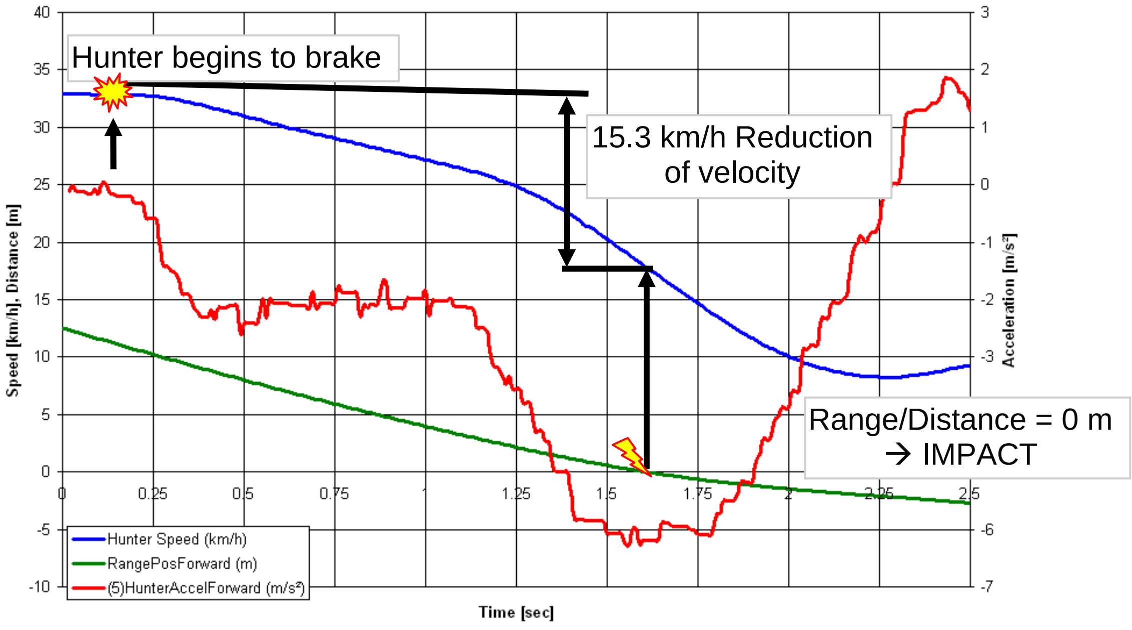
- Long-range radar mounted behind the front grill with a range of 100 meters
- Forward Collision Warning with audible alerts and flashing letters in the instrument panel area
- Reversible belt-tensioners
- 2-stage braking with maximum deceleration of 6 m/s^2*
- CIB system brake activation above 15 km/h**

<u>Vehicle C</u>

- Long-range radar mounted behind the grill with a range of 150 meters
- Two short-range radar sensors mounted behind the front bumper with a range of 30 meters
- Forward Collision Warning with audible alerts and symbol displayed in the cockpit
- Reversible belt-tensioners (front seats)
- Pre-Crash positioning of the front passenger and rear seats
- 1-stage braking with maximum deceleration of 4m/s²*
- CIB system brake activation between 30 km/h and 180 km/h**

* Measured during Task 7 baseline testing
** Based on information obtained from vehicle owner's manual

As an illustration of the type of data analyzed from the baseline vehicle tests, Figure 3 presents a sample of the data collected from a Lead Vehicle Stopped scenario with points highlighted which designate "data of interest" for post-processing of each run. The highlighted points correspond to when the baseline test vehicle (referred to as the "Hunter" in the figure) begins to brake (shown at approximately 0.25 sec in this graph) and when impact occurs (at approximately 1.60 sec).



Hunter begins to brake

15.3 km/h Reduction of velocity

Range/Distance = 0 m → IMPACT

Figure 3 - Sample Test Data from Lead Vehicle Stopped Scenario

Analyses of Time-to-Contact (TTC) and range at automatic braking onset were used to get further information with respect to variations across different tests to find targets which minimized test-to-test variation.

2.7.4 PIP Vehicle Testing

The second iteration of development and evaluation of test methods included conducting tests using three PIP vehicles that were equipped with CIB systems. The goals of this activity included:

- Assess and develop any revised test methods for PIP testing purposes suggested by "lessons learned" during the baseline testing phase. Continue refinement of the test methods for the nine priority crash scenarios.
- Evaluate the variation and performance characteristics associated with the various test target types using the PIP vehicles. Using baseline test data, a reduced number of targets were used.
- Measure vehicle braking and deceleration levels with PIP vehicles utilizing the CIB systems hardware identified in the design alternative selection process from Task 4. The deceleration data will be used for the estimate of CIB benefits during the latter stages of the project.

The PIP vehicles used during Task 7 testing were previously described in the summary for Task 6.

As an illustration of the type of data analyzed from the PIP vehicle tests, Figure 4 presents a sample of the data collected from a Lead Vehicle Stopped scenario. The "data of interest" starts with the point labeled "Time to Contact = 1.03 sec" (shown at approximately 29.5 sec in the graph). Impact occurs when the "Longitudinal Range" is equal to zero (shown at approximately 31 sec in the graph.

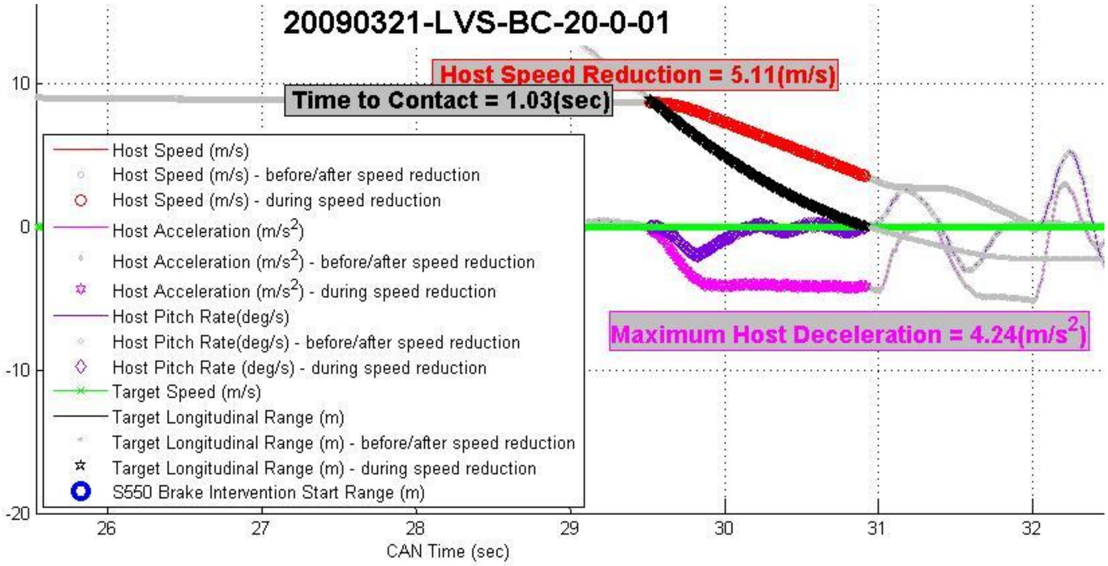


Figure 4 - Sample Test Data from Lead Vehicle Stopped Scenario

2.7.5 Selection of Test Methods for Validation in Task 8

Task 7 culminated with a milestone review with USDOT/NHTSA on May 6, 2009 in which the final test plans for the Task 8 validation process were discussed. In this review, the nine test methods evaluated in Task 7 were separated into the following “test readiness” categories:

- Continue with Task 8 Validation – this category included test methods which were shown to be repeatable during the Task 7 testing and resulted in data which clearly distinguished the performance of the different CIB system configurations evaluated.
- Further Development Needed – this category involved tests in which either test methodology improvements were needed, test repeatability required improvement, and/or in the test had insufficient data in Task 7 to determine whether the test method could be fully validated in Task 8.
- Eliminate – the method provided uncontrollable test–to-test variation or resulted in test data indicating that CIB systems, in general, would provide little or no benefit (which suggested that the scenario may be inappropriate for known CIB technologies).

Based on the information presented, the CIB and NHTSA project teams formally agreed on the categorization of the preliminary test methods as presented. This effort resulted in the following nine test scenarios to be evaluated and demonstrated in Task 8:

- Lead vehicle stopped
- Lead vehicle moving
- Lead vehicle decelerating
- Opposite direction
- Straight crossing path
- Left turn across path
- Poles/trees
- Pedestrians (in path and cut in)

2.8 Task 8 – Demonstration and Validation of Objective Tests

Principal activities completed during Year 2 included conducting validation tests of the objective test procedures evaluating CIB functional performance and preparing for the Real-world Operational Assessment Data (ROAD) Trip. The ROAD Trip was initiated late in Year 2 and will conclude in Year 3. The tests selected for validation were based on the priority crash scenarios established in Task 2 and included only the test methods designated as “Continue with Task 8 Validation” or “Further Development Needed” during the Task 7 Milestone Review (as described above) with USDOT/NHTSA. These test scenarios are listed in Section 2.7.5 .

Analysis of the data collected during these tests is ongoing and will be documented in the CIB Final Report. Results of the data collected from the ROAD Trip, including any operational test procedures developed based on the data, will also be reported in the CIB Final Report.

2.9 Task 9 – Finalization of the Performance and Test Specifications

This task is scheduled to begin early in Year 3 following completion of the data analysis of the functional test procedure validation and ROAD Trip data.

2.10 Task 10 – Finalization of the Benefits Estimates

Preliminary work was begun under this task during Year 2. NHTSA/Volpe drafted initial proposals for deriving estimated harm reduction benefits based on the CIB test data gathered under this CAMP CIB effort. A Benefits Estimation Working Group was created consisting of NHTSA/Volpe representatives, the CIB TMT, and additional crashworthiness/occupant protection technical experts from the various CIB partner companies. These latter experts provided additional expertise in the following areas: crashworthiness databases, crash-related statistics, crash injury risk functions, and benefit estimation techniques. This Working Group meets via conference call at least twice monthly to discuss, review, and exchange ideas regarding the development of the benefits estimation methodology. As test track and ROAD data becomes available in Year 3, NHTSA/Volpe will begin testing the proposed methodologies and performing preliminary benefits estimation calculations for the tested systems. This work is scheduled to continue through the end of the project and will be documented in the CIB Final Report.

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June 2010

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