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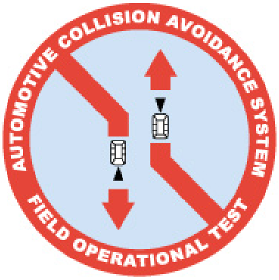
Automotive Collision Avoidance System Field Operational Test

First Annual Report



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This project is being carried out by a team lead by General Motor Corporation, North American Operations. Other major team members include: Delphi-Delco Electronic Systems, Delphi Chassis, Hughes Research Labs, HE Microwave and UMTRI.

16. Abstract

In June of 1999, the National Highway Traffic Safety Administration entered into a cooperative research agreement with General Motors to advance the state-of-the-art of rear-end collision warning technology and conduct a field operational test of a fleet of passenger vehicles outfitted with a prototype rear-end collision warning system and adaptive cruise control.

The goal of the research program was to demonstrate the state-of-the-art of rear-end collision warning systems and measure system performance and effectiveness using lay drivers on public roads in the United States.

The five-year program consists of a 2-year development phase during which refinement of component technologies will continue and be integrated into a prototype test vehicle. In the 3-year period of the second program phase, a fleet of ten vehicles will be constructed and outfitted with rear-end collision warning and adaptive cruise control systems and given to volunteer drivers to drive over a period of several weeks. Data collected from on-board vehicle instrumentation will be analyzed and used to estimate potential safety benefits, obtain information on the driving experiences of the volunteer drivers and their acceptance of this next -generation safety technology. The operational test will last approximately one year.

This document reports on the activities and results from the first year of this research program.

17. Key Words
Collision avoidance, crash avoidance, collision warning, rear-end collisions, forward collision warning, human factors, head-up display

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Automotive Collision Avoidance System Field Operational Test Program
First Annual Report

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First Annual Report

1 EXECUTIVE SUMMARY

1.1 Summary of Program Accomplishments and Conclusions

General Motors Corporation and Delphi-Delco Electronics Systems have established a Program Team to advance the science of Collision Warning (CW) systems. This Team will conduct an extensive Field Operational Test (FOT) to assess the impact of an integrated Forward Collision Warning (FCW) and Adaptive Cruise Control (ACC) system. The FCW function assesses conditions ahead of the vehicle and alerts the driver of rear-ends crash hazards. The Adaptive Cruise Control (ACC) function activates the brake and throttle to maintain a specified headway when following a slower vehicle. To support the FOT, the Program Team is designing and building ten cars equipped with FCW and ACC as well as an unobtrusive data acquisition system. During the field operational test, volunteers from the general driving public will each be given these cars for unsupervised, unrestricted use for two to four weeks.

The performance of the collision warning system will be sufficiently reliable and robust to support a meaningful field operational test. It will provide warnings to the driver, rather than taking active control of the vehicle. The FCW and ACC functions will be implemented using a combination of (a) a long-range forward radar-based sensor that is capable of detecting and tracking traffic, (b) a forward vision-based sensor that detects and tracks lanes and (c) GPS and a map database to help ascertain road geometry.

The technical activities of the program are grouped into two phases. Phase I started in June 1999, and will last approximately 27 months. Phase II will start immediately after Phase I and last approximately 32 months.

Phase I

1. Development – The program will initially improve technologies/components necessary for the FCW system, some of which were developed during the previous ACAS Program.
2. Integration – The refined FCW technologies/components will be designed into the vehicle to form an integrated rear-end collision warning system.

Phase II

3. Deployment Fleet – The validated design will be used to build a deployment fleet of ten vehicles equipped with the system.
4. Field Operational Test – The field operational test plan will be implemented. The deployed vehicles will be used to collect valuable research data to assess/validate the technology, product maturity, and the response of the public to the technology.

Table 1.1 shows how the tasks of the program are organized.

Table 1.1 Organization of Program Tasks

Task	Description
A System Integration	▪ Determination and allocation of system functions to subsystems ▪ Interface management ▪ System validation
B Subsystem Development B1 Forward Radar Sensor B2 Forward Vision Sensor B3 Brake Control System B4 Throttle Control System B5 Driver-Vehicle Interface	▪ Subsystem hardware definition ▪ Subsystem hardware refinement ▪ Subsystem validation
C Subsystem Processing Development C1 Data Fusion C2 Tracking and Identification C3 Collision Warning Function C4 Adaptive Cruise Control Function	▪ Subsystem software definition ▪ Subsystem software development ▪ Subsystem software validation
D Vehicle Build	▪ Engineering Development Vehicles ▪ Prototype Vehicle ▪ Pilot Vehicles ▪ Deployment Vehicles
E Field Operational Test	▪ FOT preparation ▪ FOT conduct ▪ FOT report

System Integration

During the first year of the program system functional requirements were documented and allocated to subsystems and components. Development began to define the complete set of signals and messages between the subsystems. This work will be documented in an Interface Control Document that will be delivered to NHTSA in March 2001.

Briefings were prepared and presented on the Prototype Vehicle Validation Plan and discussions were held with NHTSA, Volpe, and other government representatives, on system level testing scenarios. A Test Scenarios Report was delivered to NHTSA in April 2000. A System Verification Plan will be delivered to NHTSA in December 2000.

Each subsystem was reviewed to develop a preliminary hazard analysis and create a hazard mitigation plan. The plan is being developed using guidelines from Mil Standard 882C and SAE J1789. Safety plan presentations were made at meetings in November 1999 and June 2000. The Risk Management Plan will be delivered to NHTSA in January 2001.

Forward Radar Sensor

The Forward Radar Sensor Task includes transceiver/antenna integration, and development of algorithms for auto-alignment, antenna radome blockage detection, and bridge rejection. To facilitate transceiver/antenna integration, millimeter-wave monolithic integrated circuits (MMIC) were designed into the transceiver. Initial tests of the MMIC components and of the entire radar on an engineering development vehicle found some performance issues that are being addressed. The unit for the Prototype Vehicle is expected to perform as specified.

The auto-alignment algorithm is to electronically adjust the sensor mechanisms for misalignment due to vehicle wear and tire alignment. The basic algorithm has been found effective over “long” periods of time but is susceptible to peak errors of short duration when the vehicle is driven on curves. Engineering testing is continuing to isolate the cause of these errors and to develop a remedy.

The radome blockage detection algorithm is to detect when dirt, slush, or other material blocks the sensor. Development of this algorithm is behind schedule but a recovery plan is being executed. Some conceptual concerns have been identified regarding detection reliability in partial blockage situations, heavy snowfall, or when the vehicle is parked. These will be investigated and appropriate validation tests will be defined and executed.

The bridge rejection algorithm is to recognize and classify bridges as safe overhead objects so they do not cause the ACC function to slow the vehicle. Several approaches have been tested. An amplitude-slope method was found to be reliable but it requires multiple scans with range closure that can lead to delayed recognition of valid in-path stopped vehicles.

Forward Vision Sensor

The forward vision sensor is to provide lane tracking to help distinguish in-path from out-of-path targets, which is particularly difficult as the vehicle approaches a curve and during lane changes. It will use a video camera mounted behind the windshield of the vehicle to estimate road shape, lane width, vehicle heading and lateral position in the lane. Teams from the University of Pennsylvania, Ohio State University, and the University of Michigan – Dearborn were contracted to enhance their existing technology to meet the needs of the FOT. The primary challenge is to provide adequate road shape estimates at least 75 meters (preferably 100 meters) ahead of the vehicle. The work of the three universities will be evaluated to select one approach for further development and final integration into the FOT vehicles.

During the first year, Delphi-Delco Electronics defined requirements, implemented a video data acquisition system, and worked with the universities to define appropriate confidence measures. The universities have demonstrated systems that can track highway roads at 10 Hz frame rates out to 75 meters. They can handle lane changes and partial occlusion of the lane markings. Work is still required to improve tradeoffs associated with sampling schemes and to improve performance of the lane marker extraction methods with low levels of illumination and on concrete road surfaces.

Brake Control System

A new Delphi Brake Control System will replace the OEM brake components on the Prototype and FOT deployment vehicles. The brake control system includes an anti-lock brake system (ABS), vehicle stability enhancement, and traction control features. For this program, the brake system will be enhanced to respond to ACC braking commands while maintaining the braking features and functions that were in the original brake system. Delphi's common best engineering practices will be used to perform safety analysis and vehicle level verification of the brake system to ensure production-level confidence in the brake system.

Over the past two years, the DBC 7.2 brake control system has undergone significant testing for production programs. During the first year of the ACAS/FOT program, the brake system was integrated on a chassis mule and one of the Engineering Development Vehicles. Calibration and tuning of the brake system has started.

Throttle Control System

The throttle control system maintains the vehicle speed in response to the speed set by the driver or in response to the speed requested by the ACC function. The Delphi stepper motor cruise control (SMCC), standard in the Buick LeSabre, will be modified to perform the required functions. The required modifications have been used successfully in other projects. During the first year, interface requirements were defined and throttle control system modifications were designed for the prototype vehicle.

Driver Vehicle Interface

The driver vehicle interface senses the settings from the driver via buttons on the steering wheel. It also conveys information from the ACC and FCW functions to the driver. The FCW warnings must immediately direct the driver to evaluate and react to threats with sufficient time to perform some action to avoid or mitigate a potential crash. To achieve this, audible, visible, and possibly haptic cues will be employed. The ACC information must be presented so that the driver can easily determine the cruise control set speed, selected inter-vehicle separation, and whether or not a preceding vehicle has been detected by the system. For both functions, this information must be understandable at a glance by the driver and without adding extra workload to the driving task.

The primary visual interface for the FOT system will be a reconfigurable, high-resolution, full-color head-up display. During the first year of the program development of hardware began, including an agreement with a manufacturer for the visual display cells. To support development, a Buick LeSabre was procured as a test bench.

Candidate display formats were developed for three warning philosophies: a single-stage imminent alert, a two-stage warning, and a graded display with an imminent alert. The alternatives differ in the amount of information provided to the driver at times other than when immediate action is required. The differences may impact whether drivers are startled or annoyed by the warnings, and their vehicle following behavior. The graded display philosophy is the preferred alternative for the ACAS/FOT program, though interfaces for the other two approaches will be designed and evaluated in driving simulator and test track scenarios.

The warning philosophy alternatives will be refined by testing them using subjects in driving simulators, on test-tracks and public roads. A driving simulator at Delco was upgraded to support refinement of the visual aspects of the displays. Driving simulator tests conducted at the University of Iowa and on-road experiments at GM's Milford Proving Ground will also be used to provide empirical data to help refine warning timing and to select the final warning philosophy. Development of the test protocols has begun in collaboration with NHTSA. A DVI Warning Cue Implementation Summary Report will be submitted to NHTSA in February 2001.

Data Fusion

Data fusion algorithms will be used to provide estimates for road geometry using several sources of information. These sources of information include the vision sensor, scene tracking, yaw rate and speed sensors, and map-based road geometry estimation. Scene tracking is a technique to estimate road geometry by tracking the path of vehicles detected by the forward-radar sensor. Map-based road geometry estimates will be derived from data extracted from digital maps using GPS and dead reckoning to derive the vehicle's geographic location. Data fusion techniques will also be used to evaluate sensor information to modify the expected driver reaction time and braking intensity based upon the environmental conditions (rain, snow, day, night, etc.) and/or driver activity such as adjusting the climate control system.

During the first year of the program, requirements were developed and appropriate data fusion algorithmic approaches were selected. A new road model parameterization technique using multiple clothoids was developed and found to provide smaller errors than single-clothoid road models, particularly near transition between straight and curved road segments. Better road geometry estimates should translate into lower errors in distinguishing in-path targets from out-of-path targets.

Tracking and Identification

Target identification and selection uses the road geometry estimate to determine which radar returns are from objects that are (or will soon be) in the path of the vehicle. The selected targets are evaluated by the FCW function to decide whether to issue an alert. The Tracking and Identification Task includes development of the algorithms for scene tracking, map-based road geometry estimation, path estimation, target identification and selection.

In the first year of the program, the target identification algorithms were enhanced with improvements to the path prediction algorithm, lane change detection, and roadside distributed stopped object detection. These were tested with an improved tool for simulation of road scenarios. Scene tracking algorithm work included enhancement of the algorithms that handle vehicles that are not following the lanes, real-time implementation, and tuning with real-world radar target data. Map-based road geometry estimation work included completion of the sensor driver software and map data retrieval software. Limited testing of this software was completed with promising results. Assistware delivered a map enhancement approach in February 2000. This technology tracks the vehicle's route using a GPS receiver to augment the road geometry information in the map database.

To support development of the hardware and software Delphi Delco Electronics created three engineering development vehicles (EDV), by modifying them to provide the functionality of a rudimentary integrated ACC and FCW system.

CW Function

The CW Function Task includes In-Vehicle Threat Assessment Algorithm Development and Threat Assessment Simulation. The threat assessment algorithm assigns a threat level to the current situation based upon the motion of the project vehicle and each selected in-path target vehicle. Six threat assessment algorithms, including one developed by NHTSA, will be implemented and tested in simulations, on test tracks, and in real traffic. Work in the first year of the program included development and analytical evaluation of the algorithms.

The Threat Assessment Simulation is for refinement and evaluation of threat assessment algorithms. The University of California-PATH, using mathematical models of each function provided by GM, is developing it. Initial coding of the simulation was completed in August 2000.

Adaptive Cruise Control Function

The Adaptive Cruise Control Subsystem is a module from a future GM production program that includes the radar and ACC Controller. The Adaptive Cruise Control Function Task will provide the module as is for the 2002 Buick LeSabre and provide support for its integration with the rest of the ACC and FCW functions. The work is focussed on the interfaces between the module and other vehicle subsystems.

Fleet Vehicle Build

During Phase I of the program the Fleet Vehicle Build Task includes building and testing a GM Engineering Development Vehicle (GM EDV) and a Prototype Vehicle. The GM EDV is a 2000 Buick LeSabre with modifications to accommodate all the required instrumentation to investigate threat assessment, map-based path prediction, map database enhancement, and human factors. During the first year of the program the GM EDV vehicle was modified to incorporate required changes to the electrical and mechanical infrastructure, and software was developed for the interfaces. The system hardware was debugged and installed in the vehicle after which operation of the sensors was verified.

The Prototype Vehicle will integrate all the technologies developed by the partners in the program as a precursor to the Pilot Vehicles and finally the Deployment Vehicles. The

Prototype will have the functionality, but not necessarily the form factor, of the deployment vehicles. It will be used to verify the functionality of the ACC and FCW features during Phase I of the program. The Pilot Vehicles will have the functionality and form factor of the deployment vehicles and will be built during Phase II of the program. All materials to be installed in the Prototype Vehicle have been ordered and an early version of the ACC brake system has been installed. Installation of the remaining equipment will begin shortly and will require significant collaboration among the partners to complete.

Field Operational Test

The Field Operational Test (FOT) task includes preparation and execution of the test itself. In Phase I of the program this task includes planning and performing two stages of pilot tests, development of a Data Acquisition System (DAS) and developing the procedures, software, and a plan for execution of the FOT. Much of this work is being performed by University of Michigan Transportation Research Institute (UMTRI) staff, who will apply prior methodology and learning from the Intelligent Cruise Control (ICC) FOT, adapting the field-testing techniques to the ACAS platform.

In June of 2000, eight UMTRI staff with prior experience testing ACC systems evaluated one of the Delco EDVs over a 94-mile route. The ACC system was found to be highly operable and was successfully driven with the ACC engaged for approximately 90% of the mixed-route miles and for over 80% of the miles on surface streets. The intent was to explore and identify challenging conflict types that occur in the roadway environment.

Also during the first year of the program a Data Acquisition System that includes many, but not all, of the features and software of the eventual FOT package was successfully constructed and operated on the Delco EDV. The system collected many of the variables required for the FOT including the multi-target radar data. This operation confirmed the readiness of the DAS for handling the tasks of data collection in the FOT.

1.2 Major Milestones and Deliverables

Table 1.2 shows the major milestones that were accomplished during the first year of the program. Table 1.3 shows the milestones for the remainder of the year.

Table 1.2 Summary of Program Milestones Completed

Milestone	Task	Phase I Milestone Description	Completion Date
1	A	CW Architecture Definition	Dec 99
4	B2	Lane Tracking “Kick-Off” Meeting	Aug 99
7	B3	Brake System Design	Apr 00
9	B5	DVI Technology Exchange “Kick-Off” Meeting	Aug 99
12	C1	Data Fusion Architecture and Performance Requirements Definition	Sep 99
15	C3	Threat Assessment Technology Exchange “Kick-Off” Meeting	Aug 99
19	E	Submission Of FOT Pilot Test Plan	Jan 00
23	F	ACAS/FOT “Kick-Off” Program Team Meeting	Jul 99
24	F	ACAS/FOT “Kick-Off” Meeting	Aug 99
25	F	ACAS/FOT Program Review Briefing 1	Jan 00
26	F	ACAS/FOT Program Review Briefing 2	Jul 00

Table 1.3 Summary of Program Milestones Due Through 2000

Milestone	Task	Phase I Milestone Description	Due Date
2	A	CW Verification Plan	Sep 00
5	B2	Lane Tracking Technology Down-Select Meeting	Sep 00
10	B5	DVI Warning Cue Set Selection	Nov 00
13	C1	Preliminary Data Fusion Algorithm Simulation Demonstration	Nov 00
20	E	Completion Of FOT Professional Pilot, Testing & Data Processing	Nov 00

Table 1.4 below shows the deliverables that were submitted to NHTSA during the first year of the program. Table 1.5 shows the remaining deliverable to be submitted this year.

Table 1.4. Summary of Program Deliverables Completed

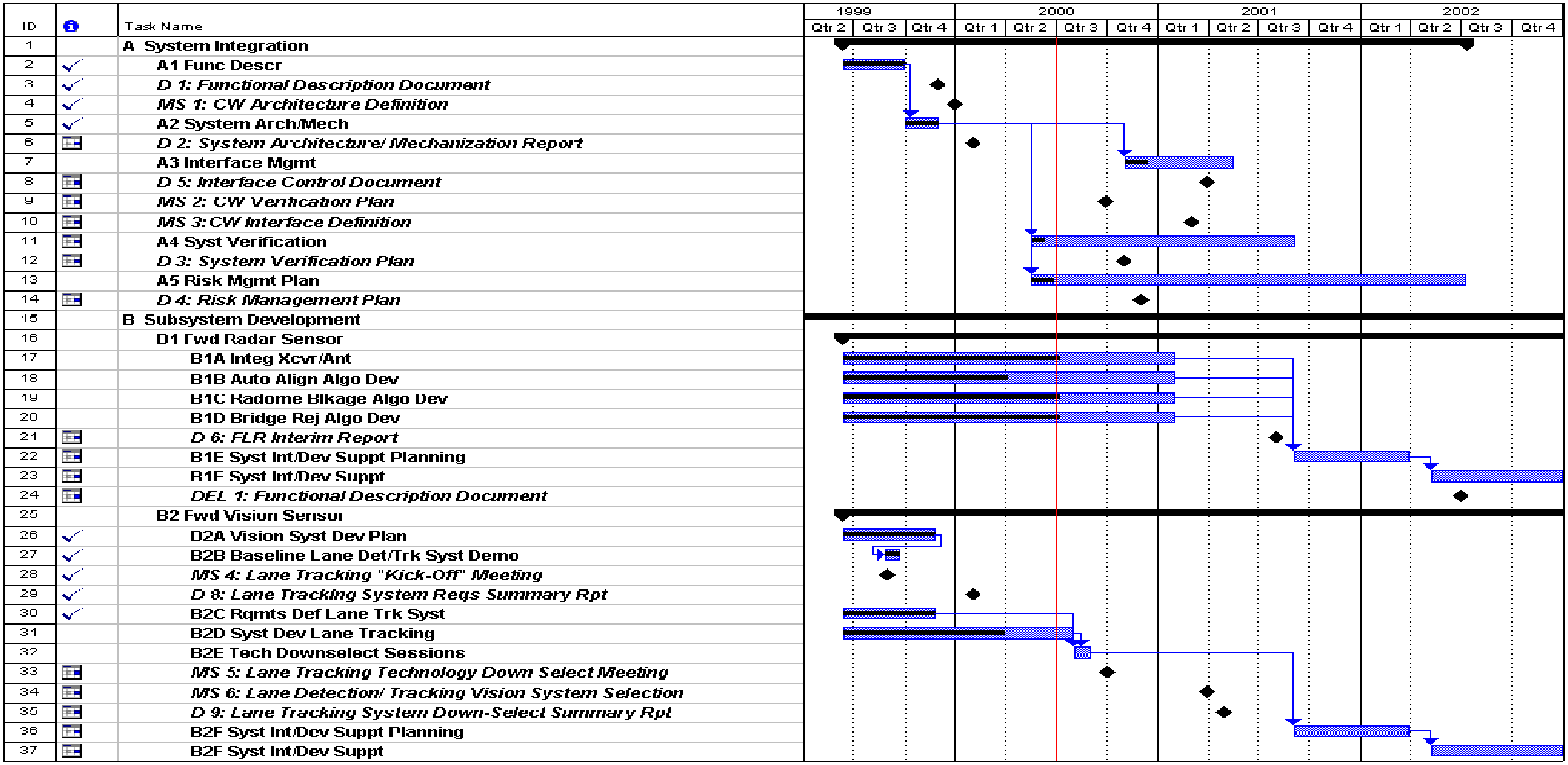
Deliverable	Task	Phase I Deliverable Description	Completion Date
1	A	Functional Description Document	Nov 99
2	A	System Architecture/Mechanization Report	Jan 00
7	B2	Lane Tracking System Requirements Summary Report	Jan 00
9	B3	Brake Actuator System Design Summary Report	Jun 00
17	E	FOT Pilot Test Plan	Jan 00
20	F	ACAS/FOT Program Schedule	Aug 99

Table 1.5 Summary of Program Deliverables Due Through 2000

Deliverable	Task	Phase I Deliverable Description	Due Date
3	A	System Verification Plan	Oct 00
4	A	Risk Management Plan	Nov 00
18	E	FOT First HURP Request	Nov 00
21	F	ACAS/FOT “Kick-Off” Meeting Briefing Package	Sep 99
22	F	ACAS/FOT Program Review 1 Briefing & Program Plan Package	Feb 00
23	F	ACAS/FOT Program Review 2 Briefing & Program Plan Package	Aug 00
24	F	ACAS/FOT First Annual Report	Sep 00

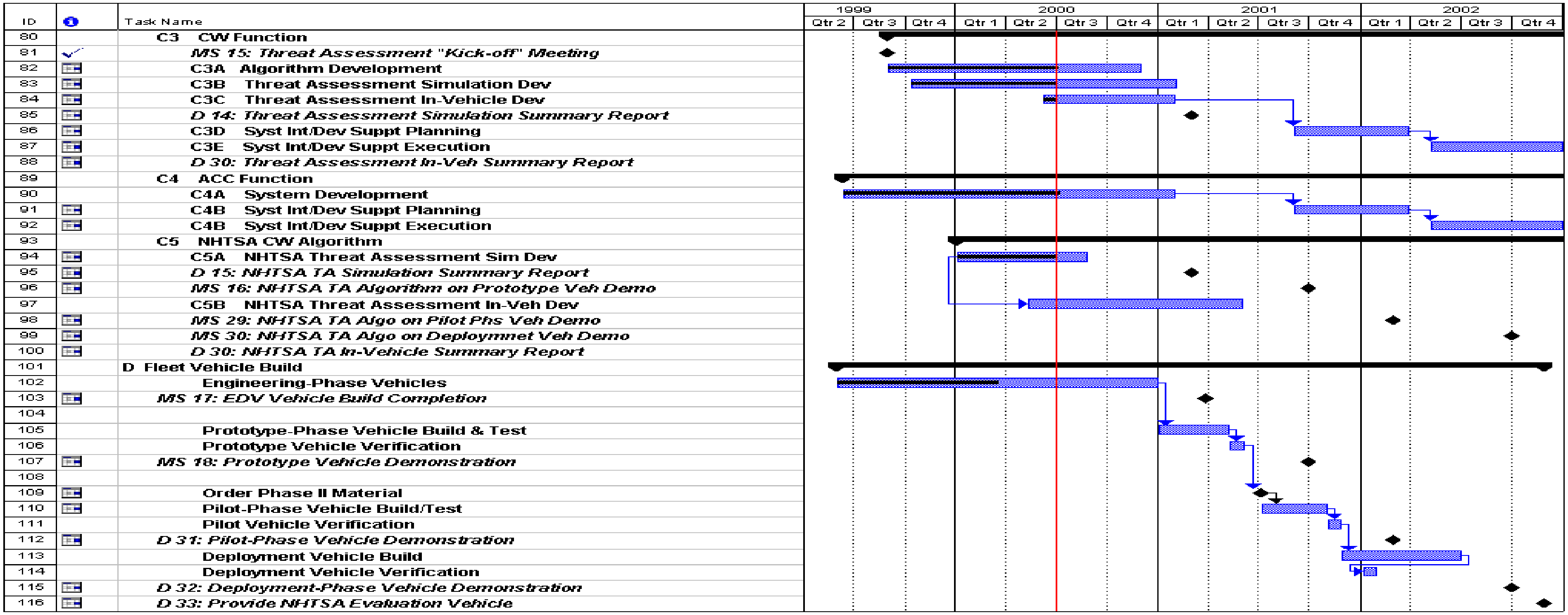
1.3 Master Program Schedule

Figures 1.1 through 1.5 show a top-level program schedule. The schedules show work completed through the end of June 2000. A more detailed schedule is provided in each Task Section.



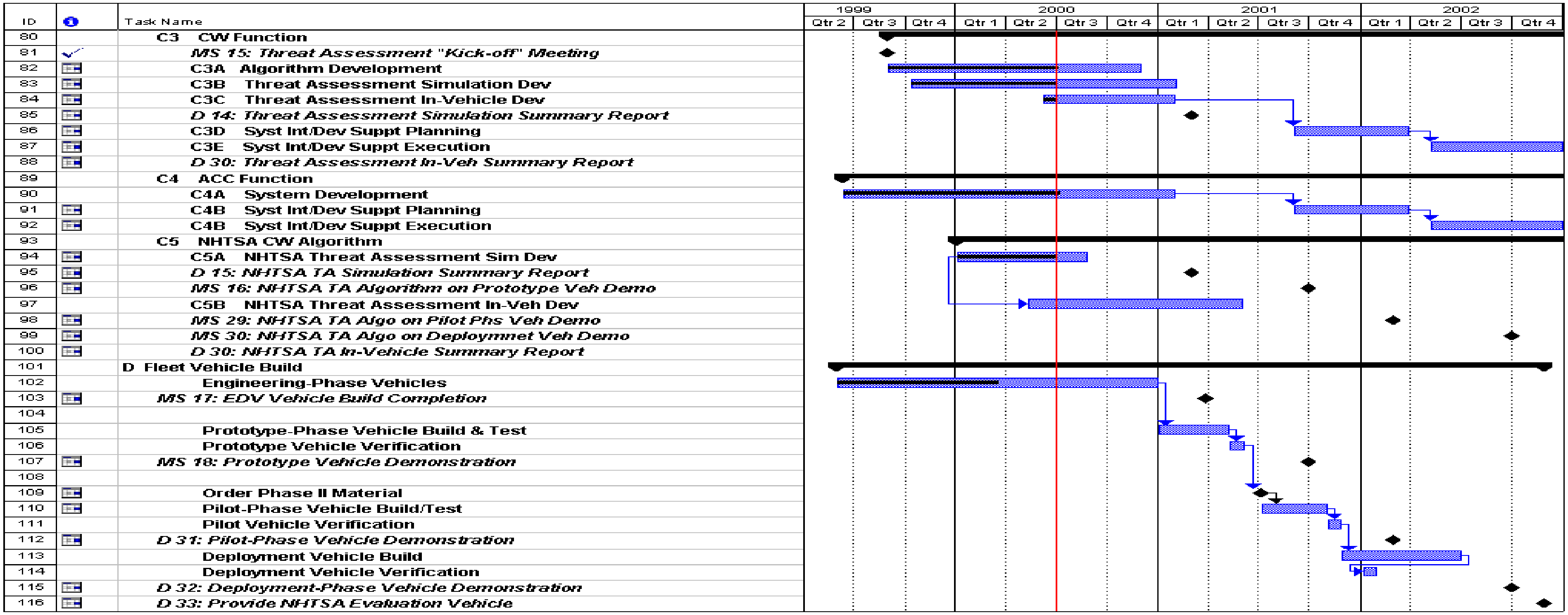
ID	ℹ	Task Name
1		**A System Integration**
2	✓	**A1 Func Descr**
3	✓	***D 1: Functional Description Document***
4	✓	***MS 1: CW Architecture Definition***
5	✓	**A2 System Arch/Mech**
6	▦	***D 2: System Architecture/ Mechanization Report***
7		**A3 Interface Mgmt**
8	▦	***D 5: Interface Control Document***
9	▦	***MS 2: CW Verification Plan***
10	▦	***MS 3:CW Interface Definition***
11	▦	**A4 Syst Verification**
12	▦	***D 3: System Verification Plan***
13		**A5 Risk Mgmt Plan**
14	▦	***D 4: Risk Management Plan***
15		**B Subsystem Development**
16		**B1 Fwd Radar Sensor**
17		**B1A Integ Xcvr/Ant**
18		**B1B Auto Align Algo Dev**
19		**B1C Radome Blkage Algo Dev**
20		**B1D Bridge Rej Algo Dev**
21	▦	***D 6: FLR Interim Report***
22	▦	**B1E Syst Int/Dev Suppt Planning**
23	▦	**B1E Syst Int/Dev Suppt**
24	▦	***DEL 1: Functional Description Document***
25		**B2 Fwd Vision Sensor**
26	✓	**B2A Vision Syst Dev Plan**
27	✓	**B2B Baseline Lane Det/Trk Syst Demo**
28	✓	***MS 4: Lane Tracking "Kick-Off" Meeting***
29	✓	***D 8: Lane Tracking System Reqs Summary Rpt***
30	✓	**B2C Rqmts Def Lane Trk Syst**
31		**B2D Syst Dev Lane Tracking**
32		**B2E Tech Downselect Sessions**
33	▦	***MS 5: Lane Tracking Technology Down Select Meeting***
34	▦	***MS 6: Lane Detection/ Tracking Vision System Selection***
35	▦	***D 9: Lane Tracking System Down-Select Summary Rpt***
36	▦	**B2F Syst Int/Dev Suppt Planning**
37	▦	**B2F Syst Int/Dev Suppt**

Figure 1.1 Master Program Schedule, Page 1



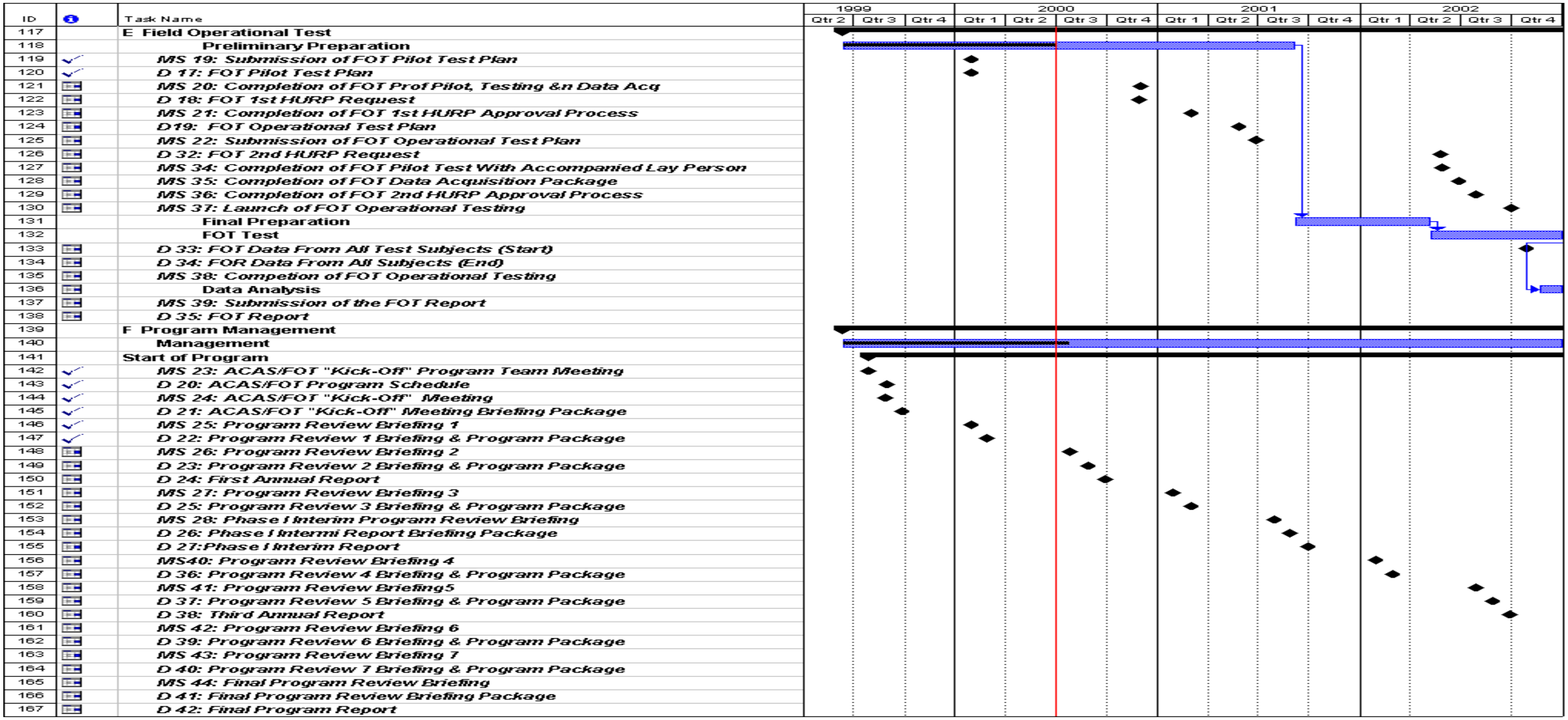
ID	ℹ	Task Name
80		C3 CW Function
81	✓	*MS 15: Threat Assessment "Kick-off" Meeting*
82	▦	C3A Algorithm Development
83	▦	C3B Threat Assessment Simulation Dev
84	▦	C3C Threat Assessment In-Vehicle Dev
85	▦	*D 14: Threat Assessment Simulation Summary Report*
86	▦	C3D Syst Int/Dev Suppt Planning
87	▦	C3E Syst Int/Dev Suppt Execution
88	▦	*D 30: Threat Assessment In-Veh Summary Report*
89		C4 ACC Function
90		C4A System Development
91	▦	C4B Syst Int/Dev Suppt Planning
92	▦	C4B Syst Int/Dev Suppt Execution
93		C5 NHTSA CW Algorithm
94	▦	C5A NHTSA Threat Assessment Sim Dev
95	▦	*D 15: NHTSA TA Simulation Summary Report*
96	▦	*MS 16: NHTSA TA Algorithm on Prototype Veh Demo*
97		C5B NHTSA Threat Assessment In-Veh Dev
98	▦	*MS 29: NHTSA TA Algo on Pilot Phs Veh Demo*
99	▦	*MS 30: NHTSA TA Algo on Deploymnet Veh Demo*
100	▦	*D 30: NHTSA TA In-Vehicle Summary Report*
101		D Fleet Vehicle Build
102		Engineering-Phase Vehicles
103	▦	*MS 17: EDV Vehicle Build Completion*
104		
105		Prototype-Phase Vehicle Build & Test
106		Prototype Vehicle Verification
107	▦	*MS 18: Prototype Vehicle Demonstration*
108		
109	▦	Order Phase II Material
110	▦	Pilot-Phase Vehicle Build/Test
111		Pilot Vehicle Verification
112	▦	*D 31: Pilot-Phase Vehicle Demonstration*
113		Deployment Vehicle Build
114		Deployment Vehicle Verification
115	▦	*D 32: Deployment-Phase Vehicle Demonstration*
116	▦	*D 33: Provide NHTSA Evaluation Vehicle*

Figure 1.2 Master Program Schedule, Page 2



ID	ⓘ	Task Name
80		C3 CW Function
81	✓	*MS 15: Threat Assessment "Kick-off" Meeting*
82	▦	C3A Algorithm Development
83	▦	C3B Threat Assessment Simulation Dev
84	▦	C3C Threat Assessment In-Vehicle Dev
85	▦	*D 14: Threat Assessment Simulation Summary Report*
86	▦	C3D Syst Int/Dev Suppt Planning
87	▦	C3E Syst Int/Dev Suppt Execution
88	▦	*D 30: Threat Assessment In-Veh Summary Report*
89		C4 ACC Function
90		C4A System Development
91	▦	C4B Syst Int/Dev Suppt Planning
92	▦	C4B Syst Int/Dev Suppt Execution
93		C5 NHTSA CW Algorithm
94	▦	C5A NHTSA Threat Assessment Sim Dev
95	▦	*D 15: NHTSA TA Simulation Summary Report*
96	▦	*MS 16: NHTSA TA Algorithm on Prototype Veh Demo*
97		C5B NHTSA Threat Assessment In-Veh Dev
98	▦	*MS 29: NHTSA TA Algo on Pilot Phs Veh Demo*
99	▦	*MS 30: NHTSA TA Algo on Deploymnet Veh Demo*
100	▦	*D 30: NHTSA TA In-Vehicle Summary Report*
101		D Fleet Vehicle Build
102		Engineering-Phase Vehicles
103	▦	*MS 17: EDV Vehicle Build Completion*
104		
105		Prototype-Phase Vehicle Build & Test
106		Prototype Vehicle Verification
107	▦	*MS 18: Prototype Vehicle Demonstration*
108		
109	▦	Order Phase II Material
110	▦	Pilot-Phase Vehicle Build/Test
111		Pilot Vehicle Verification
112	▦	*D 31: Pilot-Phase Vehicle Demonstration*
113		Deployment Vehicle Build
114		Deployment Vehicle Verification
115	▦	*D 32: Deployment-Phase Vehicle Demonstration*
116	▦	*D 33: Provide NHTSA Evaluation Vehicle*

Figure 1.3 Master Program Schedule, Page 3



ID	ℹ	Task Name
117		E Field Operational Test
118		Preliminary Preparation
119	✓	*MS 19: Submission of FOT Pilot Test Plan*
120	✓	*D 17: FOT Pilot Test Plan*
121	▦	*MS 20: Completion of FOT Prof Pilot, Testing &n Data Acq*
122	▦	*D 18: FOT 1st HURP Request*
123	▦	*MS 21: Completion of FOT 1st HURP Approval Process*
124	▦	*D19: FOT Operational Test Plan*
125	▦	*MS 22: Submission of FOT Operational Test Plan*
126	▦	*D 32: FOT 2nd HURP Request*
127	▦	*MS 34: Completion of FOT Pilot Test With Accompanied Lay Person*
128	▦	*MS 35: Completion of FOT Data Acquisition Package*
129	▦	*MS 36: Completion of FOT 2nd HURP Approval Process*
130	▦	*MS 37: Launch of FOT Operational Testing*
131		Final Preparation
132		FOT Test
133	▦	*D 33: FOT Data From All Test Subjects (Start)*
134	▦	*D 34: FOR Data From All Subjects (End)*
135	▦	*MS 38: Competion of FOT Operational Testing*
136	▦	Data Analysis
137	▦	*MS 39: Submission of the FOT Report*
138	▦	*D 35: FOT Report*
139		F Program Management
140		Management
141		Start of Program
142	✓	*MS 23: ACAS/FOT "Kick-Off" Program Team Meeting*
143	✓	*D 20: ACAS/FOT Program Schedule*
144	✓	*MS 24: ACAS/FOT "Kick-Off" Meeting*
145	✓	*D 21: ACAS/FOT "Kick-Off" Meeting Briefing Package*
146	✓	*MS 25: Program Review Briefing 1*
147	✓	*D 22: Program Review 1 Briefing & Program Package*
148	▦	*MS 26: Program Review Briefing 2*
149	▦	*D 23: Program Review 2 Briefing & Program Package*
150	▦	*D 24: First Annual Report*
151	▦	*MS 27: Program Review Briefing 3*
152	▦	*D 25: Program Review 3 Briefing & Program Package*
153	▦	*MS 28: Phase I Interim Program Review Briefing*
154	▦	*D 26: Phase I Intermi Report Briefing Package*
155	▦	*D 27:Phase I Interim Report*
156	▦	*MS40: Program Review Briefing 4*
157	▦	*D 36: Program Review 4 Briefing & Program Package*
158	▦	*MS 41: Program Review Briefing5*
159	▦	*D 37: Program Review 5 Briefing & Program Package*
160	▦	*D 38: Third Annual Report*
161	▦	*MS 42: Program Review Briefing 6*
162	▦	*D 39: Program Review 6 Briefing & Program Package*
163	▦	*MS 43: Program Review Briefing 7*
164	▦	*D 40: Program Review 7 Briefing & Program Package*
165	▦	*MS 44: Final Program Review Briefing*
166	▦	*D 41: Final Program Review Briefing Package*
167	▦	*D 42: Final Program Report*

Figure 1.4 Master Program Schedule, Page 4

2 INTRODUCTION

2.1 Program Review

General Motors Corporation and Delphi-Delco Electronics Systems have joined together to establish a Program Team in order to pursue the next logical progression in advancing the science of automotive safety in the field of Collision Warning (CW) systems. This Team will conduct a Field Operational Test (FOT) of an automotive collision warning system. The 59 month program will implement an extensive field operational test plan which is designed to assess the impact of an integrated Forward Collision Warning (FCW) system by giving volunteers from the general driving public unsupervised, unrestricted use of a host vehicle for a period of time. The integrated collision warning system will incorporate the functionality of both FCW and Adaptive Cruise Control (ACC). The FCW functionality will be effective in detecting, assessing, and alerting the driver of potential hazard conditions associated with rear-end crash events in the forward region of the Host vehicle. The ACC function will provide active vehicle actuation (brake and throttle control) in response to maintaining a specified longitudinal headway control. The Program Team will design and build ten passenger-style host vehicles, which are equipped with a collision warning vehicle package and an unobtrusive data acquisition system, which will support the field operational test.

The FOT is the natural next step of the technology development cycle that was initiated with the Automotive Collision Avoidance System (ACAS) Development Program. This program was sponsored through the Technology Reinvestment Project (TRP) and administered by the National Highway Traffic Safety Administration (NHTSA) between January 1995 and October 1997. Delphi-Delco Electronics Systems (DDE) and General Motors (GM) were major participants of the eight-member ACAS Consortium. Additionally, DDE led the ACAS Consortium. The primary objective of the ACAS Program was to accelerate the commercial availability of key collision warning countermeasure technologies, through either improved manufacturing processes or accelerated technology development activities. The next logical technical progression of the product development cycle was the upward integration of these ACAS-developed essential building blocks to form a complete seamless vehicle system that will be evaluated through a field operational test program.

It is apparent that the introduction of Adaptive Cruise Control (ACC) systems is imminent. Therefore, posing the notion of a field operational test of the collision warning technology at this time is apropos. An extensive, comprehensive collision warning FOT has never been undertaken in the United States (or anywhere else for that matter). As such, very few studies exist which adequately understand the relationship between system performance capability, user acceptance, and safety benefits based on involvement by the general driving public. This test program provides an ideal opportunity for the

Government, industry, and ITS community to gain a more thorough understanding of the requirements, functions and societal impact of this technology. Additionally, any potential adverse operational and safety-related issues could be identified, analyzed, and addressed while the technology is still in the early stages of product development. This program has the opportunity to make a positive contribution in the development of this technology.

The derived benefits of performing a collision warning field operational test are many. At this time, credible collision warning related data is spotty, incomplete, and certainly not comprehensive. This program effort will be the first attempt to gather some of this much-needed data. The Government will gain some understanding in assessing the benefits of collision warning systems. Therefore, the benefits of a meaningful clinical examination of a collision warning system is expected to provide data regarding:

1. Identifying any potential adverse operational and safety-related issues.
2. Evaluating the maturity of the proposed system design synthesis and mechanization.
3. Obtaining a broad range of market-based data with respect to system perception and appraisal provided by a diverse group of lay-person driving population, such as: perceived value, perceived cost, customer acceptance, product maturity, etc.
4. Identifying potential key system features that may require an industry consensus or perhaps require adoption of standards and/or practices in order to expedite and facilitate system commercialization.

2.2 Objectives

The main mission of the ACAS/FOT Program is to identify key enabling technologies that can accelerate the development of a cohesive collision warning vehicle package which in turn can be used to assess the technological impact of a collision warning system through a comprehensive field operational test program. The performance of the cohesive collision warning vehicle package will be of sufficient fidelity, robustness, and maturity so that a meaningful field operational test program can be executed.

In support of this mission, other secondary goals and objectives are also specified which will provide focus to the technology design process and facilitate advancing the science of automotive safety. Specifically, they are to:

1. Form a team that has demonstrated expertise and capability in the technology, manufacturing, and marketing of collision avoidance products.
2. Leverage, capitalize, and exploit existing high-value developed portfolio of ACC and FCW technologies/component for implementation in the proposed ACAS/FOT Program. Of primary interest are the achieved successes from the initial ACAS Program and the recent development activities of other NHTSA/FHWA sponsored programs. These activities will provide value added

program benefits by minimizing new learning curve experiences, preventing duplication of efforts, streamlining the system design process, and accelerating the activities of the proposed program.

3. Incorporate human factors into the design process. Of primary interest are the successes achieved from the initial ACAS Program and the recent development activities of other NHTSA/FHWA sponsored programs of relevance.
4. Utilize system engineering design procedures and practices to focus the accelerated development of a validated comprehensive collision warning system that is seamlessly upward integrated into the vehicle infrastructure. The tested and validated design will be used to produce a fleet of ten deployment vehicles for use in the field operational test program.

2.3 Approach

In support of achieving a successful field operational test, the ACAS/FOT Program has assembled a highly focused technical activity with the goal of developing a comprehensive FCW system that is seamlessly integrated into the vehicle infrastructure. The performance of the cohesive collision warning vehicle package will be of sufficient fidelity, robustness, and maturity so that a meaningful field operational test program can be executed. The FCW system will incorporate the combined ACC & rear-end CW functionality. The ACC feature will only be operational when engaged by the driver. On the other hand, the FCW feature will provide full-time operating functionality whenever the host vehicle is in use (above a certain minimum speed). This feature will be effective in detecting, assessing, and alerting the driver of potential hazard conditions associated with rear-end crash events in the forward region of the host vehicle. This will be accomplished by implementing an expandable system architecture that uses a combination of: (a) a long range forward radar-based sensor that is capable of detecting and tracking vehicular traffic, and (b) a forward vision-based sensor which detects and tracks lanes. The proposed program effort is focused on providing warnings to the driver, rather than taking active control of the vehicle.

Due to the complexity and breadth of the system goals, the on-going design process has heavily relied on using the established principles of system engineering as a framework to guide this highly focused deployment design effort. As such, the technical activities of the program can be grouped into four main activities within two phases. Phase I started immediately after program inception in, June 1999, and will last approximately 27 months. Phase II will start immediately after the end of Phase I. The objective is that the two program phases will be continuous with minimal disruption of program flow and continuity between them. Consequently, activities that enable the continuous workflow into Phase II will be initiated during Phase I. The program phases are summarized as:

Phase I

1. Development - The program will initially focus on a variety of activities associated with the enhancement, improvement, and maturation processes applied to existing FCW technologies/components that were developed during the ACAS Program, while accelerating the development of other key subsystems,
2. Integration - The refined FCW portfolio of technologies/components will be upwardly integrated into the vehicle platform infrastructure to form a comprehensive rear-end collision warning system,

Phase II

3. Deployment Fleet - The validated design will be used to build a deployment fleet of ten vehicles equipped with the system; and
4. Field Operational Test - The culmination of this program activity will be the design and implementation of the FOT plan. The deployment vehicle fleet will be used to collect valuable market research data in order to assess/validate the technology, product maturity, and general public perception.

A more detailed discussion of these program activities is provided by Task in the remaining portion of this report.

3 SYSTEM INTEGRATION (TASK A)

The ACAS Team has been following the GM Vehicle Development Process to ensure that a robust, safe vehicle is provided for the field operational test. Task A consists of the following Subtasks, which are discussed in this Section.

1. Functional Description (Task A1)
2. System Architecture/Mechanization (Task A2)
3. Interface Management (Task A3)
4. System Verification (Task A4)
5. Risk Management Plan (Task A5)

Milestones and Deliverables for Task A are summarized below. The overall schedule for Task A is given at the end of Section 3.

<u>Milestones and Deliverables</u>
The CW Architecture Definition was completed in December 1999. The Functional Description Document was delivered in December 1999 followed by the System Architecture and Mechanization Report in January 2000.

3.1 Functional Description (Task A1)

<u>Objectives</u>
The purpose of this Subtask is to:

1. Capture the system functional requirements
2. Allocate system functional requirements to subsystems and components

<u>Approach</u>
The approach for this task is based on the work of Hatley-Pirbhai [Strategies for Real-Time System Specification, 1988, Doerst House Publishing Co.]. System Requirement, Architecture and Specification models are developed using the Process Model (Data Context Diagram and Data Flow Diagram) and the Control Model (Control Context Diagram and Control Flow Diagram). Here functions are presented as bubbles with Data and Control Flows indicating their interactions.

<u>Work Accomplished and Research Findings</u>
The following paragraphs provide a description of the controls, displays and operating modes that will be provided for the ACC and FCW systems.

System Functional Description

The vehicle will provide an adaptive cruise control capability that:

a. Detects and tracks motor vehicles in its forward path,
b. Maintains the selected cruise speed when there is no vehicle limiting its forward motion,
c. Maintains a selected headway between the host vehicle and a lead vehicle, which is traveling slower than the selected cruise speed and thus limiting the forward motion of the host vehicle.

The ACC Subsystem will provide operating modes similar to conventional cruise control with the following additional features:

a. For the purposes of the FOT, the cruise control may be commanded to operate like a conventional cruise control. The conventional cruise control mode will be maintained until conditions specified by the ACAS/FOT engineers cause it to change to adaptive cruise mode.
b. When active, the ACC will have two modes, maintaining the set speed and maintaining the selected headway.
c. When maintaining headway, the system will be capable of slowing the vehicle to pace a moving lead vehicle that is traveling slower than the set speed.
d. Once the ACC Subsystem slows the host vehicle below the minimum cruise speed, a message will indicate that the driver should take full control of the vehicle. The system will not command the host vehicle to accelerate until the driver manually accelerates above the minimum set speed and then initiates the resume function or the set speed function.

The primary driver interface to engage and operate the ACC function will consist of the standard production cruise controls and a headway selection switch. Using this interface, the driver will be provided with the following capabilities:

a. Turn the ACC On and Off
b. Set the desired cruise speed (set speed)
c. Increase Set Speed by fixed steps
d. Decrease Set Speed by fixed steps
e. Accelerate to a new set speed
f. Coast (decelerate) to a new set speed
g. Resume a previously set speed
h. Set the desired headway (Headway Adjustment)

Additionally, the accelerator pedal may be used to over-throttle the ACC system. As in standard cruise control, manual braking shall cause the system to go to standby mode. When the ACC is first turned on, the initial headway setting will be set to the maximum.

The primary ACC Subsystem display will be in a head-up display. The primary ACC display will include the following information:

a. ACC On/Off
b. Set Speed
c. Current Speed
d. Tracking/Not Tracking a Lead Vehicle
e. ACC Operational/Failed

The vehicle will provide a forward collision warning capability that will provide alerts and advisory displays to assist drivers in avoiding or reducing the severity of crashes involving the equipped vehicle striking the rear-end of another motor vehicle. For the purposes of the FOT, the FCW will have enabled and disabled modes. The FCW will be enabled and disabled when conditions specified by the ACAS/FOT engineers are met using the same mechanism that enables and disables the adaptive capability of the cruise control. The driver will not be able to disable the FCW, but the driver will be provided with a control to adjust the sensitivity (alert range) of the FCW function. The sensitivity adjustment will not permit the FCW function to be disabled by the vehicle operator.

The FCW crash warnings will include visual, auditory, and perhaps haptic cues to the driver. The FCW crash warning should be sufficiently conspicuous and interpretable to support timely return of an inattentive driver to active driving involvement under conditions where the system determines that driver involvement may be lacking**.** The visual indicator will support the driver in maintaining a safe distance behind other motor vehicles.

The process model, functional diagrams, and descriptions resulting from work performed under this Subtask can be found in Appendix A. The process model shows the functional decomposition of the system through data and control flow diagrams.

Modality Tables

The Advanced Features Disabled/Enabled modes (Table 3.1) are used in the field operational test. The advanced features include the adaptive capability of the ACC and the FCW features. The advanced features will be disabled when the vehicle is initially provided to each subject. After a preset condition, and while the vehicle is not in use, the advanced features will be enabled.

Table 3.1 Advanced Features Disabled/Enabled Modes

Disabled	The cruise control system operates like a conventional cruise control system. No collision warnings are provided. No displays associated with the adaptive cruise capabilities or the collision warning functions are provided. The system is put in this state before the vehicle is provided to each subject.
Enabled	The adaptive capability of the cruise control system is available and the collision warning functions are provided. The system goes into this mode when predefined conditions are met. Generally this would be at night one week after the vehicle is turned over to a subject but only when the vehicle is not being operated.

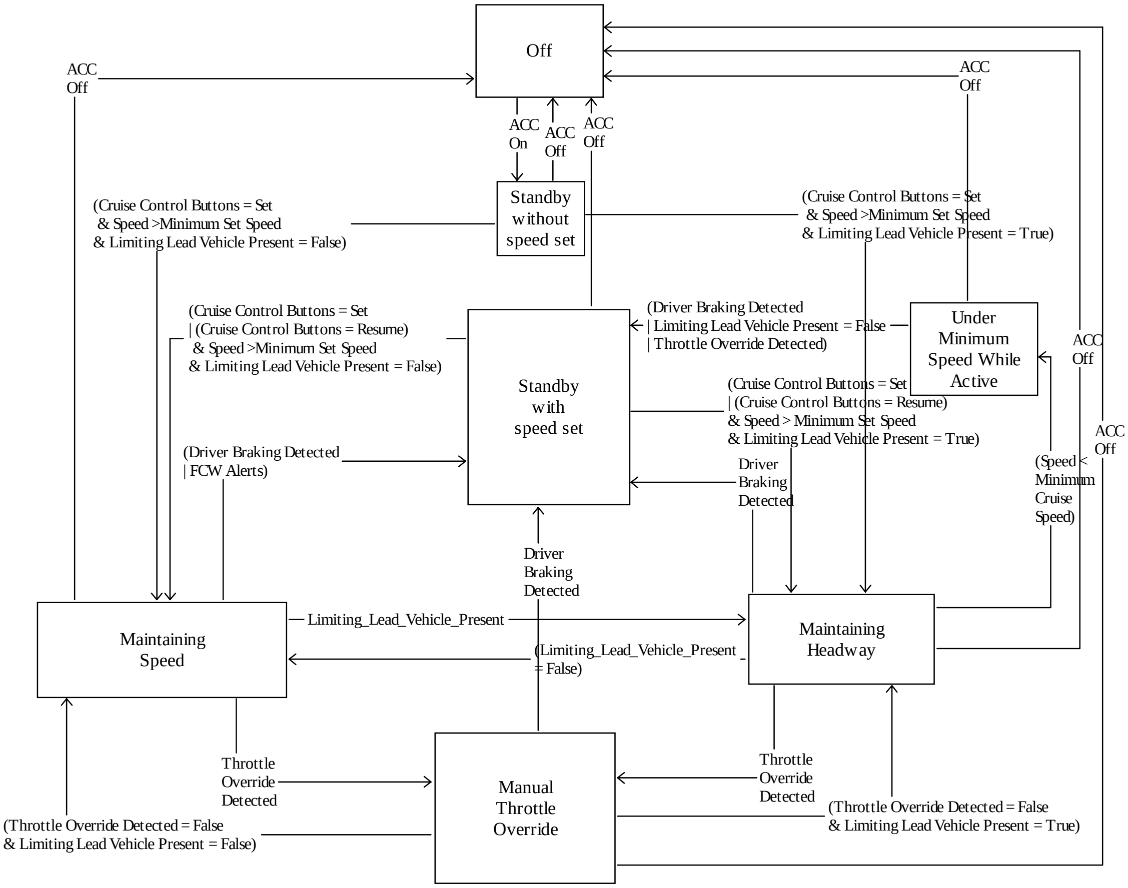
The FCW algorithms (Table 3.2) depend upon whether the ACC is active. The ACC is considered to be active in the Maintain Speed or Maintain Headway modes.

Table 3.2 FCW Modes

FCW with ACC Inactive	In this mode the FCW does not expect the ACC to provide any braking.
FCW with ACC Active	In this mode the FCW warning algorithm takes into account the braking function that the ACC can provide. An alert is produced if the ACC braking authority is inadequate to prevent a collision.

Cruise Control Modes-Adaptive Cruise Control Enabled

The cruise control behaves like a standard cruise control system until the adaptive features are enabled (Table 3.3). Figure 3.1 shows the states and transitions for the cruise control when the adaptive features are enabled.



STD: ACC Vehicle Controls.c

Figure 3.1 ACC Vehicle Controls

Table 3.3 Adaptive Cruise Control Modes

ACC Off	The ACC system is not functional. This state is entered whenever the ignition is on and the ACC is turned off.
Standby without speed set	The system is waiting to take control of the throttle and brakes. This state is entered when the ignition is turned on and the ACC is turned on. From this state the system can be activated by pressing the set button after the vehicle has reached the minimum set speed.
Standby with speed set	The system is waiting to take control of the throttle and brakes. A set speed has been established previously.
Maintaining Speed	In this mode the ACC system attempts to reach and hold a specified speed. While in this mode the set speed can be increased or decreased by pushing or tapping on the resume/accel or set/coast buttons.
Maintaining Headway	In this mode the ACC system attempts to reach and hold a specified headway. While in this mode the set speed can be increased or decreased by pushing or tapping on the resume/accel or set/coast buttons.
Manual Throttle Override	In this mode the driver is pushing on the throttle to force the vehicle to go faster than the cruise control function would command.
Under Minimum Speed While Active	In this mode the ACC has reduced the vehicle speed below a minimum cruise speed because a slow vehicle is ahead. Once this happens the ACC will not cause the vehicle to accelerate. When this state is entered the driver is given a message to take control of the vehicle.

Subsystem/Component Partition Diagram

Table 3.4 below lists the system modules and their primitive functions. The left column lists the physical modules and the right column lists the primitive functions performed by the software in each module. The connections between the modules are shown in Figure 3.2. A more detailed description of the primitive functions is given in Appendix A.

Table 3.4 System Modules and Their Primitive Functions

Architecture Module	**Function**
Scene Tracking	Scene Tracking
Path Prediction & Target Selection	Yaw-Based Path Estimation Lane Position Estimation Target Selection
Map-based Road Geometry	Map-Based Road Geometry Estimation
FCW Processor	All of the Data Fusion Functions Threat Assessment
ACC Controller	ACC Vehicle Controls
Data Acquisition System (DAS)	All of the Data Acquisition Functions
Radar	Target Detection Multi-Target Tracking Target Classification Auto-alignment and Blockage Detection
Vision	Vision-Based Lane Tracking
Vehicle Sensor Filtering & Interface	Vehicle Sensor Filtering
Driver Vehicle Interface (DVI)	Driver-Vehicle Interface function

<u>Plans through December 2000</u>

This work is essentially complete and we foresee only minor changes in the future.

3.2 System Architecture/Mechanization (Task A2)

Objectives
The main objectives of this Subtask are to:

1. Partition the system into subsystems and components
2. Allocate functional requirements to the subsystems and components
3. Designate interfaces among the subsystems and components

Approach
Following the structured method of Hatley and Pirbhai, the total vehicle, with all its embedded systems, was considered as one supersystem. All our functional requirements must fit and be allocated to a well-defined physical structure, interconnected by communication buses with appropriate protocols meeting safety, maintainability and reliability requirements.

The supersystem was partitioned into physical boxes which, in their totality, satisfy all the functional requirements in an optimum way. Processes in our requirement model are allocated to slots in the architecture model.

Work Accomplished and Research Findings
Figure 3.2 shows the physical architecture, subsystems and components of the system with connections and buses between the processors. This mechanization provides the top-level hardware required for the Prototype Vehicle and the flow and sources of information from and for each physical box (block). The functional interaction between the blocks as well as the internal functions of each block has been explained in Section 3.1. The main information artery is a high-speed CAN Bus (500kbs) which transfers a large body of communication messages among the subsystems or the components. Additionally, a GM Class 2 Bus provides information linkage from the vehicle-based signals to all subsystems requesting such signals, either directly or indirectly via the CAN Bus. Other harnesses are direct wires.

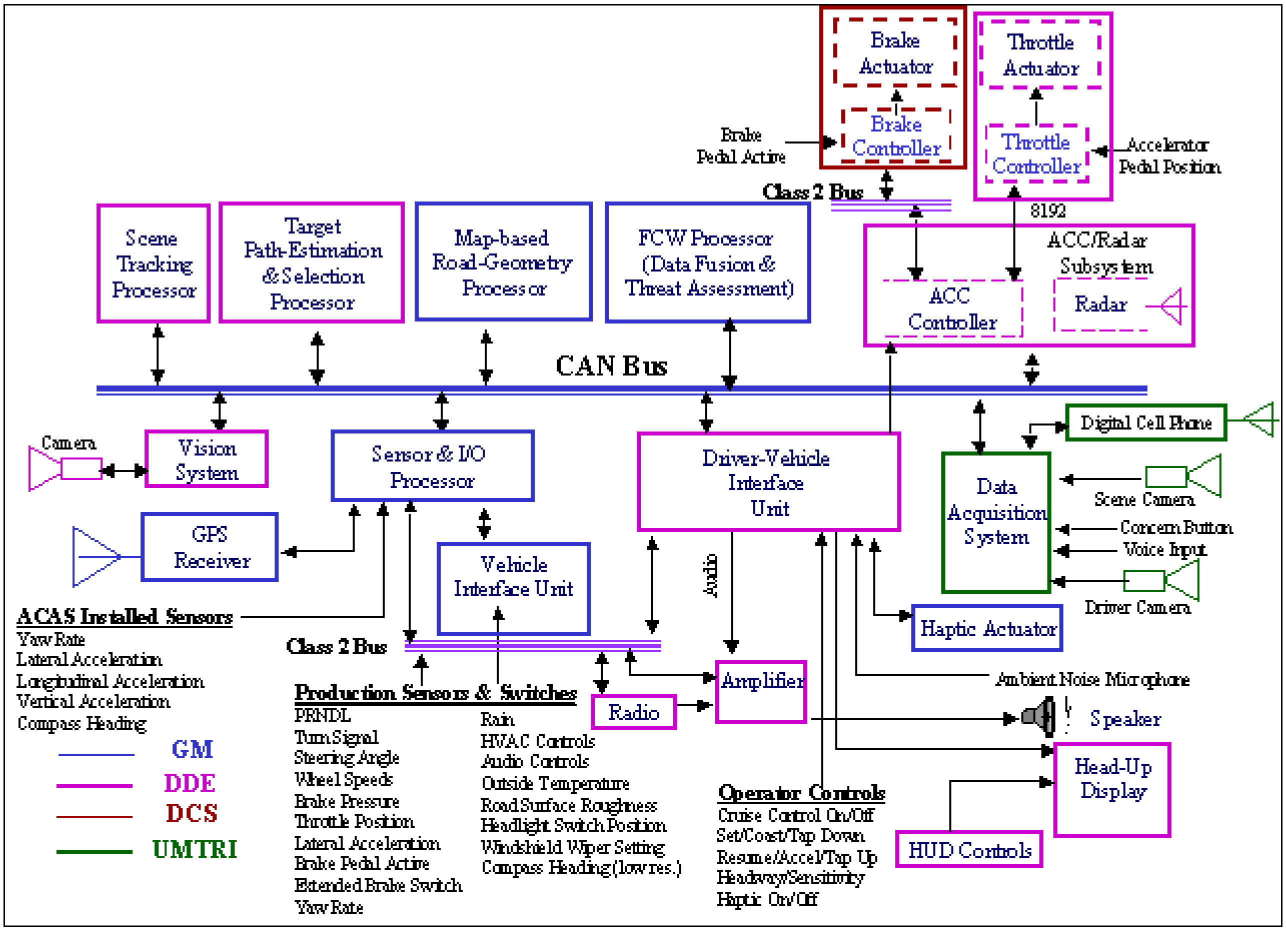


Figure 3.2 Prototype Vehicle System Block Diagram & Mechanization

Plans through December 2000

This work is essentially complete and we foresee only minor changes in the future.

3.3 Interface Management (Task A3)

Objectives

The main objective of the Interface Management Task is to ensure that subsystems or components developed independently satisfy the prescribed requirements and operate according to the specifications and in adherence with the communication protocol when connected as a system.

Approach

To ensure subsystem interface compatibility and traceability, a systematic approach is followed. First, the interface signals between each and every hardware block in the Prototype Vehicle System Block Diagram & Mechanization diagram are labeled. For example, C1 can indicate the set of signals being communicated between the CAN bus and the Scene Tracking Processor. The individual signals between these two modules will be designated by C1_1, C1_2, etc. Then, every signal source, destination, type of harness, bit structure, and other relevant information will be tabulated. This approach allows:

1. Developing a complete record of all signals among different subsystems or components,
2. Mapping a one-to-one correspondence between each requested signal (by a block) and its source,
3. Implementing changes with minimal effort.

Work Accomplished

Presently, this is work in progress. A complete set of signals and their associated attributes will be provided to NHTSA in March 2001.

Plans through December 2000

We will continue working towards the completion of the Interface Control Management document. This draft will be used as a living document to guarantee correct and well-understood interfaces among all subsystems and components.

3.4 System Verification (Task A4)

Objectives

The overall objective of the ACAS System Verification Task is to make sure the system is ready for use by subjects in the FOT. This requires verification that the system satisfies certain minimum performance requirements at the component, subsystem, and system level. The System Verification Task (Task A4) includes:

1. Definition of the system verification process
2. Supervision of the definition and execution of verification tests at the component and subsystem level
3. Definition and execution of the verification plan at the system level

Approach

Verification will occur at several levels: component, subsystem, and system. Component-level verification will include the operation of the ACAS-specific on-board sensors. These include sensors for vehicle kinematics, environment sensors, and driver activity sensors. Subsystem-level verification will include testing the operation of the interfaces between the subsystems and the functionality of each subsystem. System-level verification will include subjecting the prototype vehicle to crash and nuisance alert scenarios on a test track and driving the vehicle on a prescribed route in traffic. The subsystem designers are responsible for definition of the test procedures at the component and subsystem level. The subsystem designers under supervision of the systems engineers will perform execution of these tests. The systems engineers will be responsible for definition of the test procedures at the system level. The systems engineers will perform execution of these tests.

The dynamic scenarios, shown in Tables 3.5 and 3.6 were selected for use for system-level verification.

Table 3.5 Crash/In-Path Alert Scenario Test Descriptions

Test	**Scenario Description**	**ACC On**	**ACC Off**
C-1	100 kph to lead vehicle stopped in travel lane (night)	X	X
C-2	80 kph to lead vehicle at 16 kph (uneven surface)	X	X
C-3	100 kph to lead vehicle braking moderately hard from 100 kph	X	X
C-6	Host vehicle to lead vehicle stopped in transition to curve (wet pavement)	X	X
C-8	Host vehicle to slower moving lead vehicle, in tight curve	X	X
C-9	Lead vehicle at 67 kph cuts in front of 100 kph host vehicle	X	X
C-10	Host vehicle at 72 kph changes lanes and encounters stopped lead vehicle	X	X
C-12	Lead vehicle brakes while host vehicle tailgates at 100 kph.		X
C-13	Greater size and equal distance (100 kph host vehicle approaches 32 kph motorcycle that is alongside two 32 kph trucks)	X	X
C-14	Greater size and greater distance (100 kph host vehicle approaches 32 kph motorcycle that is behind a 32 kph truck)	X	X
C-16	Host vehicle to lead vehicle stopped in transition to curve (poor lane markings)	X	X
V-8	Both following and lead vehicles are traveling at constant speed on a curve; lead vehicle then decelerates.	X	X
A-7	At highway speeds when tailgating a lead vehicle		X
A-9	Lead vehicle brakes at unusual intensity	X	
A-13	Lead vehicle comes to a stop	X	
A-14	2 lead vehicles; closer one moves out of lane to reveal a slow or stopped vehicle ahead	X	X

Table 3.6 Nuisance Alert Test Description

Test	Test Description	ACC On	ACC Off
N-2	Road surface objects on flat roads	X	X
N-4	Guard-rails and concrete barriers along curve entrance	X	X
N-5	Roadside objects along straight and curved roads (dry & wet pavement)	X	X
N-6	U-turn with sign directly ahead		X
N-7	Slow cars in adjacent lane, in transition to curve	X	X
N-8	120 kph between two 60 kph trucks in both adjacent lanes	X	X
N-9	Slow cars in adjacent lane at a curve (poor lane markings)	X	X
A-1	Following a lead vehicle at typical distances	X	X
A-2	Lead vehicle cuts in at higher speed with typical clearances	X	X
A-3	Open road (no other traffic) with hills & curves	X	

Work Accomplished

Briefings were prepared and presented on the validation plan during technical interchange meetings in Malibu, CA on November 16, 1999 and in Warren, MI on June 29, 2000. In addition, a briefing and discussion was held on system level testing scenarios with NHTSA, Volpe, and other government representatives in Washington, DC on March 28, 2000. These technical interchange meetings led to the preparation and delivery of a testing scenarios report that was delivered to NHTSA in April 2000.

Plans Through December 2000

This task will produce a detailed System Verification Plan, which will be delivered to NHTSA in October 2000.

3.5 Risk Management Plan (Task A5)

Objectives

The overall objective of the Risk Management Task is to define the hazard analysis and safety risk management program to be implemented by the Team in the performance of the ACAS/FOT program. The plan is being developed using guidelines from Mil Standard 882C and SAE J1789. Safety plan presentations have been prepared and presented at meetings in November 1999 and June 2000. In addition, the Safety Engineering team has met with the principal engineers working on each subsystem to gather the required information for the safety analysis and hazard mitigation plan. The Risk Management Plan is deliverable to NHTSA in November 2000.

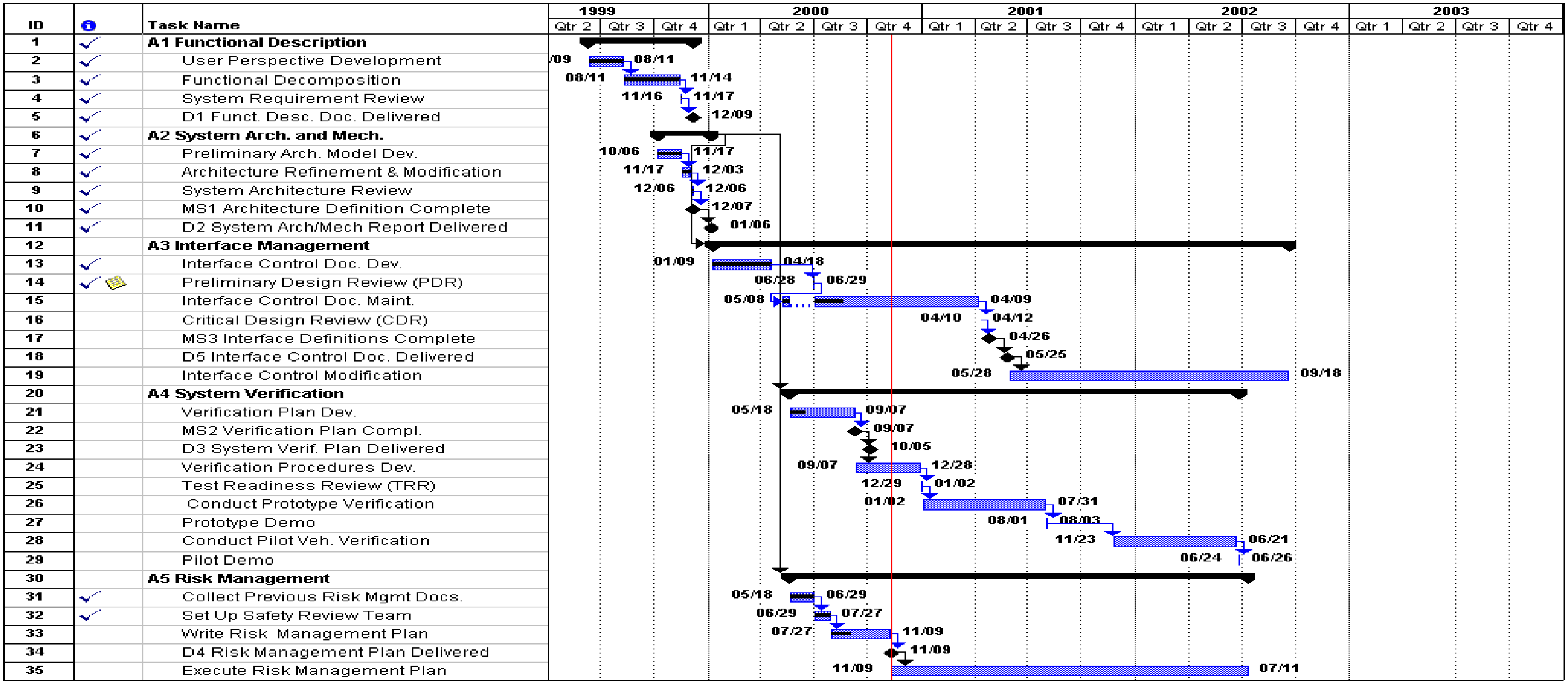
Work Accomplished

Through June 2000 the primary focus under Subtask A5 was on developing:

1. A preliminary list of significant hazards
2. Guidelines for risk severity and likelihood analysis
3. A sample fault tree analysis
4. Guidelines for hazard mitigation

Plans Through December 2000

The Safety Team's plan is to develop the detailed Risk Management Plan for delivery to NHTSA in January 2001. Simultaneously, team members are reviewing the designs and testing plans for each subsystem and the systems as a whole with the responsible engineers to ensure that the Risk Management Plan is properly implemented.



ID	ℹ	Task Name
1	✓	**A1 Functional Description**
2	✓	User Perspective Development
3	✓	Functional Decomposition
4	✓	System Requirement Review
5	✓	D1 Funct. Desc. Doc. Delivered
6	✓	**A2 System Arch. and Mech.**
7	✓	Preliminary Arch. Model Dev.
8	✓	Architecture Refinement & Modification
9	✓	System Architecture Review
10	✓	MS1 Architecture Definition Complete
11	✓	D2 System Arch/Mech Report Delivered
12		**A3 Interface Management**
13	✓	Interface Control Doc. Dev.
14	✓ 📝	Preliminary Design Review (PDR)
15		Interface Control Doc. Maint.
16		Critical Design Review (CDR)
17		MS3 Interface Definitions Complete
18		D5 Interface Control Doc. Delivered
19		Interface Control Modification
20		**A4 System Verification**
21		Verification Plan Dev.
22		MS2 Verification Plan Compl.
23		D3 System Verif. Plan Delivered
24		Verification Procedures Dev.
25		Test Readiness Review (TRR)
26		Conduct Prototype Verification
27		Prototype Demo
28		Conduct Pilot Veh. Verification
29		Pilot Demo
30		**A5 Risk Management**
31	✓	Collect Previous Risk Mgmt Docs.
32	✓	Set Up Safety Review Team
33		Write Risk Management Plan
34		D4 Risk Management Plan Delivered
35		Execute Risk Management Plan

Figure 3.3 Task A Schedule

4 FORWARD RADAR SENSOR (TASK B1)

4.1 Integrated Transceiver/Antenna (Task B1A)

Objectives

The objectives of this subtask are to:

1. Develop an integrated transceiver-antenna interface.
2. Perform sensor characterization and "road to lab" correlation tests.

Approach

A MMIC based transmitter is being designed into the transceiver to optimize reliability and performance. Large sections of the ACAS Program Gunn-based transceiver will be replaced with MMIC components. The transceiver-antenna assembly will be integrated into the sensor, and the sensor housing and electronics will be modified to accommodate the new motor and transceiver-antenna assembly.

Work Accomplished

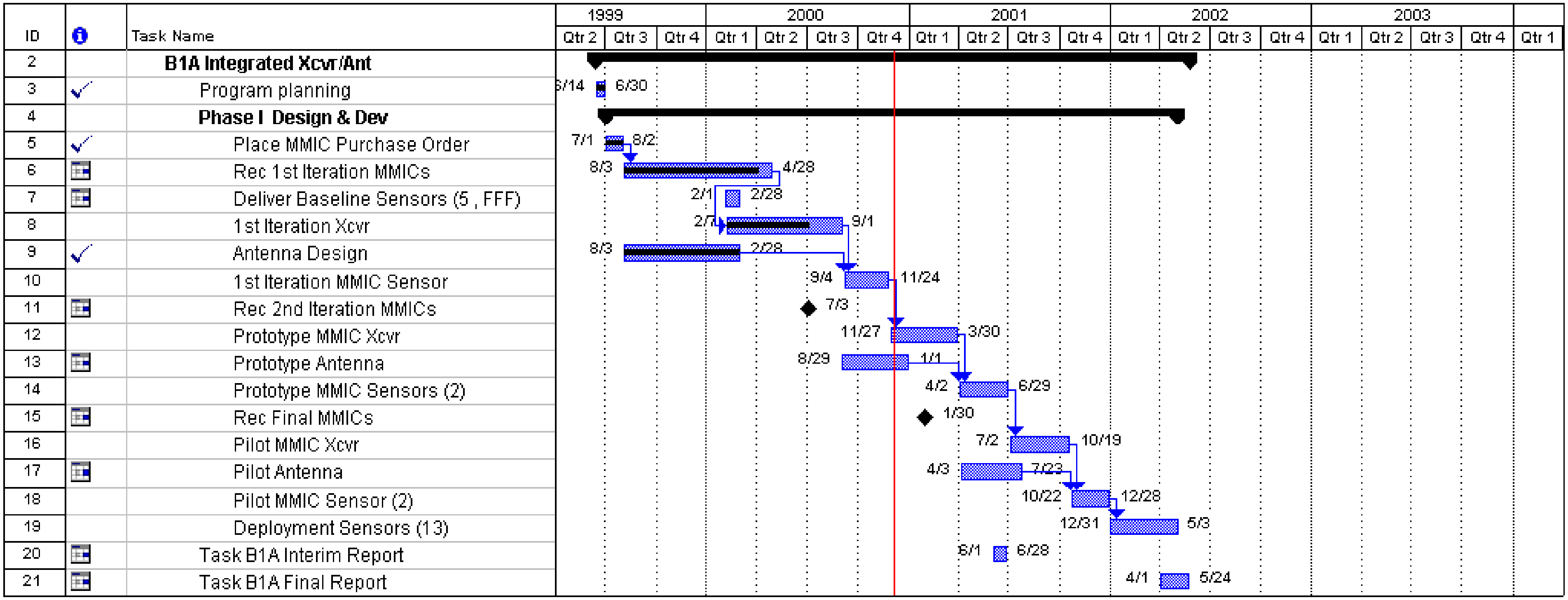
1. The mechanically scanned folded reflector narrow beam antenna design is complete.
2. First iteration MMIC chips were received and were tested at chip level and in test circuits.
3. The second iteration wide-band phase lock loop design was fabricated and tested and was integrated with 38 GHz MMIC VCO. Test data showed good noise performance.
4. The EDU transceiver layout is complete.
5. The first two functional sensors were delivered to GM for integration.

Research Findings

Good MMIC test data correlation between wafer tests and substrate tests was observed. Test data correlation between the supplier and Delphi was also established. Initial results indicate excellent performance from the VCO and 76 GHz amplifiers. Existing chips will be useable in 1st iteration transceivers. The frequency doubler has high VSWR and temperature issues and the VCO has yield issues due to temperature variation. A design review was held with the supplier to address the VSWR and temperature issues. Actuator control software was found inadequate for dynamic tests due to mechanical resonance leading to redesign of the antenna actuator system. Sidelobe levels on the EDU (Engineering Development Unit) antennas were found to be inadequate for good on-road performance. EDU antennas will be replaced with prototype units which perform as specified.

Plans through December 2000

During the next reporting period, the EDU transceiver design will be completed, and the second iteration chip set will be released to fabrication. Initial sensors will be replaced with upgraded versions for on-road test.



ID	ℹ	Task Name
2		**B1A Integrated Xcvr/Ant**
3	✓	Program planning
4		**Phase I Design & Dev**
5	✓	Place MMIC Purchase Order
6	▦	Rec 1st Iteration MMICs
7	▦	Deliver Baseline Sensors (5 , FFF)
8		1st Iteration Xcvr
9	✓	Antenna Design
10		1st Iteration MMIC Sensor
11	▦	Rec 2nd Iteration MMICs
12		Prototype MMIC Xcvr
13	▦	Prototype Antenna
14		Prototype MMIC Sensors (2)
15	▦	Rec Final MMICs
16		Pilot MMIC Xcvr
17	▦	Pilot Antenna
18		Pilot MMIC Sensor (2)
19		Deployment Sensors (13)
20	▦	Task B1A Interim Report
21	▦	Task B1A Final Report

Figure 4.1 Task B1A Schedule

4.2 Auto Alignment Algorithm Development (Task B1B)

Objectives

Implement an algorithm that electronically adjusts the sensor for mechanical misalignment due to vehicle wear and tire alignment.

Approach

Automatic alignment development starts with a generic study of possible system approaches that include use of radar data, external sensor data, and external vehicle data. This study is followed by selection of one or two technically feasible approaches as possible solutions. Detailed development of the selected approaches will then take place, followed by design, fabrication and bench testing of the completed approaches into the CW sensor and road evaluation of the integrated units. The final version will be used in the deployment vehicles.

Work Accomplished

Initial algorithm development has been completed and the algorithm has been tested. The following activities have been completed:

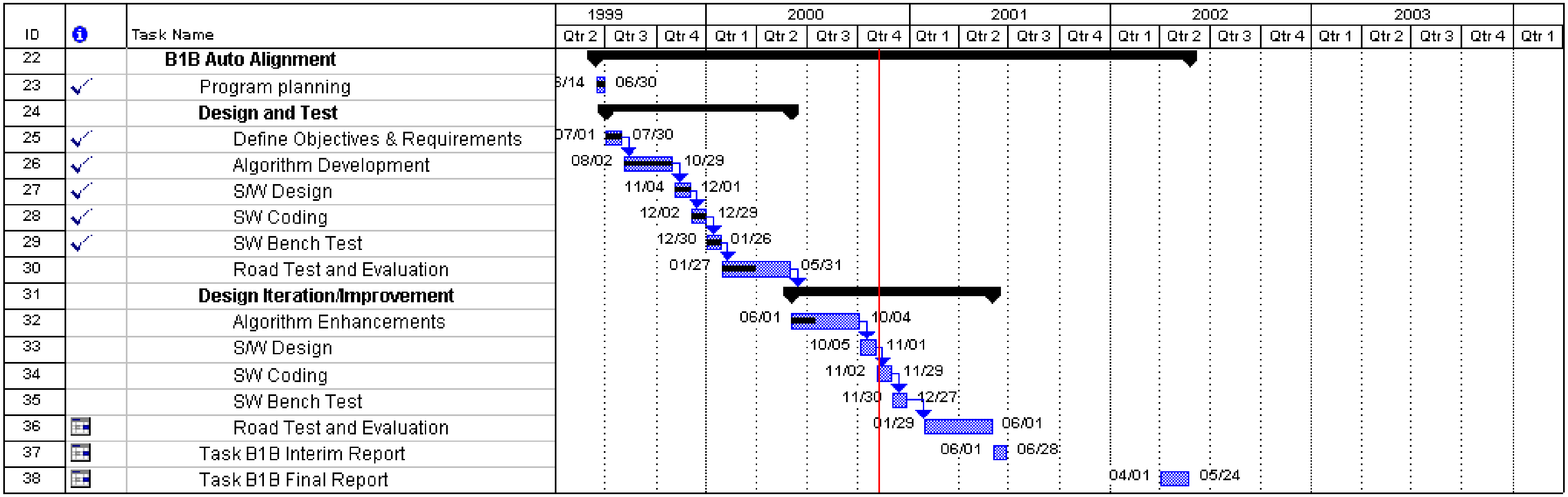
1. Define objectives and requirements
2. Perform algorithm development
3. Perform software development
4. Perform bench and road test and evaluation.

Research Findings

The basic algorithm is functioning quite well with the alignment process found effective over “long” periods of time. Azimuth offset angles were correctly characterized and removed by the alignment process. Occasional peak errors of short time duration were observed in the data and found to be caused by curves. The intent to warn the driver if the data was not converged has not been possible due to these curve induced data errors. Field-testing is continuing to isolate the effect that caused temporary peak errors in the correction process. The remaining task is to identify and correct causes of the curve induced errors resulting in separating true misalignments from curve events, and the ability to caution the driver that the unit is re-aligning.

Plans for through December 2000

Data gathering will continue as will development of alternate approaches to address the problem with curves. Road test data gathering has slowed, though the basic algorithm is functioning well in a variety of test vehicles. This task has fallen behind schedule with regards to data collection and algorithm enhancement; A recovery plan is being executed.



ID	ℹ	Task Name
22		**B1B Auto Alignment**
23	✓	Program planning
24		**Design and Test**
25	✓	Define Objectives & Requirements
26	✓	Algorithm Development
27	✓	S/W Design
28	✓	SW Coding
29	✓	SW Bench Test
30		Road Test and Evaluation
31		**Design Iteration/Improvement**
32		Algorithm Enhancements
33		S/W Design
34		SW Coding
35		SW Bench Test
36	▦	Road Test and Evaluation
37	▦	Task B1B Interim Report
38	▦	Task B1B Final Report

Figure 4.2 Task B1B Schedule

4.3 Radar Blockage Algorithm Development (Task B1C)

Objectives

Implement an algorithm that detects and warns the driver when the sensor is blocked by dirt, slush, or other material.

Approach

Several possible system approaches are being investigated including the use of radar data, external sensor data, and external vehicle data. This study will be followed by selection of two to three technically feasible approaches as possible solutions to the radome blockage problem. The best approach will be selected based on bench testing, simulation, and road evaluation and will be implemented in sensors used for deployment vehicles.

Work Accomplished

Two generations of radome blockage detection algorithms were designed and implemented. The upgraded technique uses non-coherent integration of main beam clutter. An alternative technique utilizing radar track data was also defined. A data collection test plan was created to evaluate more comprehensively the candidate techniques. Initial data collection was completed for the initial, upgraded, and alternate techniques. Data reduction is in progress. The following activities have been completed:

1. Define objectives and requirements
2. Perform algorithm development
3. Perform software development
4. Perform bench and road test and evaluation.

Research Findings

This task has fallen behind plan and a recovery plan is being worked. No problems have been identified to date. Some conceptual concerns with radome blockage detection have been identified regarding detection reliability. Concerns over detection reliability in a partial blockage condition or during heavy snowfall or when the host vehicle is parked will be investigated, and adequate test and validation scenarios are being defined.

Plans through December 2000

Data collection and analysis will be completed. Algorithm enhancements will be implemented and the schedule recovery plan executed.

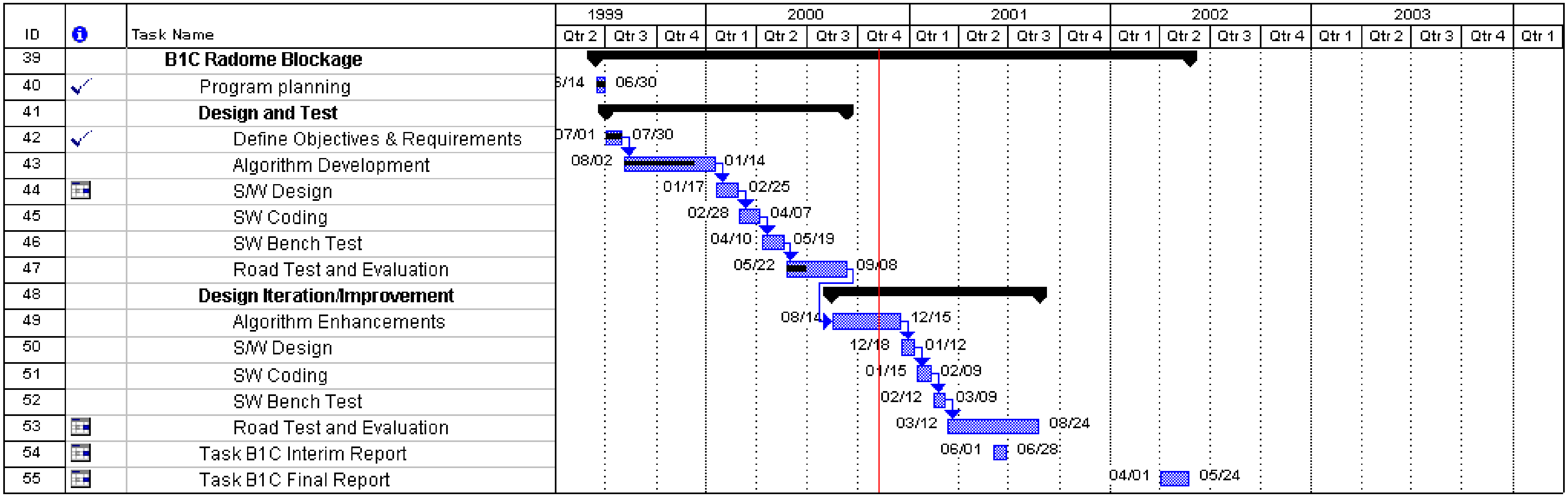


Figure 4.3 Task B1C Schedule

4.4 Bridge rejection Algorithm Development (Task B1D)

Objectives
Implement an algorithm that classifies bridges as "safe" overhead obstacles and does not slow the vehicle unnecessarily.

Approach
Several possible system approaches will be investigated using radar data from the wide field of view multi-beam ACAS/FOT radar sensor. This study will be followed by selection of two to three technically feasible approaches as possible solutions to the bridge rejection problem. The best approach will be selected based on bench testing, simulation, and road evaluation and will be implemented in sensors used for deployment vehicles.

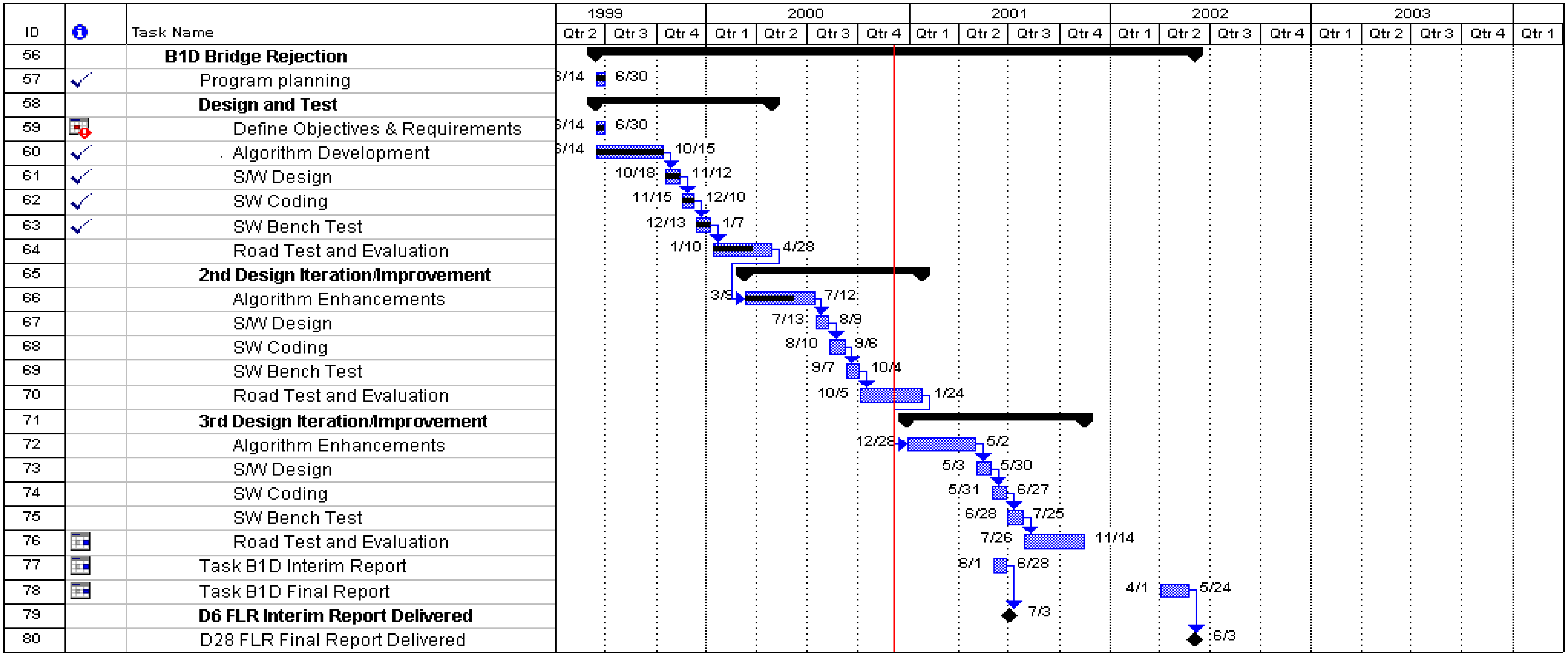
Work Accomplished
Several candidate approaches for bridge discrimination were investigated. Based on initial data collection and analysis, one approach was selected as the initial design. Initial road test and evaluation was completed for the initial design. A second design iteration was completed after analysis and review of first iteration design test results. Road test data was collected to evaluate the second iteration design. Data was collected on approximately 150 bridges and overhead signs in the Detroit and Indianapolis metropolitan areas. Tests were performed against 23 stopped vehicle situations involving 15 different vehicles. Initial data reduction and evaluation was completed. Definition of further algorithm improvements is in progress. The following activities have been completed:

1. Define objectives and requirements
2. Perform algorithm development
3. Perform software development
4. Perform bench and road test and evaluation.

Research Findings
It was determined that the multipath lobing structure is not a reliable discriminant because multipath lobing on some stopped vehicles can lead to significant amplitude deviation. Two amplitude discriminants (deviation and slope) were also investigated for potential use in distinguishing bridges from valid in-path stopped objects. It was found that amplitude deviation is not a reliable discriminant. Amplitude slope is a reliable discriminant, but this method takes time (range closure) to develop, which can lead to delayed recognition of valid in-path stopped vehicles.

Plans through December 2000

The second iteration algorithm design and implementation will be completed. Bench testing of the second iteration design will be completed and road test and evaluation of this design will be started.



ID	ℹ	Task Name
56		**B1D Bridge Rejection**
57	✓	Program planning
58		**Design and Test**
59	▦	Define Objectives & Requirements
60	✓	Algorithm Development
61	✓	S/W Design
62	✓	SW Coding
63	✓	SW Bench Test
64		Road Test and Evaluation
65		**2nd Design Iteration/Improvement**
66		Algorithm Enhancements
67		S/W Design
68		SW Coding
69		SW Bench Test
70		Road Test and Evaluation
71		**3rd Design Iteration/Improvement**
72		Algorithm Enhancements
73		S/W Design
74		SW Coding
75		SW Bench Test
76	▦	Road Test and Evaluation
77	▦	Task B1D Interim Report
78	▦	Task B1D Final Report
79		**D6 FLR Interim Report Delivered**
80		D28 FLR Final Report Delivered

Figure 4.4 Task B1D Schedule

5 FORWARD VISION SENSOR (TASK B2)

Objectives

The overall goal of the Forward Vision Sensor Task is to facilitate the development of a robust, real-time forward looking lane tracking system to enhance the overall forward Path Estimation and Target Selection algorithms (Task C2). Additional objectives are to:

1. Integrate the selected vision system with other subsystems
2. Support FOT deployment.

Approach

The system will consist of two components. A video camera, mounted behind the windshield of the vehicle, will acquire images of the roadway ahead of the host. A remotely located image processing unit will then detect and track the position of the lane boundaries in the images, and will provide a model of the changing road geometry. In addition to road shape, the lane tracking system will provide estimates of lane width and of the host's heading and lateral position in the lane. In the Data Fusion Module (Task C1) this information will be fused with road and host data from other sources, such as Scene Tracking and GPS Map, to provide more accurate estimates of road and host state to the Target Selection Module.

Although many different vision-based lane detection and tracking systems have been developed worldwide, their primary focus has been on applications such as lane departure warning and lane keeping, where the required range of operation is usually less than 25 meters. Host heading and lateral lane position derived from such systems can be used to reduce the effects of driver hunting and host lane changes on the task of in-path target selection, but the more serious problems associated with curve entry/exit scenarios remain. To address these, an accurate prediction of the roadway geometry up to 100 meters ahead of the host is desired. The goal of this task is to develop a vision-based lane tracking system that will provide these long-range road curvature estimates as well as complement the Scene Tracking and GPS approaches under development in Tracking and Identification Task (Task C2).

To develop the robust vision system required for this program, and to take advantage of existing automotive vision technology, three short-range real-time lane tracking systems were identified as potential starting points for this task. Selection of these systems was based on their developer's demonstrated competency in the development, integration, and road testing of these systems, and on their willingness to extend their system to meet the goals of this program. Teams from the University of Pennsylvania (U-Penn), Ohio State University (OSU), and the University of Michigan – Dearborn (UM-D) were each contracted by DDE[1] to further the development of their respective systems. During the first fourteen months of development, DDE is providing technology direction and

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[1] UM-D contact: Sridhar Lakshmanan; OSU contact: Umit Ozguner; U-Penn contact: C. J. Taylor.

evaluating the progress of the three competing university teams. Based upon the results of this activity and an official technology down-select process, one approach will be identified for further development and final integration into the FOT vehicles.

Milestones and Deliverables through June 2000

The Lane Tracking System Requirements Document was prepared and delivered to NHTSA and to the university teams. It defined performance and interface requirements, specifying output data content and accuracies, system update rate and latencies, range and realm of operation, and road and marker types.

Work Accomplished

An initial vision kick-off meeting was held in August 1999 in conjunction with the overall Program kick-off. This review was intended to provide the Team and NHTSA an opportunity to formally assess the status of each lane sensing system (i.e., level of performance, capability, maturity) and overall current system design. In an open forum, each university team presented a top level overview of their vision system's architecture, their performance design requirements (requirements to which their baseline system was originally designed), and a real-time lab demonstration of their current baseline lane tracking system operating on video taped imagery.

Private meetings where also held with each university team to discuss, in detail, their plans for enhancing their system to meet the preliminary system requirements. Each contractor presented a System Analysis Review in which they described anticipated algorithmic changes and challenges, calibration issues, and various vehicle interface requirements (i.e., desired camera features, vehicle sensors, diagnostics). This task has been completed.

One objective was for the vision teams to work with the Team members to define specific performance and interface requirements for the vision subsystem. In general, the performance requirements flow down from the overall FCW system and, specifically, from the needs of the Target Selection Module. The interface requirements have been selected to conform to the overall system design as well as to the specific needs of the Data Fusion Module, which is the primary user of the vision system data.

In summary, the requirements state that the system should provide host and road state estimates to within these specified one-sigma accuracy requirements:

1. Lateral position in lane: ≤ 0.2 meters
2. Lane width: ≤ 0.2 meters
3. Heading: ≤ 0.2°
4. Road Geometry: ≤ 0.75 meters at 75 meter range[2]

The Forward Vision Sensor should produce confidence estimates (which may be a function of range) for the road-geometry and host vehicle state. The system should also report the number of lane markers (i.e. left, right or none) that it has acquired as well as some indication of when a lane change event has occurred. The minimum update rate is 10 Hz with an initial maximum acquisition time of 5 seconds. The system should work on the freeways, freeway transitions, expressways and parkways where the minimum horizontal radius of curvature is 300 meters, and when the host speed is between 25 and 75 mph. The system will operate in clement weather, in both day and night conditions, and under natural and artificial lighting. The road surface should be paved, clear, and free from glare, and the road markings should have good contrast. The lane markings can be of single or double lines that are either solid or dashed. This task has been completed.

Research Findings

The bulk of the lane tracking system development falls on the shoulders of the university teams, who continue to develop, test, and enhance their algorithms to meet the specified performance and interface requirements. In support of that work, DDE efforts have concentrated on defining requirements, implementing the video data acquisition system, constructing and coordinating use of the Vision EDV, managing the university teams, and setting priorities and providing technology direction when appropriate. DDE and HRL have been working with the universities to define confidence measures appropriate to each system and which are meaningful to the Data Fusion Task. The following paragraphs describe some of these activities in more detail.

Video Data Acquisition System

To facilitate algorithm development/iteration, system evaluation, and the eventual migration to the final platform, a simple method of collecting video imagery and correlated inertial data was devised. In the FOT FCW system, the vision subsystem will communicate with other subsystems via the CAN bus. Both vehicle speed and yaw rate are available on the bus, as well as the radar scan index, which can be used like a system clock to synchronize data from various sources. A system was designed and implemented to collect this data and store it on the audio track of videotape. Then, on video playback in the laboratory, the audio track is decoded, and converted back to the original CAN

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[2] Estimates should be such that the error in calculation of lateral displacement of the lane from the host current position should have standard deviation no greater than 0.75 m at any point starting at 15 m and continuing out to a distance of 75 m from the front of the vehicle.

messages. Thus, the vision system can be used in the vehicle and on the bench without modification. A diagram of the system is shown in Figure 5.1.

Each vision team was provided with an audio encoder/decoder for their vehicle and laboratory setups. Having adopted this system, encoded videotape can be provided to each vision team for system evaluation. By outputting the scan index with their system's results we are able to compare the different vision system's performance on identical scenarios.

Vision EDV

A Vision EDV was configured as a test bed for the development and evaluation of the lane tracking systems. GM supplied a 1996 Buick which was outfitted by DDE with a CCD-camera, CAN bus, speed and yaw rate sensors, a vehicle interface processor to format and transmit the vehicle data on the CAN bus, and the video encoder system described above. This vehicle was provided for the shared use of all vision teams, and has been driven by each to collect the video scenarios that are currently being used for system refinement and validation. During the down-select process, each of the vision systems can be integrated into the vehicle, and data collected from each simultaneously.

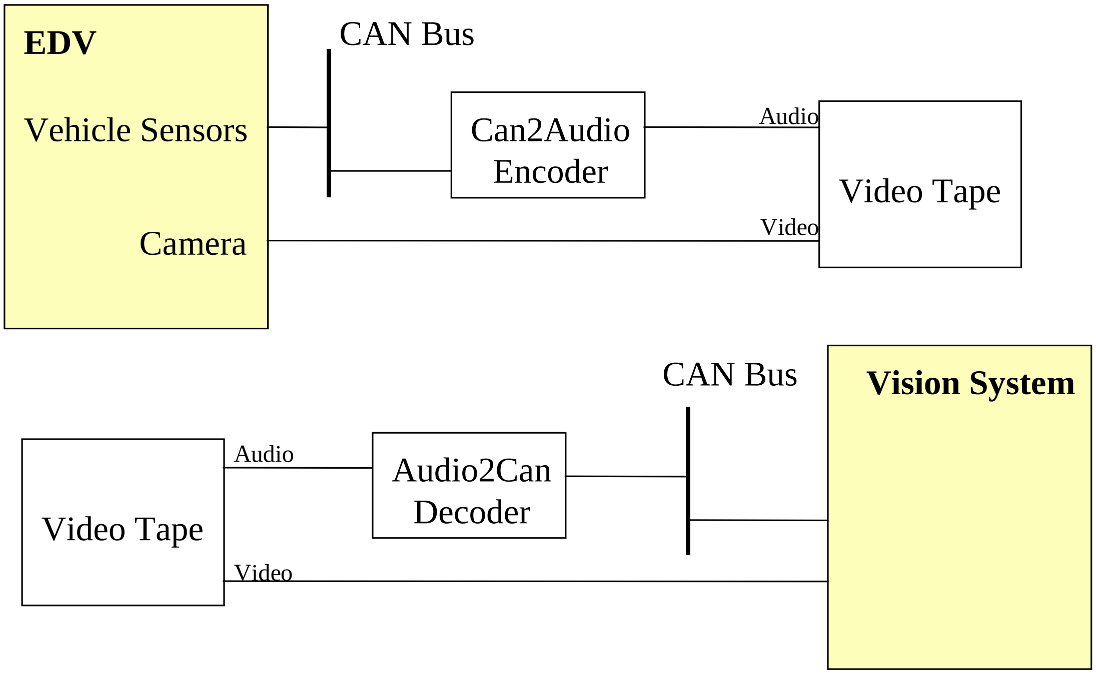


Figure 5.1 System to Collect and Replay Video

Definition of Confidence Measures

The correct interpretation and degree of reliability of confidence measures generated by the vision subsystem (as well as the GPS and Scene Tracking subsystems) is critical to a successful Fusion task. HRL and DDE have been working with the university teams to define a common output format and confidence measures that will allow the vision system results to be readily compared to those from other vision and non-vision subsystems, and to ground truth data. The resulting Output Format Specification defines the expected road curvature model, common units on all variables, and five levels of confidence in up to four range zones. The university teams have adapted their systems to use this output format.

Algorithm Development

Initial system development has been carried out in the laboratory with data sets collected in the Vision EDV. Since the start of the program, each university team has extended its system to process image data out to the required ranges, and to provide the specified host and road state variables and confidence measures. Efforts continue to improve the system performance on real-world scenarios in which complications such as suspension rock, lane changes, dashed lane markers, freeway exits and intersections, vertical roadbed curvature, and traffic provide challenges to all.

The rest of this section contains a brief progress report from each vision team describing their approach, progress since program inception, and future plans. All three university teams continue to improve the performance of their systems. The milestones for the hardware/software requirements and final performance requirements are complete. The in-lab development and in-vehicle development are progressing according to schedule.

University of Pennsylvania

Approach

At the start of this project our lane tracking system could be broken into three stages: a feature extraction stage which found candidate lane markers in the imagery using a variant of a matched filter, a lane fitting stage which fit straight lines to the extracted features in the near field, and a Kalman filter which combined the resulting line estimates with the inertial measurements obtained from the yaw rate and velocity sensors to produce a final estimate for lane state. The system was capable of estimating the vehicle's orientation and offset with respect to the lane along with the lane width and curvature in the near field.

Improvements

During this project we have extended our approach to incorporate lane tracking in the far field (out to 75m). In order to do this, the lane tracking system has been extended to include two new parameters, the curvature of the road at 100 meters and the pitch of the camera with respect to the road surface. In order to incorporate the expansion in the state vector the current implementation is based on a technique referred to as particle filtering rather than a Kalman filter. In this framework, multiple hypotheses for the lane state are maintained, propagated and scored over time to approximate the evolution of a joint probability distribution over the parameter space. In addition to allowing us to model the effects of far field curvature and pitch, this approach also allows us to characterize better the uncertainty associated with our estimates for these parameters. Two additional techniques have been exploited to improve the convergence of the estimation system. Firstly, a factored sampling approach has been used to split the search for lane parameters into two connected pieces, one concerned with estimating the vehicle's position, orientation, and pitch, and the lane width and the curvature parameters. Secondly, an importance sampling approach is employed where the results from a Hough Transform analysis are used to bias the hypothesis proposal process.

Summary Results and Future Plans

The current system is able to track highway roads at a rate of 10Hz out to the 75meters. The system has the ability to handle lane changes and partial occlusions of the lane markings. Our plan is to focus our efforts on exploring the tradeoffs associated with the factored sampling and importance sampling schemes and on experimenting with various lane marker extraction methods to improve performance in low light conditions and on concrete road surfaces.

Ohio State University

Approach

The road ahead of the camera/car is modeled as a clothoid. The clothoid parameterizes curvature of the road as a linear function of distance from the camera. Starting with an initial estimate of the curvature (usually zero, which corresponds to a straight road), a search area is defined in the image in which potential lane marker candidates are identified. Once this is done, an optimization scheme using dynamic programming is used to select a final set of lane marker candidates. This is done separately for the left and right lanes. The optimization scheme takes into account the structure of the lane candidates involved, the proximity to the estimated lane position, and the local smoothness of the lane boundary contour that is being constructed. Finally, using the generated left and right lanes, a centerline is constructed taking into account the confidence that the system has in the two lanes. The parameters associated with the centerline are then Kalman filtered to remove any minor variations that might arise, and to make a smooth prediction. This filtered set of parameters forms the estimate of lane centerline for the current image being analyzed. This is projected into the next image frame and the entire process is repeated.

Improvements

1. Initially, all geometry was confined to the image plane. This means that the models used were for pixel locations and had no correlation to the real world geometry that the camera is in. We have now implemented a perspective-mapping scheme that translates image coordinates of candidate lane markers into real world locations, and only after this are the other processes in the algorithm carried out. The procedure of coordinate translation allows for more realistic modeling of lane boundaries.
2. A simple quadratic was used to model the lane boundary contours. The clothoid model is a comparatively better way of modeling lane contours, since the clothoid is used in road construction and highway models.
3. The matched filter used to identify lane marker candidates in the image was of constant dimensions. This means that the same matched filter was used to search for all markers, even though the size of markers in the image diminishes with distance from the camera. We have now modified the matched filter. The scale of the matched filter decreases with geometric distance from the camera, to account for reducing size of lane markers in the image as we move away from the camera.
4. We now use confidence measures to assess relative validity of the left and right lanes, and to combine the two into a single centerline estimate.

Summary Results and Future Plans

1. The clothoid based lane marker identification system has been designed and implemented. Performance of the system is good in terms of candidate lane markers identified.
2. Currently, the left and right lanes are identified separately and combined only at the end of analysis into a single centerline. This does not yet take into account some geometric realities like the fact that the left and right lanes are always parallel. We are investigating the performance of a scheme in which the centerline itself is identified in the dynamic programming procedure, using supporting lane markers on the left and right sides.

University of Michigan

Approach

The Likelihood Of Image Shape (LOIS) Lane Detector, developed by Dr. Karl Kluge of the University of Michigan and Prof. Sridhar Lakshmanan of the University of Michigan-Dearborn, applies a deformable template approach to the problem of estimating lane shape using computer vision. The set of possible lane edges in the image plane consists of a parametric family of curves corresponding to a model in which lane edges are concentric circular arcs on a flat ground plane. A simple matching function (based on how much the image brightness changes near the lane edges) measures how well a particular hypothetical pair of lane edges matches a given input image. A discrete Metropolis optimization method is used to find the pair of lane edges, which maximizes that matching function for each successive image captured by a forward-looking video camera mounted on a car. The parameter estimates from the LOIS lane detector are tracked from frame-to-frame in order to: (a) provide a good initial guess as to where the lanes are in any given frame based on where the lanes were detected in past frames, and (b) signal a lane change.

<u>Improvements</u>

Since the start of the program, U of M's focus has been on:

1. Improvements to execution speed: As a result of algorithm improvements and porting to a single board computer, we have achieved a four-fold improvement in speed.
2. Development of estimator confidence measures: A new estimator confidence measure has been developed based on the curvature of the shape/image matching function surface.
3. Far range distraction problem: LOIS, like other lane detection/tracking systems, has unacceptable lane estimation errors in far ranges. A systematic study as to why this problem occurs, and what measures can be taken to alleviate this problem has been done. This includes changes to the LOIS matching function, use of a better optimization method, and data trimming.
4. Testing on large data sets: Large lane image data sets were collected using the FOT vehicle. LOIS' performance was tested on these data sets, as well as those provided by DDE.

<u>Summary Results and Future Plans</u>

1. LOIS currently runs at approximately 8 frames per second on images with 320 (Columns) x 240 (Rows) resolution.
2. LOIS currently provides an acceptable error rate up to 40m range. Effort is being made to further extend this range of acceptable performance.
3. LOIS currently provides an off-line estimator confidence measure. Computation of this measure is being incorporated into LOIS, so that it too is real-time.
4. LOIS' performance on large data sets is currently being determined by visually inspecting the graphical overlay of the detected lanes on the processed image. An effort is being made to determine system performance in a more coherent and repeatable manner.

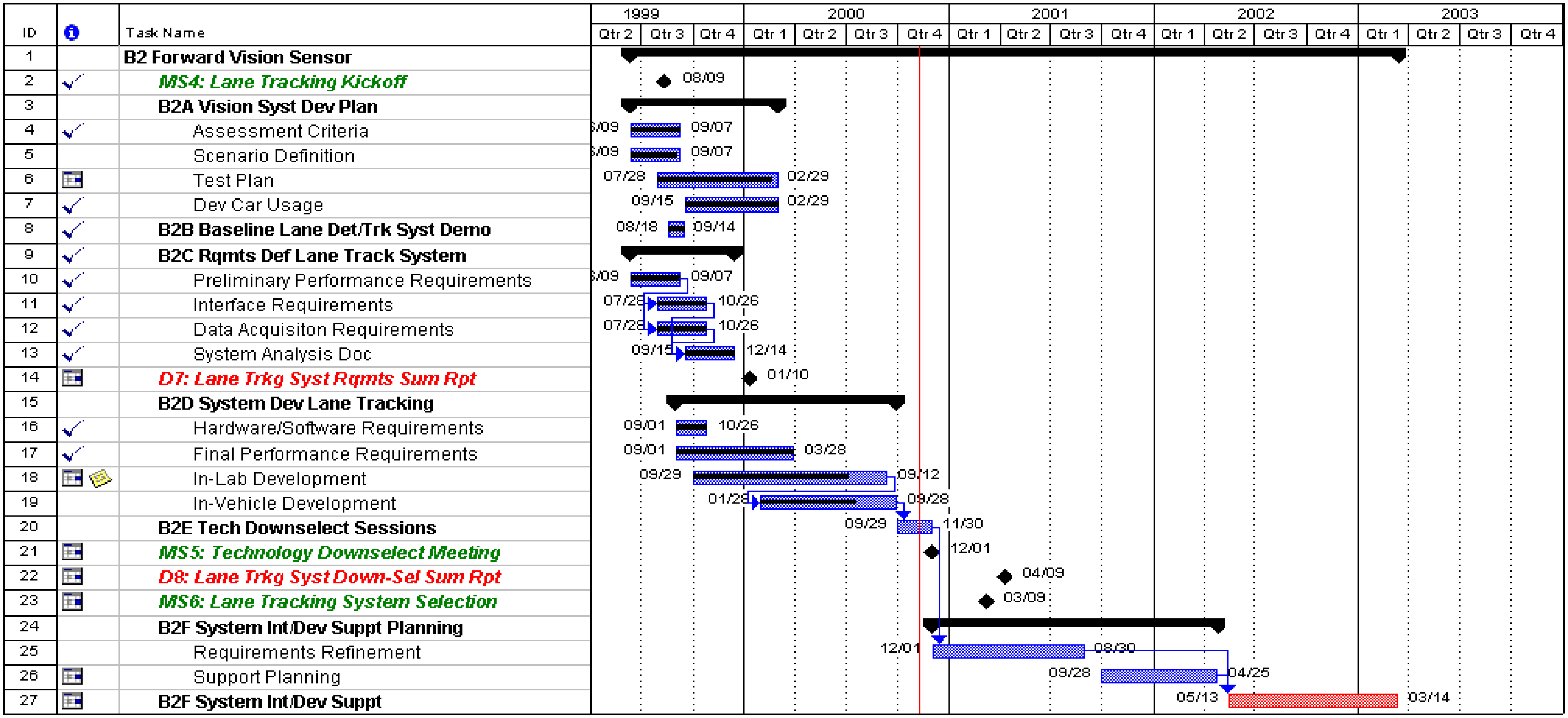
All three university teams continue to improve the performance of their systems. The milestones for the hardware/software requirements and final performance requirements are complete. The in-lab development and in-vehicle development are progressing according to schedule.

Plans through December 2000

DDE will manage the technology down-select activities in order to identify the vision system that best meets the agreed-upon lane tracking system performance requirements. The selected vision team will then work with the other FOT team members in order to integrate their system with the full portfolio of CW subsystems. The final down select is scheduled for the end of the second year of development. Adhering to this schedule would mean that the Data Fusion and other tasks would have to characterize and design interfaces to all three vision systems until the final down select was completed. To reduce the amount of parallel effort, and more effectively concentrate on the many issues that arise in extended on-road operation, the teams will be subjected to an early down select. This process is scheduled to begin in October 2000, with a meeting in which each vision team will present their work and a bench demonstration of the current system.

DDE and HRL have been working together to formulate a test plan for the lane tracking system down select. As part of this plan, a suite of test scenarios have been defined to evaluate the lane tracking system performance against the specified subsystem requirements. First-round situational videotape was created, and consists of a series of calibration images followed by six driving sequences, each 7–11 minutes in length. The data set exhibits variations in sun angle, traffic densities, road curvature, lane marker quality, and driving patterns (include lane changes and weaving). Vehicle data was encoded on the tape as described above, and for some scenarios, correlated high-accuracy GPS data was collected to aid in determining ground truth.

The vision teams will soon begin processing the first-round tape. They have been asked to provide a system log following the guidelines in the Output Format Specification, and videotape displaying their system's graphical output. The results will initially be compared against ground truth determined using post-processed yaw rate and GPS data. During the next six months, we will complete the technology down-select process and begin focusing on tuning the performance of the selected system.



ID	ℹ	Task Name
1		**B2 Forward Vision Sensor**
2	✓	***MS4: Lane Tracking Kickoff***
3		**B2A Vision Syst Dev Plan**
4	✓	Assessment Criteria
5		Scenario Definition
6	▦	Test Plan
7	✓	Dev Car Usage
8	✓	**B2B Baseline Lane Det/Trk Syst Demo**
9	✓	**B2C Rqmts Def Lane Track System**
10	✓	Preliminary Performance Requirements
11	✓	Interface Requirements
12	✓	Data Acquisiton Requirements
13	✓	System Analysis Doc
14	▦	***D7: Lane Trkg Syst Rqmts Sum Rpt***
15		**B2D System Dev Lane Tracking**
16	✓	Hardware/Software Requirements
17	✓	Final Performance Requirements
18	▦ 🗒	In-Lab Development
19		In-Vehicle Development
20		**B2E Tech Downselect Sessions**
21	▦	***MS5: Technology Downselect Meeting***
22	▦	***D8: Lane Trkg Syst Down-Sel Sum Rpt***
23	▦	***MS6: Lane Tracking System Selection***
24		**B2F System Int/Dev Suppt Planning**
25		Requirements Refinement
26	▦	Support Planning
27	▦	**B2F System Int/Dev Suppt**

Figure 5.2 Task B2 Schedule

6 BRAKE CONTROL SYSTEM (TASK B3)

6.1 Brake System Development

Objective
The objective of this task is to replace the Original Equipment Manufacturer's (OEM) brake components in FOT deployment vehicles with Delphi Chassis and Energy Systems hardware and software that meets the FOT requirements.

Approach
The ACAS brake system will be a DBC 7.2 System that provides state-of-the art, full performance, wheel lock control to optimize the vehicle car stopping distances while maintaining the electrical and diagnostic interface. The development of brake controls to meet both the vehicle requirements and the ACAS/FOT program requirements are being accomplished through common best engineering practices at Delphi. The safety analysis and vehicle level verification of the brake system will be accomplished to ensure production-level confidence the brake system. The brake system will include an "autobraking" feature in addition to the braking features and functions that were previously on the vehicle before replacement with the Delphi Brake System.

Milestones and Deliverables
The brake system design milestone is completed. This work was accomplished as a result of laboratory testing with hardware-in-the loop. Testing of the brake controls design for the autobraking feature using a dedicated chassis mule has been performed. The installation of hardware on the Prototype mule has been conducted with plans to update the hardware and software with production release levels after testing and calibration for the Buick.

Deliverable Number 9, the Brake Actuator System Design Summary report dated June 30, 2000 has been provided to NHTSA.

Work Accomplished
This section describes how functional requirements are accomplished using the DBC 7.2 System. The programs utilizes a dedicated vehicle identical to the prototype vehicle to conduct the brake systems development, system verification and vehicle level testing.

Functional Description

The hydraulic modulator unit (HCU) of DBC 7.2 incorporates Anti-lock Brake (ABS), Traction Control (TCS) and vehicle stability enhancement and provides pressure modulation capabilities into the vehicle base brake system. The major components of the modulator are: a casting/body with internal cross drills and an Electro-Hydraulic pump and motor.

An electronic control unit (ECU) of DBC 7.2 contains a microprocessor-based device that controls the hydraulic modulator in a manner that allows all vehicle requirements to be satisfied. The includes the following physical content:

1. Microprocessor with failsafe circuitry
2. Signal interface circuitry
3. Power control circuitry
4. Memory: volatile (RAM) and non-volatile (Flash and EEPROM)
5. Solenoid coils
6. Electrical connector

The ECU processes the input signals and converts them to digital form. The control algorithms are stored in non-volatile memory to achieve the vehicle performance requirements. The ECU performs diagnostic checks on internal and external hardware. It stores fault codes in non-volatile memory when a fault is detected. The ECU converts control commands to physical outputs (pulse width modulation control). It is assembled to the HCU to meet all vehicle performance requirements relative to the vehicle environment.

In addition to ABS and TCS the brake system provides a capability which aids the driver over a wide range of driving conditions and maneuvers. This vehicle stability feature, hereafter designated Traxxar, helps the driver to maintain the intended path during oversteer or understeer conditions.

Figure 6.1 depicts the HCU/ECU and the vehicle level of integration. The wheel speed, yaw rate / lateral accelerometer and steering angle sensors are inputs to the ECU for the algorithms. The hydraulic paths to each brake corner are indicated and the communications link to the power train controller for engine communications.

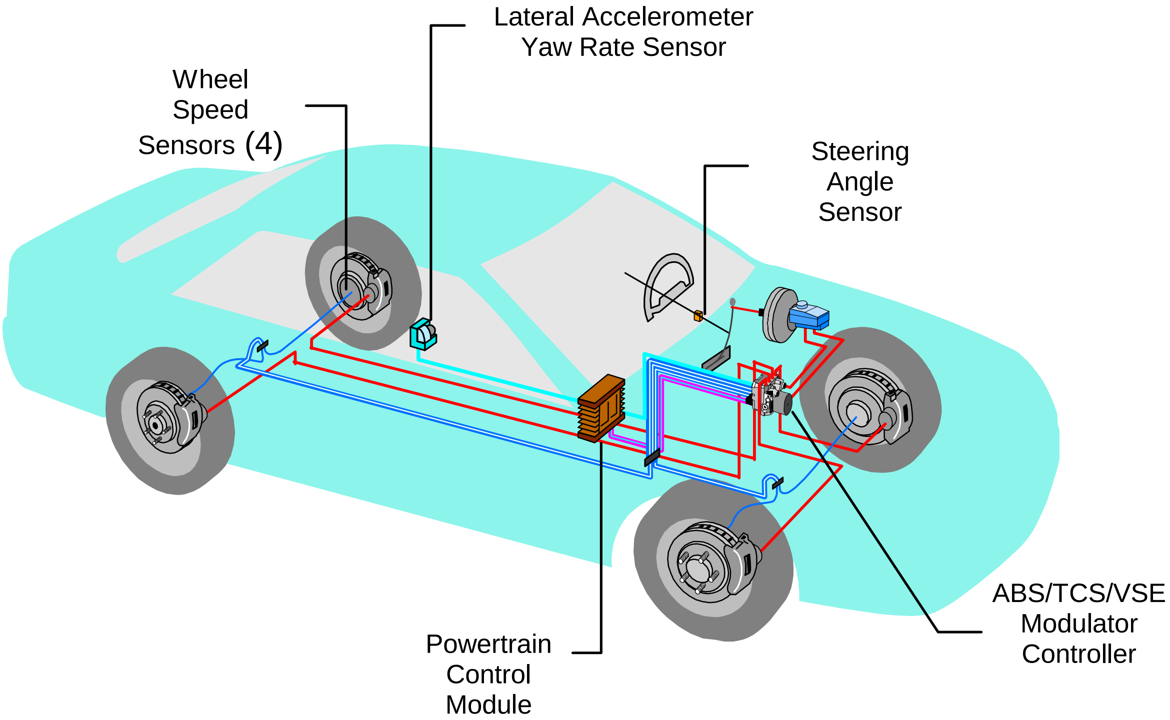


Figure 6.1 HCU/ECU and Vehicle Level of Integration

System Performance and Interfaces

The DBC 7.2 ABS/TCS/Traxxar System provides state-of-the-art, full performance, wheel lock control to optimize stopping distance, steerability, and vehicle stability along with acceleration slip control to optimize vehicle launch and traction capabilities. In addition, the Traxxar System is capable of correcting vehicle over- and understeer conditions, with or without driver braking, to significantly improve overall vehicle safety. The brake system shall also perform an autobraking function based upon decel commands from the Adaptive Control Processor and vehicle control algorithm. This autobraking function is very limited relative to absolute deceleration authority achieved by the vehicle. The autobraking feature is achieved based upon an open-loop control strategy where the ACC processor issues the braking request over a Class 2 communication protocol.

The DBC 7.2 system uses a fully sealed connector for all signal and power interfaces. The pin assignments are documented by production drawings for this program. The harness connector uses a mechanical assist mechanism to reduce the insertion force and is oriented for upward modulator installation in the vehicle. The system power is provided by battery voltage and the ECU monitors the battery supply for acceptable levels of voltage. Battery inputs are used to supply power to the electronics, the pump motor and solenoids. System diagnostics enable and disable functions per production specifications for operating voltage ranges.

The brake system includes two power grounds. The pump motor uses a vehicle power ground and the other ground for all other devices including the internal solenoids. The ECU has the capability to communicate with other vehicle systems, sensors, and offboard diagnostic test equipment. Specific software messages are designed to pass back and forth to the ACC processor. These messages contain brake control, status, sensor, and diagnostic information as appropriate.

The DBC 7.2 system provides the indication to the brake lamp relay during autonomous braking. During the autobraking scenarios a high side drive output drives the brake lamp relay which results in the brake lamps being lit during the autobraking function. Figure 6.2 shows high-level system interface block diagram.

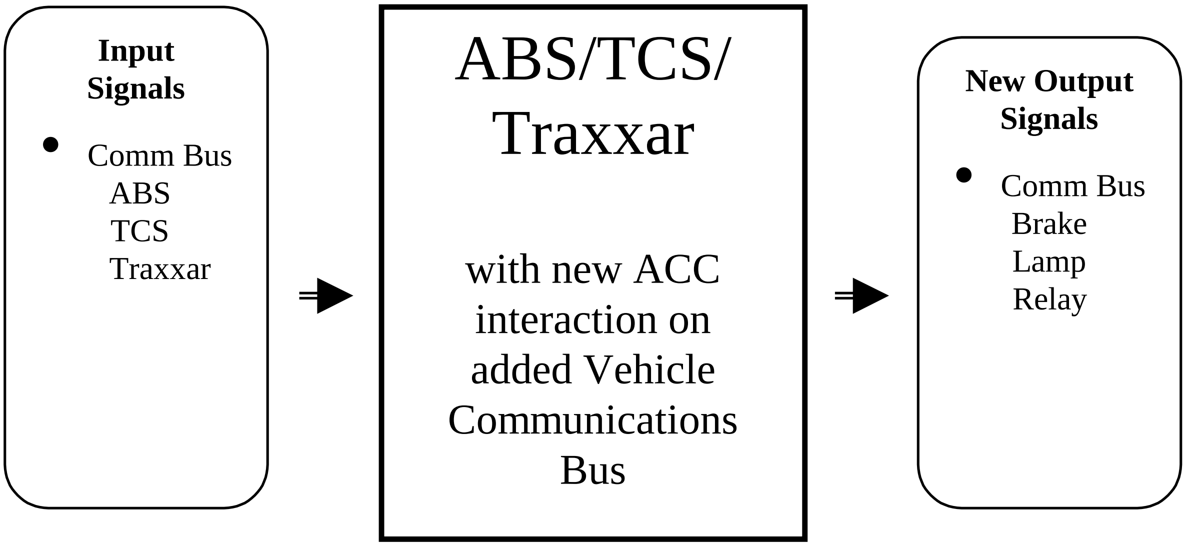


Figure 6.2 System Interface Block Diagram

6.2 System Verification

During system development, verification of the DBC 7.2 system is conducted per industry and federally regulated standards. The brake system is classified as a safety critical system and thus treated accordingly.

<u>Objectives</u>
The scope and purpose of this test is to determine if the messages are sent by the software at the specified rate. The test setup follows specific test procedures to test the applicable software version such that the communication bus is monitored for message transmissions. Delphi Engineering practices for production programs for brake system verification are followed.

Worked Accomplished
The communication interface between the DBC 7.2 brake system and the vehicle was tested on the functional bench during the design and development phases. This test setup incorporates hardware-in-the-loop to simulate sensor inputs for control algorithm testing. An example of a typical test consists of verification of message periodicity.

A second phase of brake system verification occurred at the vehicle level. The vehicle level tests were conducted in full compliance with the FMVSS Requirements. Additionally, an ABS/TCS/Traxxar/ACC test and verification plan for the ACAS/FOT program was used to direct the maneuvers to be performed and the test surfaces on which the tests were performed.

The vehicle level testing of the brake system will be conducted on a dedicated mule vehicle which is identical to the ACAS/FOT Prototype vehicle. This engineering development vehicle has identical brake hardware and performance capabilities. This vehicle is dedicated to support brake system development, testing, and verification of ACAS/FOT braking requirements. Corrective actions will be taken as necessary to ensure that all quantitative targets are met.

6.3 Vehicle Builds

Objectives
Development and refinement of the ACAS brake system for integration into the final vehicles.

Work Accomplished
Both the chassis mule and the prototype vehicles have the Delphi Brake System integrated on the vehicle. The release level of hardware is identical on both vehicles and significant production testing for production programs has occurred over the past two years. The calibration and tuning of the brake system for this program is the central focus. The engineering mule contains instrumentation used for calibration and data collection. This vehicle will be utilized as a resource for development and testing in support for the prototype vehicle.

The initial build of prototype vehicle with the Delphi brake system is complete. Work completed includes:

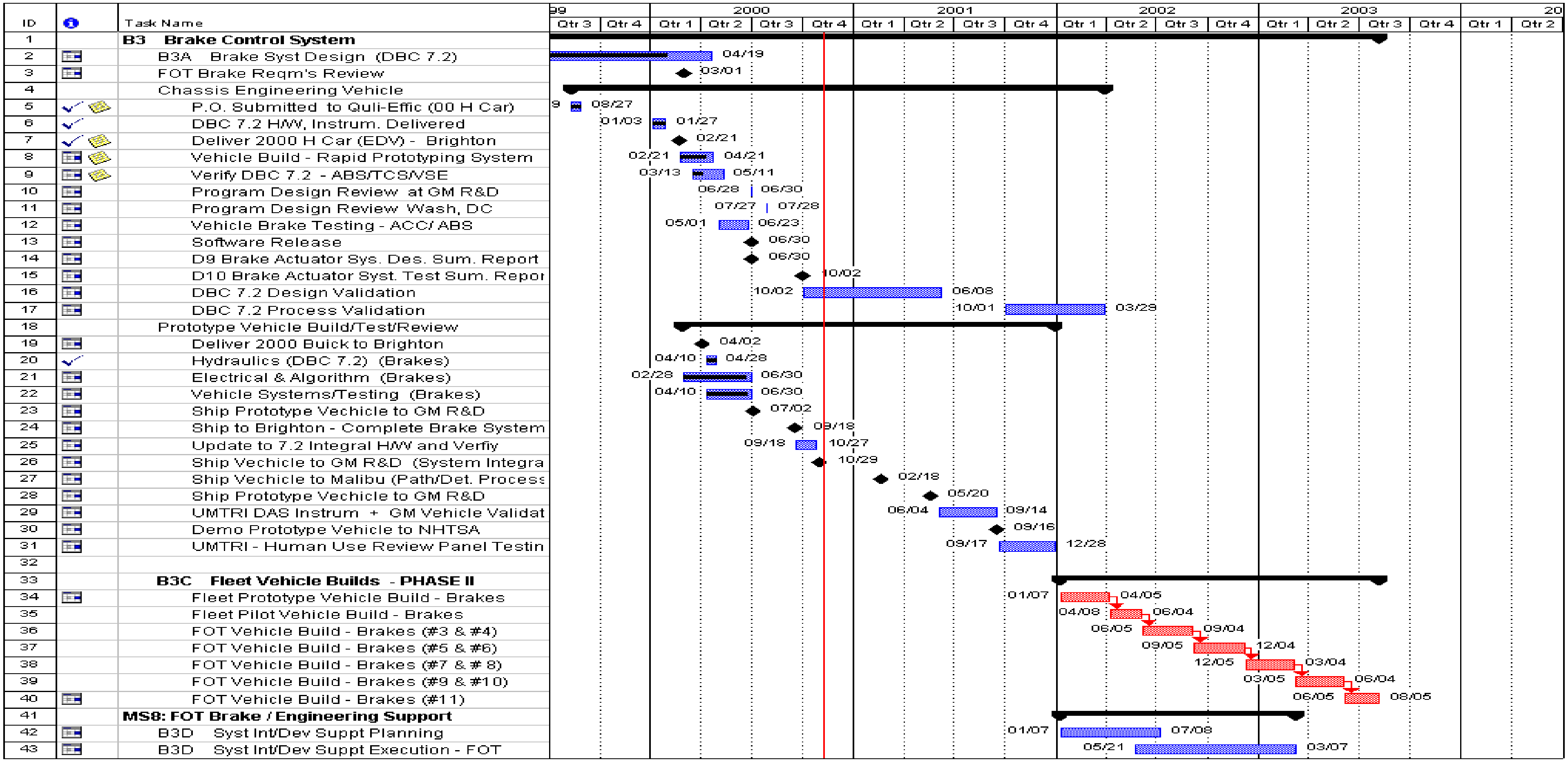
1. Removal of the production ABS Hydraulic Modulator Assembly
2. Installation of DBC 7.2 Hydraulic Modulator with a Passthru controller
3. Alignment of the front end of the vehicle to production alignment specifications
4. Fabrication and installation of a harness to convert the OEM connector to a DBC 7.2 vehicle harness connector
5. Installation of an extension harness from the DBC 7.2 Modulator Passthru to an emulator in the trunk.

This vehicle will be updated with an integral ECU and the harness will be removed. The software will be flashed in the ECU. The rapid prototyping hardware will also be removed from prototype vehicle trunk. In summary, the brake system will all be contained underhood within the engine compartment of the prototype vehicle.

Plans are in place to update the prototype hardware toward the end of the third quarter 2000. Additional details for brake system integration, calibration and testing are provided in the Gantt Chart in Figure 6.3.

Plans through December 2000 for Task B3

Testing and calibration of the software package on the Chassis Brake Engineering vehicle will be the primary focus over the next six months. The objective shall be to provide a production software package that meets vehicle requirements for a safe, reliable, smooth and quiet brake system. Engineering support for specific areas within Delphi such as ABS, TCS, Vehicle Stability Enhancement, and calibration engineering will support achieving standard brake system metrics and requirements. Approved software releases resulting from the above tests shall be used to support and update the ACAS/FOT prototype vehicle per the master schedule.



ID	Task Name
1	**B3 Brake Control System**
2	B3A Brake Syst Design (DBC 7.2)
3	FOT Brake Reqm's Review
4	Chassis Engineering Vehicle
5	P.O. Submitted to Quli-Effic (00 H Car)
6	DBC 7.2 H/W, Instrum. Delivered
7	Deliver 2000 H Car (EDV) - Brighton
8	Vehicle Build - Rapid Prototyping System
9	Verify DBC 7.2 - ABS/TCS/VSE
10	Program Design Review at GM R&D
11	Program Design Review Wash, DC
12	Vehicle Brake Testing - ACC/ ABS
13	Software Release
14	D9 Brake Actuator Sys. Des. Sum. Report
15	D10 Brake Actuator Syst. Test Sum. Repor
16	DBC 7.2 Design Validation
17	DBC 7.2 Process Validation
18	Prototype Vehicle Build/Test/Review
19	Deliver 2000 Buick to Brighton
20	Hydraulics (DBC 7.2) (Brakes)
21	Electrical & Algorithm (Brakes)
22	Vehicle Systems/Testing (Brakes)
23	Ship Prototype Vechicle to GM R&D
24	Ship to Brighton - Complete Brake System
25	Update to 7.2 Integral H/W and Verfiy
26	Ship Vechicle to GM R&D (System Integra
27	Ship Vechicle to Malibu (Path/Det. Process
28	Ship Prototype Vechicle to GM R&D
29	UMTRI DAS Instrum + GM Vehicle Validat
30	Demo Prototype Vehicle to NHTSA
31	UMTRI - Human Use Review Panel Testin
32	
33	**B3C Fleet Vehicle Builds - PHASE II**
34	Fleet Prototype Vehicle Build - Brakes
35	Fleet Pilot Vehicle Build - Brakes
36	FOT Vehicle Build - Brakes (#3 & #4)
37	FOT Vehicle Build - Brakes (#5 & #6)
38	FOT Vehicle Build - Brakes (#7 & # 8)
39	FOT Vehicle Build - Brakes (#9 & #10)
40	FOT Vehicle Build - Brakes (#11)
41	**MS8: FOT Brake / Engineering Support**
42	B3D Syst Int/Dev Suppt Planning
43	B3D Syst Int/Dev Suppt Execution - FOT

Figure 6.3 Task B3 Schedule

7 THROTTLE CONTROL SYSTEM (TASK B4)

Objectives

The objectives of Task B4 are to:

1. Provide modified throttle control systems for the development and deployment vehicles.
2. Provide interface requirements to other vehicle systems.
3. Provide support to development and deployment groups.

Approach

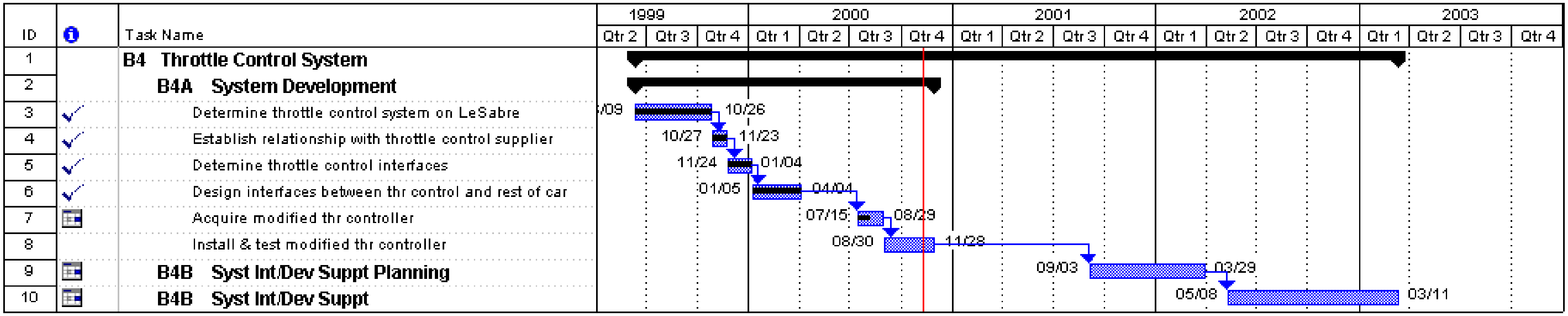
The basic approach to accomplishing this task is to use the existing throttle control system on the Buick LeSabre. The throttle control in the Buick LeSabre is a stepper motor cruise control (SMCC) designed and built by Delphi. This SMCC has been used successfully in other projects and the modifications required are known.

Work Accomplished

Delphi-E has been contacted and will provide the necessary engineering support for the hardware and software modification that will be required. The interface is a serial 8192 link that is compatible with the Buick LeSabre. The modifications required are to modify the standard unit to accept input from the ACC system, and to report the driver's input without taking any action, with the exception of on/off and safety related functions.

Plans through December 2000

The plans for the next 6 months are to make the modifications to the Stepper Motor Cruise Control hardware and software in anticipation of installing and tuning it for the prototype vehicle, which will arrive at Malibu in February 2001.



ID	ℹ	Task Name
1		**B4 Throttle Control System**
2		**B4A System Development**
3	✓	Determine throttle control system on LeSabre
4	✓	Establish relationship with throttle control supplier
5	✓	Detemine throttle control interfaces
6	✓	Design interfaces between thr control and rest of car
7	▦	Acquire modified thr controller
8		Install & test modified thr controller
9	▦	**B4B Syst Int/Dev Suppt Planning**
10	▦	**B4B Syst Int/Dev Suppt**

Figure 7.1 Task B4 Schedule

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8 DRIVER-VEHICLE INTERFACE (TASK B5)

Objectives

The primary objective of the Driver-Vehicle Interface Task is to develop an interface that will convey information from the Adaptive Cruise Control and Forward Collision Warning systems to the vehicle operator in as unambiguous a fashion as possible. For the FCW system, warning cues and presentation methodology must be selected and developed so as to immediately direct the driver’s attention to the primary task of evaluating and reacting to the critical crash event, while allowing sufficient time to perform some corrective vehicle control action to either avoid the event or at a minimum to mitigate the crash energy. For the Adaptive Cruise Control system, sufficient information must be presented to the driver so that he/she is constantly aware of the current status of the system (e.g., cruise control set speed, selected intervehicle separation distance, and whether or not a preceding vehicle has been detected by the system). For both systems, this information must be presented in such a fashion as to be easily understandable at a glance by the operator and in such a manner so as not to induce extra workload onto the driving task.

Approach

Based on previous research, a number of potential Driver-Vehicle Interface philosophies could be followed in the ACAS FOT program. The first, focused on in the previous CAMP program, would be to utilize a single-stage imminent collision alert which would unambiguously cue the driver that corrective action was immediately required to avoid a collision. There are a number of positive and negative aspects to this approach. On the positive side, such a single stage alert provides a clear indication to the driver that immediate corrective action must be undertaken while minimizing the amount of information presented to the driver at other points in time (i.e., the information is only presented when an imminent collision situation is detected and no additional workload is imposed on the driver at other points in time). On the negative side, no advance information regarding the potential for an imminent collision warning is provided, so the warning may potentially come as a surprise to the driver. A second approach involves the utilization of a multi-stage warning, with the initial stage providing a lower level, preparatory warning cue to the driver that an emergency response may be necessary. From a positive standpoint, such a system might serve to lessen the potential “startle” reaction on the part of the driver (a delay in response stemming from the surprise effect of a sudden collision alert). From a negative standpoint, timing for such a system is a critical issue. Set too early, such a preliminary warning may occur too often and prove annoying to the driver or be ignored routinely, drastically lessening the effectiveness of both the cautionary alert and imminent collision warning. A third approach would be to provide continuous information to the driver regarding his/her current “following” safety, taking into account such considerations as average preceding vehicle braking, road conditions, etc. and combining this with a imminent collision alert. Such an approach might have the effect of increasing inter-vehicle separation distances under manual driving conditions, thus addressing the second most common cause of rear-end collisions (inadequate following distances), as well as that of driver inattention. Previously published studies have showed promise in this regard. The one potentially negative effect of such an approach would be driver annoyance at the continuously displayed information.

The third approach detailed above has been selected as the preferred alternative for the ACAS-FOT program, though interfaces for the other two approaches will be designed and evaluated in both driving simulator and test track scenarios during the development process. The hardware selected for incorporation in the fleet vehicles is being designed to allow for maximum flexibility in terms of being able to be used for any of the three primary alternatives or variations thereof.

Milestones and Deliverables

A DVI technology exchange “Kick-Off” meeting was conducted in September of 1999 involving NHTSA, industry, and academic parties with interests/expertise in the collision avoidance arena. Relevant research in the area was identified and shared collectively among all participants. This collaboration continues as the program progresses. An interesting outcome of this information sharing was the fact that while considerable research has been performed in the area of rear-end collision avoidance displays and warnings and a lesser volume has been produced regarding adaptive cruise control interfaces, relatively little has been done addressing the human interface for a system combining both.

A DVI warning cue implementation summary report detailing the behavioral and performance issues associated with each of the possible DVI approaches will be produced and submitted to NHTSA in February 2001.

Work Accomplished

Candidate display formats have been developed for all three of the primary DVI approaches identified earlier. The primary focus has been on a gradient display as is illustrated in Figure 8.1 below. This option provides the driver with continuously updated information regarding their current ‘‘following status’’ relative to a preceding vehicle at all times.

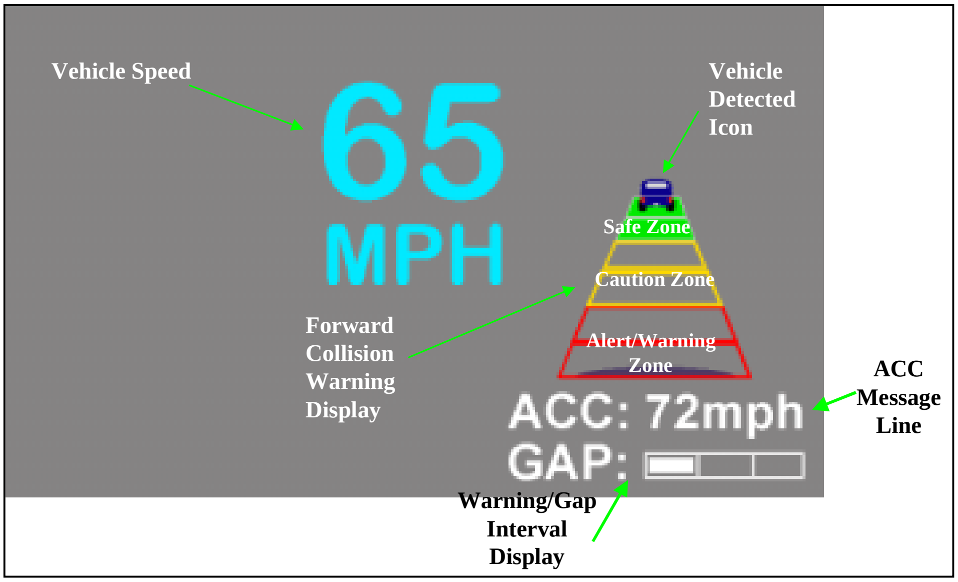


Figure 8.1 Gradient Display

Earlier research has indicated that a similar display had the effect of increasing inter-vehicle spacing in the test vehicles by a significant amount, thus giving this DVI approach a potential additional positive affect not present in two alternative approaches (influencing drivers to maintain adequate vehicle separation to allow themselves time to react appropriately in potential collision situations).

An upper-level systems drawing of the DVI hardware is presented in Figure 8.2. Hardware is currently under development to produce a Head Up Display (HUD) for the FOT test fleet capable of showing any of the DVI candidate visual displays. A developmental agreement is in place with a manufacturer of visual display cells to produce a high resolution, full-color, daylight brightness unit to be employed in the HUD and prototypes are expected to be available in the first months of CY2001. The CAMP collision avoidance audio tone has been selected for use with any potential visual display and work in currently underway to develop apparatus allowing the volume of this tone to be adjusted automatically to an appropriate level based on current in-vehicle ambient sound levels. Electronics to remap the existing steering wheel controls and allow both ACC/FCW and conventional cruise functionality depending on the current phase of the

FOT field-testing are also under development. A current model Buick LeSabre has been procured to serve as a development/test bench to allow prototype hardware to be designed and built to fit within the existing LeSabre instrument panel with minimal modification.

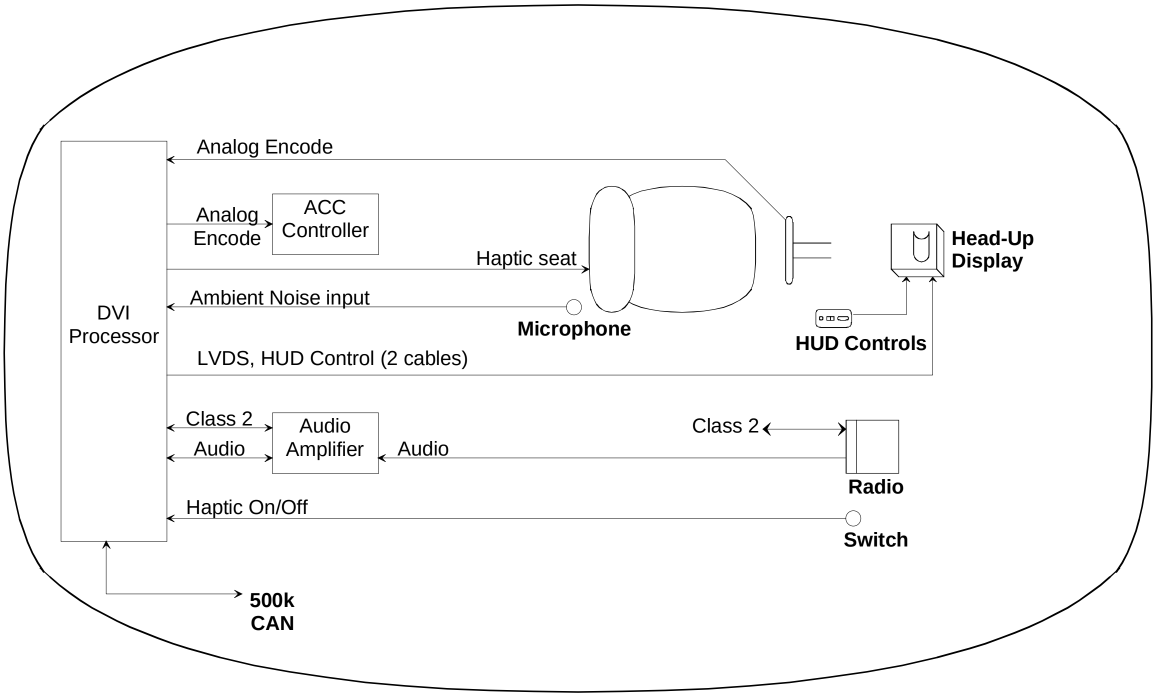


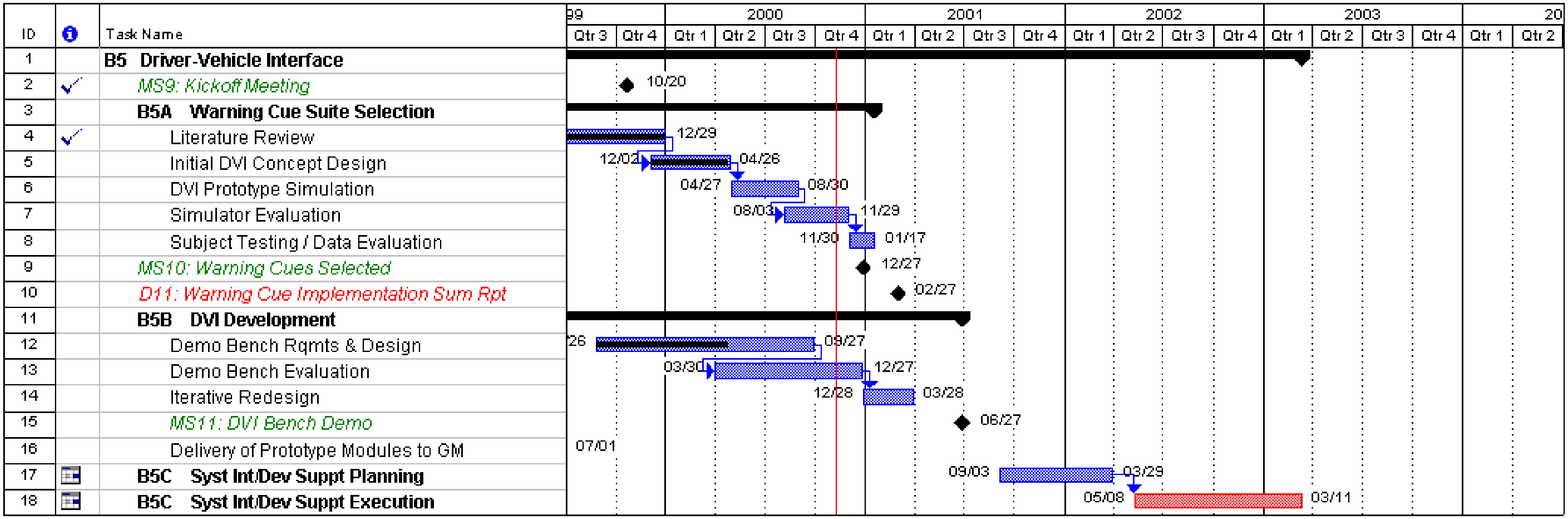
Figure 8.2 DVI Hardware

Research Findings

No new research has been performed to date under this task. Research will, however, be a necessary component of DVI visual format candidate refinement and eventual down selection. To this end, the Delco Electronics facility is being upgraded to include a current generation Hyperion Technologies driving simulator. This simulator allows for the real-time output of “opposing” vehicle information to be processed by the collision avoidance threat algorithms that are used to drive the driver alerts.

Plans through December 2000

During the next six months prototype hardware design, build, and test for the DVI supporting infrastructure will continue using the Delco Electronics engineering development vehicle as a test bench. The DVI candidate visual displays will undergo a refinement and test process employing Delco and GM driving simulators and the engineering test vehicles under both closed course and on-road evaluations. Variables of interest include timing parameters for all DVI candidates, utility of displayed information (whether drivers actively make use of intervehicle spacing information if provided), the distraction potential of continuously presented information, subjective (driver preference) data regarding each format, potential saliency augmentations of visual and aural cues, and the relative performance of integrated vs. discrete visual cues for following health and imminent collision (the current gradient display integrates the collision alert---tests will be performed to evaluate the efficacy of utilizing the gradient display only for following distance information and the CAMP visual alert for imminent collisions). A two-stage alternative displaying cautionary information regarding following distance and warning information regarding imminent collisions will also be evaluated.



ID		Task Name
1		**B5 Driver-Vehicle Interface**
2	✓	*MS9: Kickoff Meeting*
3		**B5A Warning Cue Suite Selection**
4	✓	Literature Review
5		Initial DVI Concept Design
6		DVI Prototype Simulation
7		Simulator Evaluation
8		Subject Testing / Data Evaluation
9		*MS10: Warning Cues Selected*
10		*D11: Warning Cue Implementation Sum Rpt*
11		**B5B DVI Development**
12		Demo Bench Rqmts & Design
13		Demo Bench Evaluation
14		Iterative Redesign
15		*MS11: DVI Bench Demo*
16		Delivery of Prototype Modules to GM
17	▦	**B5C Syst Int/Dev Suppt Planning**
18	▦	**B5C Syst Int/Dev Suppt Execution**

Figure 8.3 Task B5 Schedule

9 DATA FUSION (TASK C1)

9.1 Requirements Definition and Architecture Development (Task C1A)

Objectives

The objective of this task is to develop performance and interface requirements and the architecture for the data fusion subsystem.

Approach

The approach is to gather information on each sensor subsystem – data provided, performance specifications, confidence measures, and information on the requirements for the subsystems that use the output of the data fusion subsystem to develop performance and interface requirements. This information will also be used to determine the fusion algorithms and set requirements on the data fusion architecture.

Milestones and Deliverables

The initial data fusion architecture and performance requirements definition was completed and presented at a meeting at HRL on 9/16/99.

Work Accomplished

HRL developed performance and interface requirements for the data fusion subsystem, which have been incorporated into the Data Fusions requirements.

Research Findings

The main research finding of this task is that the data fusion subsystem must be robust and able to detect and handle situations when there is missing or invalid data.

Plans through December 2000

This task has been completed.

9.2 Initial Algorithm Development (Task C1B)

Objectives
The objective of this task is to develop fusion algorithms to fuse radar, lane tracking, GPS/map, and host vehicle sensors to produce a robust estimate of the host lane geometry, host state, driver distraction level, and environmental state.

Approach
The data fusion subsystem can be divided into four main functional subunits:

1. Host lane geometry estimation: The data fusion subsystem provides an estimate of the forward lane geometry of the current host vehicle lane by fusing forward lane geometry estimates from the vision sensor subsystem, map-based subsystem, scene-tracking subsystem, and curvature estimates based upon vehicle dynamics sensors. Since vehicle motion along the road makes forward road geometry a quantity that varies dynamically with time, HRL needed to use a dynamic recursive estimation approach such as the Kalman filter. Kalman filters perform recursive estimation using both a model-based update of state variables and an update of the state estimates using a weighted version of the new measurements. Fusion is done using Kalman filters as it provides a natural framework of fusing incomplete and inaccurate information from multiple sources and can provide more accuracy and improved robustness to stochastic errors (e.g., sensor noise) as it acts as a sort of ‘‘low-pass’’ filter. A fundamental issue in fusing different forms of information about forward lane geometry in a Kalman filter framework is the choice of a good road model. HRL investigated several different road models (parabolic, single-clothoid, spline) and chose a “ higher-order” road model after extensive testing on simulated and some real data.

2. Host state estimation: The data fusion subsystem provides a ‘‘fused’’ host state estimate by fusing information from vision and scene-tracking subsystems. Host state primarily consists of host vehicle offset and orientation in its lane. HRL used a Kalman filter approach for host state estimation as well for reasons discussed above. In addition, since host vehicle sideslip angle needs to be estimated in the process model, this parameter was also included in the state-space representation of the Kalman filter.

3. Driver distraction estimation: The approach to estimating driver distraction is based on determining if and what type of secondary task the driver is performing. HRL then use a fuzzy rule-based system to estimate the driver distraction depending on the type of task and when the task was initiated.

4. Environmental state estimation: When used to interpret environment state, the data fusion subsystem detects and reports conditions indicative of slippery road surfaces. Data on conditions is used to modify the expected braking intensity the driver will achieve when responding to an alert. In turn, the expected intensity has an impact on the timing of the alerts. Our approach is to develop a rule-based system to indicate road conditions and an associated confidence measure as a function of windshield wiper activity and outside temperature.

Milestones and Deliverables

The first milestone for this task is the Preliminary Data Fusion Algorithm Demonstration. This demonstration, which is scheduled for December 2000, will be an offline (i.e., non real-time) demonstration of all four parts of the data fusion subsystem: host lane geometry estimation, host-state estimation, driver distraction level estimation, and environment state estimation.

Although not part of the official list of program deliverables, a preliminary version of the data fusion software was delivered to GM for insertion into the EDV in September 2000. Also, a model of the data fusion subsystem was provided to PATH for use in the PATH simulator.

Work Accomplished

HRL has developed and implemented initial versions of algorithms for host lane geometry, host state, driver distraction and environment state estimation. These algorithms were chosen and developed after extensive literature survey and testing of several competitive and promising approaches. For example, as discussed above, HRL tested several different commonly used road models and compared errors in estimating road geometry in both a recursive (Kalman) and a non-recursive (least-squares) framework. This performance evaluation demonstrated that conventional “single-clothoid” road models have estimation errors that would not meet the system performance requirements. This motivated us to develop a higher-order road model that was amenable to state-space representation in a Kalman filter framework.

We have completed development and implementation of this novel road model and evaluated its performance. Results show that this model is superior to a conventional “single clothoid” road model as it has smaller road geometry estimation errors, especially during sharp transitions in road curvature. Fig. 9.1 shows a simulation scenario used to evaluate these road models. The simulated road geometry is shown in the left half of the figure, while the clothoid coefficients c0 and c1 are shown in the right half. The transition points (changes in c1 coefficient) are also shown in Fig. 9.1. A host vehicle is simulated to traverse the road with a speed of 20m/sec with a look-ahead distance of 100m. Road geometry information is provided as offsets of 10 points along the road spaced 10m apart starting in front of the host vehicle. The sampling rate is chosen as 10Hz. A Kalman filter based on single-clothoid and new road model uses these offsets as measurements and estimates road geometry. The estimated road geometry is compared to the simulated road geometry and errors computed. Figure 9.2 shows the mean and maximum estimation errors of the single-clothoid and new road models as a function of time (x-axis).

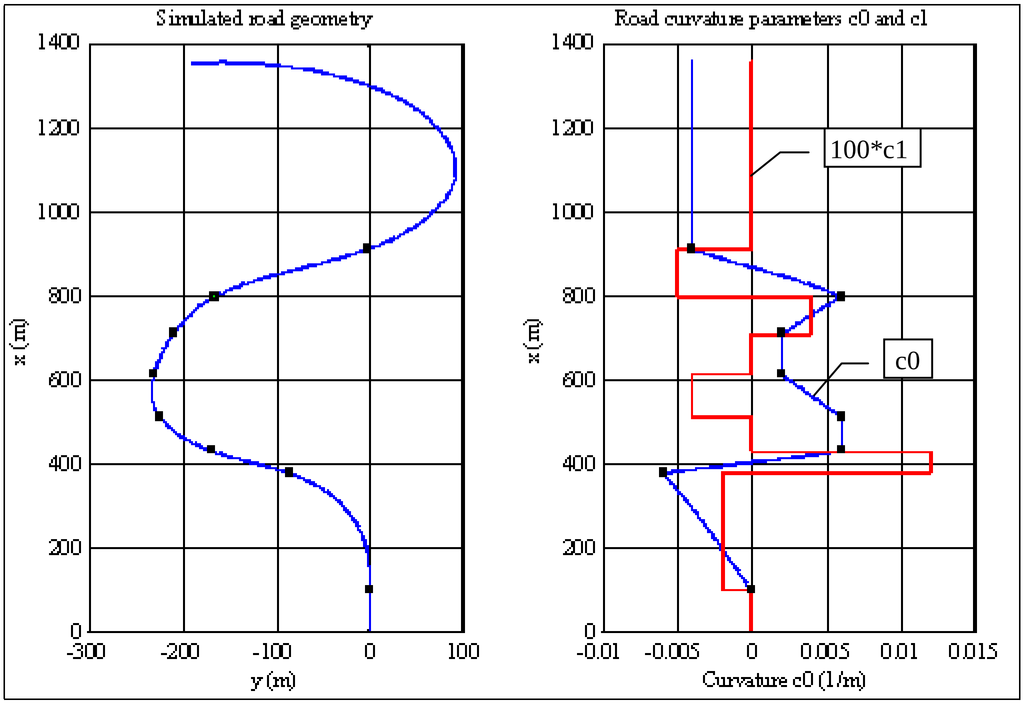


Figure 9.1 Simulation Scenario Used to Evaluate These Road Models

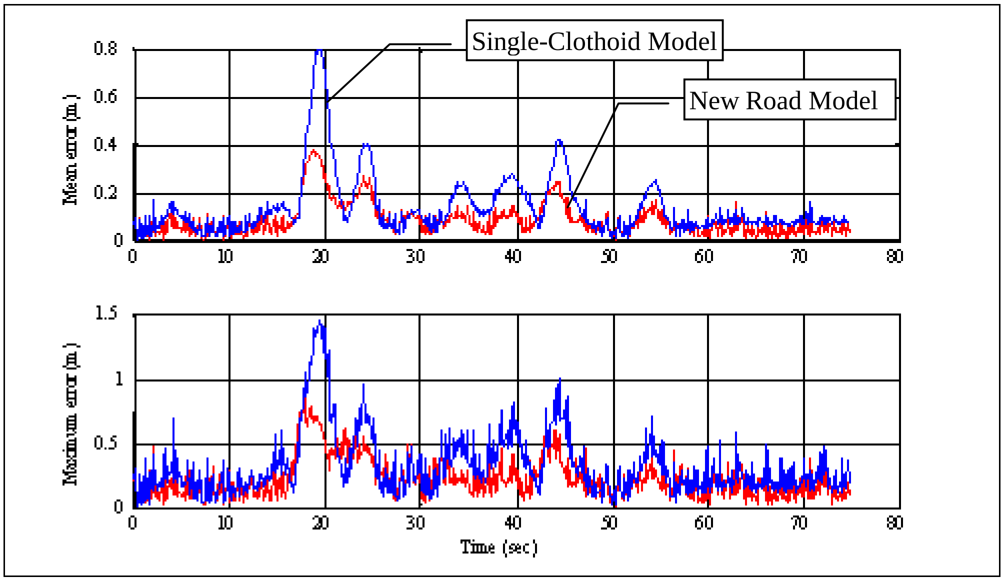


Figure 9.2 Mean And Maximum Estimation Errors

The performance of this model is currently being evaluated on roads obtained from the NavTech database.

HRL has also developed an adaptive Kalman filter approach for road geometry and host state estimation which is superior to a conventional Kalman filter. The adaptive Kalman filter performs better during sharp transitions in road geometry compared to a conventional Kalman filter. Performance evaluation using real data is in progress.

We developed a fuzzy-rule based algorithm to estimate driver distraction. The data fusion subsystem provides an estimate of driver distraction by monitoring if the driver is performing a secondary task. In our working model, there are two major categories of secondary tasks that may affect driver situation awareness. The first one is a simple task that just requires one glance to complete the necessary visual aspect. The second one is complex and requires many short sampling glances away from the forward view. For the first category, once the control is activated, the amount of distraction left to predict is insignificant. In other words, the activation of the control essentially follows the single-glance distraction time. In complex secondary tasks the driver's vision is time-shared with the primary driving task. The driver cyclically samples the task, activates the control and returns to the forward view for as many glancing cycles as are needed to complete his task (adjusting the radio, perhaps, or turning on the air conditioning). The domain knowledge assumes that the first activation of any of the controls (FACT) for such tasks follows the first glance time and predicts a high degree of distraction for the next 8-10 seconds. In fact, the elapsed time (**1stAct**) from the FACT is used to predict the coming level of driver distraction for a given complex task such as radio knob adjustments. The **1stAct** is defined as the difference between current time and the time of FACT. The longer the **1stAct** is, the less predictable is the driver distraction level for the remaining glance time. In other words, the strength of the **1stAct** is inversely proportional to its length. To predict driver distraction level, fuzzy rules are based on the strength of **1stAct** and Duration as depicted by the matrix shown in Table 9.1. "Duration" relates to the current given cycle of activation of control and is quantized as long, normal, short, or off; and the strength of 1stAct, as off, weak, medium, or strong. Performance evaluation of the driver distraction estimation algorithm is in progress using simulated inputs.

Table 9.1 Driver Distraction Level

Radio, HVAC & DVI with knob adjustments						
Driver Distraction		Duration				
		long	normal	short	off	fault
1stAct	off	**LOW**	LOW	LOW	NONE	NONE
	weak	**MED**	MED	LOW	NONE	NONE
	medium	MED	HIGH	MED	LOW	NONE
	strong	MED	HIGH	HIGH	MED	NONE

The environment state estimation algorithm detects and reports conditions indicative of slippery road surfaces. Data on conditions is used to modify the expected braking intensity the driver will achieve when responding to an alert. In turn, the expected intensity has an impact on the timing of the alerts. HRL defined road conditions as dry, dry-icy, wet, or icy. They are provided at a confidence level specified as none, low, medium or high. Both the road conditions and their associated confidence levels are derived based first upon the windshield wipers activity; then further refined through use of outside temperature measurements, as shown by the matrix in Table 9.2. Performance evaluation of the environment state estimation algorithm is in progress using simulated inputs.

Table 9.2 Environment State Estimation

Road condition based on wiper activity and temperature				
	wiper not active		wiper active	
	above freezing	below freezing	above freezing	below freezing
Road surface condition	DRY	DRY-ICY	WET	ICY
Confidence level	HIGH	LOW	HIGH	MED

Research Findings

1. The ‘‘new’’ road model is superior to a conventional single-clothoid road model as it produces smaller road geometry estimation errors, especially during sharp transitions in road curvature. In some of the simulation studies, during a transition form a straightaway to a 300m curvature segment, the single-clothoid road model had errors of about one-half lane width, while the new model had maximum errors of the order of less than one-quarter of lane width. Better road geometry estimation should translate into lower errors in identifying in-path targets vs. out-of-path targets.
2. The adaptive Kalman filter performs better during sharp transitions in road geometry compared to a conventional Kalman filter. This allows the system to respond rapidly to changing road curvature and could once again provide increased accuracy in determining host vehicle path and reducing errors in detecting in-path vs. out-of-path targets. The same approach is also applicable to host state estimation where the system will have better ability in tracking host state accurately during transitions and lane-change maneuvers. Performance of this approach will be evaluated on real data in the near future.

Plans through December 2000

Plans for the next six months are to work with GM to collect synchronized data from all of the sensor subsystems so that we can test the performance of the fusion algorithms on real data. The real data will also be used to refine the fusion algorithms to improve performance.

9.3 Real-time algorithm development (Task C1C)

Objective

The objective of this task is to develop real-time versions of the algorithms developed in Task C1B for integration into pilot and deployment vehicles.

Approach

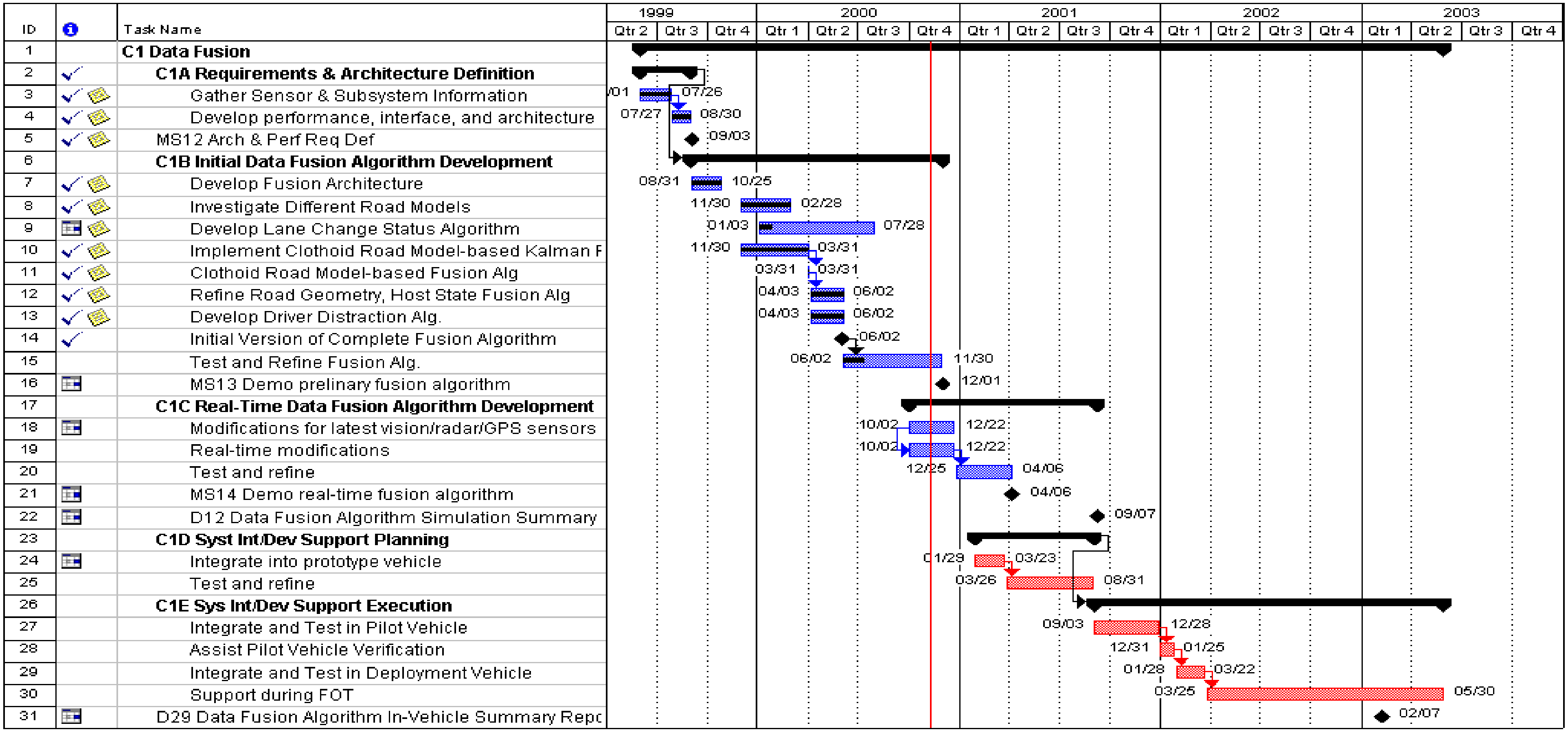
To develop real-time versions of the algorithms developed in Task C1B, our approach is first to port the algorithms onto the real-time hardware platform specified by GM for the data fusion subsystem. After porting the algorithms, we will evaluate algorithm real-time performance to determine if there are portions of the fusion algorithm that must be tuned or modified to meet real-time processing requirements.

Milestones and Deliverables

The first milestone for this task is the Data Fusion Algorithm Demonstration, which is scheduled for the end of April 2001.

Work Accomplished
This task has not yet started.

Plans Through December 2000
This task is scheduled to start in October 2000. We will begin porting of the data fusion algorithms to hardware specified by GM and begin real-time performance evaluation.



ID	ℹ	Task Name
1		**C1 Data Fusion**
2	✓	**C1A Requirements & Architecture Definition**
3	✓ 📝	Gather Sensor & Subsystem Information
4	✓ 📝	Develop performance, interface, and architecture
5	✓ 📝	MS12 Arch & Perf Req Def
6		**C1B Initial Data Fusion Algorithm Development**
7	✓ 📝	Develop Fusion Architecture
8	✓ 📝	Investigate Different Road Models
9	📅 📝	Develop Lane Change Status Algorithm
10	✓ 📝	Implement Clothoid Road Model-based Kalman F
11	✓ 📝	Clothoid Road Model-based Fusion Alg
12	✓ 📝	Refine Road Geometry, Host State Fusion Alg
13	✓ 📝	Develop Driver Distraction Alg.
14	✓	Initial Version of Complete Fusion Algorithm
15		Test and Refine Fusion Alg.
16	📅	MS13 Demo prelinary fusion algorithm
17		**C1C Real-Time Data Fusion Algorithm Development**
18	📅	Modifications for latest vision/radar/GPS sensors
19		Real-time modifications
20		Test and refine
21	📅	MS14 Demo real-time fusion algorithm
22	📅	D12 Data Fusion Algorithm Simulation Summary
23		**C1D Syst Int/Dev Support Planning**
24	📅	Integrate into prototype vehicle
25		Test and refine
26		**C1E Sys Int/Dev Support Execution**
27		Integrate and Test in Pilot Vehicle
28		Assist Pilot Vehicle Verification
29		Integrate and Test in Deployment Vehicle
30		Support during FOT
31	📅	D29 Data Fusion Algorithm In-Vehicle Summary Repc

Figure 9.3 Task C1 Schedule

10 TRACKING AND IDENTIFICATION (TASK C2)

The objectives of the Tracking and Identification Task are to:

1. Refine the path estimation and target identification algorithms,
2. Incorporate vision and GPS-derived information
3. Integrate algorithms into the FOT vehicle system
4. Support FOT Deployment.

A significant amount of progress has been accomplished during the first program year under this task. Delphi is largely responsible for the conventional target path estimation (Task C2A) and radar based scene tracking activities (Task C2B) associated with the Tracking and Identification Task. GM is responsible for the enhanced GPS approach (Task C2C). This section provides a summary of the major activities that were initiated and the achievements that were accomplished.

10.1 Conventional Approach Development (Task C2A)

Objectives

Adaptive Cruise Control (ACC) and Forward Collision Warning (FCW) systems require an ability to resolve and identify robustly the existence of both stationary and moving ‘target’ vehicles that are in the motion path of the Host vehicle. The performance of these systems is affected by their ability (a) to estimate the relative inter-vehicular path motion (i.e.: range, relative speed, radius of curvature, etc.) between the host vehicle, the roadway ahead of the host, and all of the appropriate targets (i.e.: roadside objects, and in-lane, adjacent lane, and crossing vehicles, etc.); and (b) to predict the mutual intersection of these motion paths. In addition, these systems must be robust in the presence of various types of driving behavior (e.g.: in-lane weaving/drift, lane change maneuvers, etc.) and roadway conditions (e.g. straight roads, curved roads, curve entry/exit transitions, intersections, etc.) that are encountered in the ‘real-world’ environment.

During the previous ACAS Program (1995-1998), significant activities were undertaken by Delphi to improve our existing path estimation and in-path target selection algorithms. The target selection approach pursued used a single active forward looking radar sensor augmented with a yaw rate sensor. The forward-looking radar sensor provided target range, range rate, and angular position information. The yaw rate sensor was used to estimate the roadway curvature ahead of the Host vehicle. Delphi’s first generation target discrimination algorithms were used to identify overhead bridge objects and to discriminate between moving cars and trucks. The Target / Host kinematics were evaluated to determine target motion status (i.e.: oncoming, stopped, moving, cut-in and cut-out, etc.), and geometric relationships were employed to determine which of the valid roadway objects fell within the Host’s forward projected path. The improved algorithms yielded very good results, but they were prone to false alarms during curve entry/exit scenarios and during host lane changes.

Approach

In the current ACAS FOT program, four complementary host and road state estimation approaches are being developed. The complementary approaches are as follows: (a) vision based road prediction (Task B2), (b) GPS based road prediction (Task C2C), (c) radar based scene tracking (Task C2B), and (d) yaw rate based road and host state estimation (Task C2A). These four road and host state estimation approaches are being correlated and fused by the Data Fusion Task (C1) and provided parametrically to the Tracking and Identification Task. The fused road and host state information provides an improved estimate of the roadway shape/geometry in the region ahead of the Host vehicle, and an improved estimate of the Host vehicle's lateral position and heading within its own lane. This information is being incorporated into the Tracking and Identification functions to provide more robust roadside object discrimination and improved performance at long range, during lane change maneuvers, and during road transitions. In addition, a new radar-based roadside object discrimination algorithm is also being developed to cluster and group roadside stationary objects, and the first generation truck discrimination algorithms developed during the previous ACAS program are being enhanced. Furthermore, a new yaw rate based host lane change detection algorithm is also being developed.

Work Accomplished and Research Findings

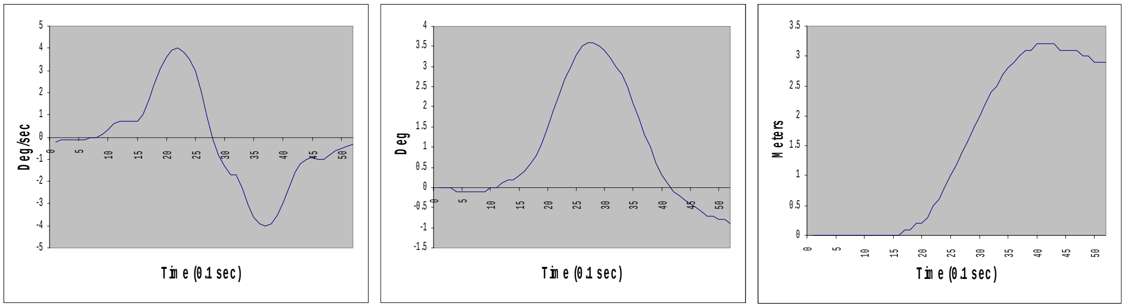
Under this task accomplishments have been made in the areas of Path Algorithm development, Host Lane Change Detection Development, Roadside Distributed Stopped Object Detection, and simulated Road Scenario generation. In addition, significant progress has been made on the testing and integration of the various Target Tracking and Identification sub-systems.

Path Algorithm Development

During the first year of the program, enhancements to the target selection algorithms were developed to improve performance during curve transitions and host lane changes. Modifications were made to compute target lateral lane positions using the road and Host state derived from the radar based scene tracking sub-system (Task C2B), and to use this information to better distinguish between in-lane and adjacent-lane vehicles. Improvements were also made to shift the target selection zone to the adjacent lane during host lane changes, and to alter the zone's characteristics while the host is settling into the new lane.

Host Lane Change Detection Development

Prior to the start of the ACAS FOT program, Delphi began an effort to develop and evaluate alternative host lane change classifiers. The classifiers were designed to satisfy the requirements that (a) lane-change must be detected before it is approximately 50% complete, and that (b) the cost of false lane-change detections is very high. A variety of neural network classifiers, decision-tree classifiers, and individual template-matching classifiers were constructed. In addition, ensemble classifiers consisting of various combinations of these individual classifiers were also been constructed. The inputs to each classifier have included various combinations of yaw-rate data, heading angle data, and lateral displacement data (Figure 10.1); the outputs denote whether the host vehicle is currently making a left lane-change, a right lane-change, or being driven in-lane.



(a) Yaw-Rate (b) Heading Angle (c) Lateral Displacement

Figure 10.1 Sample Input Data

During the past year, refinements have been made to the core host lane change detection algorithms. Thus far, an ensemble classifier consisting of three neural networks has shown the most promise. Tests on a very limited amount of data suggest that this classifier can detect approximately 50% of the lane-changes made while generating on the order of 5-10 false alarms per hour of driving. Delco is continuing to look at techniques for improving this performance. In addition, the neural network ensemble classifier is currently being incorporated into the target tracking and identification simulation.

Roadside Distributed Stopped Object Detection

During the past year, an effort was initiated to detect roadside distributed stopped objects (DSOs) using various linear and curve fit approaches. Examples of such a distributed stopped object are a guardrail, a row of parked vehicles, a row of fence posts, etc. Two advantages of having this information are that it allows: (a) discrimination of false targets from real targets during curve transitions and pre-curve straight segments, and during host lane changes; and (b) utilization of the geometry of the distributed stopped object to aid in predicting curves in region ahead of the host vehicle.

This task is still in the very earliest stages of development. Several algorithms have been tried, with varying results. Much of the work has focused on finding useful ways to separate radar returns associated with DSOs from the other stopped object returns. In the early algorithms, it has been assumed that distributed stopped objects will provide returns that form a distinguishable line. The focus of these algorithms has been to find the line amid all of the stationary object returns. Other algorithm efforts have concentrated on defining the geometry of the DSO to aid in predicting the location of the road edge. Figure 10.2 shows an example of Delphi's DSO clustering approach. The figure depicts stopped objects taken from a single frame of data that was collected with the HEM ACC2 radar during a road test. The circles in the figure represent stopped object returns that were seen for the first time in the current frame. The squares represent "persistent" stopped object returns (i.e.: returns that have appeared on enough successive scans to be considered real objects). The triangles represent formerly persistent radar returns that have disappeared momentarily and are being "coasted" by the radar tracker. Color-coding of the objects is used to denote radar track stage of each return.

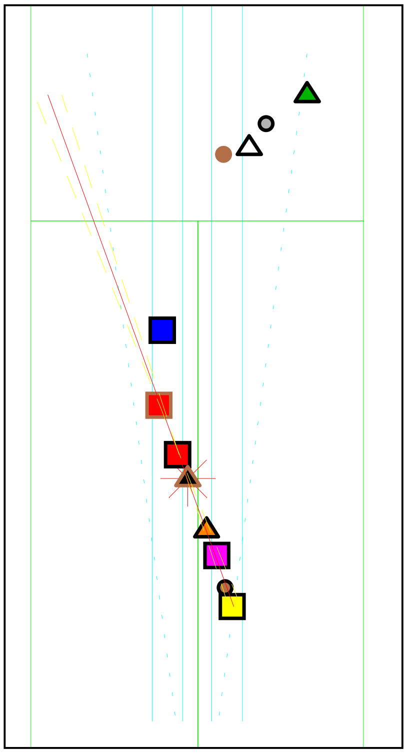


Figure 10.2 Distributed Object Detection Example

In this figure, the Host Vehicle is on a road with a guardrail on the right side, approaching a left turn, and will then encounter a T-intersection. Some cars are parked along the other road. The algorithm was able to detect the guardrail and not be distracted by the parked cars. Work on this effort will continue as time permits.

Road Scenario Generator

During the past year, DDE has developed a Matlab™ based road scenario generator that propels the host and various scene targets along different predefined road scenarios. The model includes a host steering controller, radar model, and yaw rate and speed sensor models. The scenario generator also allows host and target weaving and lane change behavior to be specified. These simulated scenarios are used to evaluate the Target Tracking and Identification algorithms.

Delphi Engineering Development Vehicles

During the past year, DDE has modified three of its engineering development vehicles that are being used to support the ACAS FOT Program. These vehicles are: (a) 1994 Toyota Lexus LS400, (b) 1994 GM Cadillac Seville, and (c) 1998 Opel Vectra. These vehicles have been modified to provide the basic functionality of fully integrated ACC and FCW systems.

Lexus LS400

The Lexus LS400 was DDE's first attempt at developing a completely integrated FCW system. The planning and build of this vehicle was initiated during the negotiation of the first ACAS Cooperative Agreement. It was completed and demonstrated prior to the ACAS contract award date of January 1995. However, this demonstration vehicle was used extensively during the first ACAS Program in order to further the understanding of the pertinent underlying issues associated with collision avoidance technologies. During the past year, the Lexus has been upgraded. The vehicle has been rewired and the serial interfaces between the vehicle interface processor and the radar, yaw rate, and target selection processor have been converted to CAN. In addition, an HE Microwave (HEM) ACC2 radar and Delphi's vision-based lane tracking processor and camera have been integrated on the vehicle. This updated sensor suite has been used to collect correlated radar, vision, and vehicle data to support the Data Fusion, Vision Based Lane Tracking, and Target selection tasks.

Opel Vectra

The Opel Vectra is a radar/laser based ACC vehicle that was developed internally within Delphi in 1998. In February of this year, the Vectra ACC vehicle was prepared for a May delivery to UMTRI. The Vectra was upgraded with a HEM ACC1 pilot radar, and its control and target selection algorithms were refined. In addition, various CAN bus termination problems were resolved. The vehicle was used by UMTRI for various FOT related data collection and human use studies, and it will be later used by Delphi to support its FOT related ACC integration tasks.

Cadillac Seville

The Cadillac was Delphi's second generation integrated FCW system. The planning and build of this vehicle was initiated during the contract negotiation phase of the first ACAS Program. It was completed and demonstrated after the ACAS Program contract award date of January 1995. This demonstration vehicle has proved to be a useful learning tool in expanding the knowledge base of the underlying issues associated with collision avoidance technologies.

This vehicle is currently equipped with two centralized processors, a Target Selection Processor (TSP) and Vehicle Interface Processor (VIP). The TSP and VIP are specialized hardware components, designed by Delphi. The VIP is the primary interface between all of the vehicle subsystems. It provides a platform to implement Delphi's FCW threat assessment algorithms and control the Driver Vehicle Interface (DVI). The Driver-Vehicle Interface (DVI) warning cues include: (a) customized audio system with capabilities to mute the audio system and generate various warning tones, (b) tactile response in the form of short duration brake pulse, and (c) visual warning cues generated on an improved Delphi *Eyecue*™ color re-configurable HUD.

During the past year, the Cadillac has been upgraded. The vehicle has been rewired and the serial interfaces between the vehicle interface processor and the radar, yaw rate, and target selection processor have been converted to CAN. In addition, the following new components have been integrated on the vehicle and interfaced to the Target Selection Processor (TSP): (a) an ACC2 radar, (b) Delphi's vision-based lane tracking processor, (c) a real-time PC104 implementation of Delphi's radar based scene tracking (Task C2B). This vehicle will serve as the primary test bed and data collection platform for Delphi's target selection and scene tracking subsystems.

The HEM ACCA radar that is targeted for the FOT prototype vehicle is currently being integrated on the bench with Delphi's Target Selection Processor. During the next month, the ACCA radar will be installed and integrated on the Cadillac EDV. Subsequently, a series of new field tests will be held to characterize the performance of the ACCA radar and target selection subsystems.

Diagnostic Tools and Sub-System Validation

Each Delphi EDV test vehicle has been equipped with a suite of tools and used to (a) observe near real-time and real-time system behavior while performing system integration on laboratory bench hardware; (b) evaluate real-time system performance while performing on-road vehicle testing; (c) perform in-depth ACC/FCW system data analysis and quantify ACC/FCW system performance; and (d) iterate, refine, and validate key algorithm improvements (i.e.: ACC Control Algorithms, Scene Tracking Algorithms, Target Selection Algorithms, etc.) with real on-road data , both in simulation and on the lab bench.

Figure 10.3 summarizes Delphi's Target Tracking and Identification validation and refinement process and the suite of tools that are used. The data collection and validation process can be performed in real-time on a vehicle, on lab bench hardware, and in the PC environment. A PC-type laptop computer is used to interface to the CAN bus and to host the various data collection tools. The tools consist of the various graphically oriented custom Delphi data collection utilities, and the commercial Canalyzer™ CAN bus utility, by Vector CANtech. In addition, a video system (i.e.: camera, 8mm video recorder, and mixer) is used to mix time-stamped video with the graphical output from the Delphi diagnostic tools.

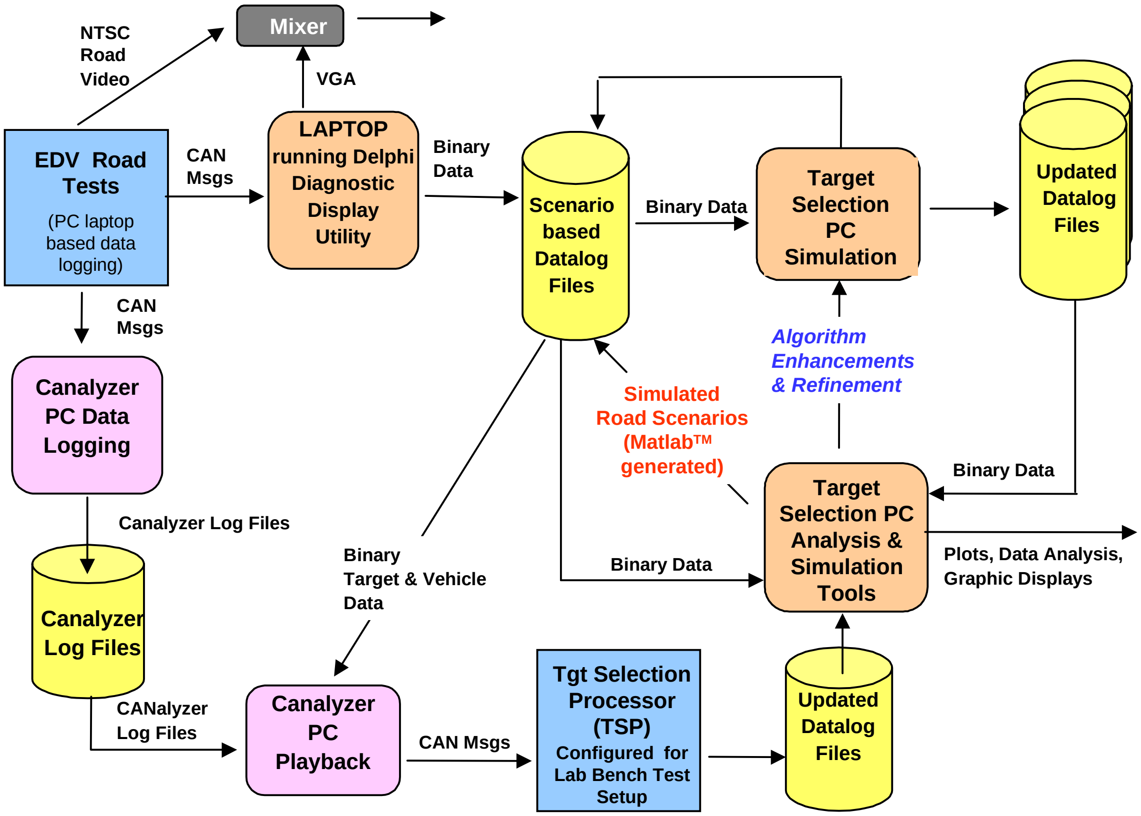
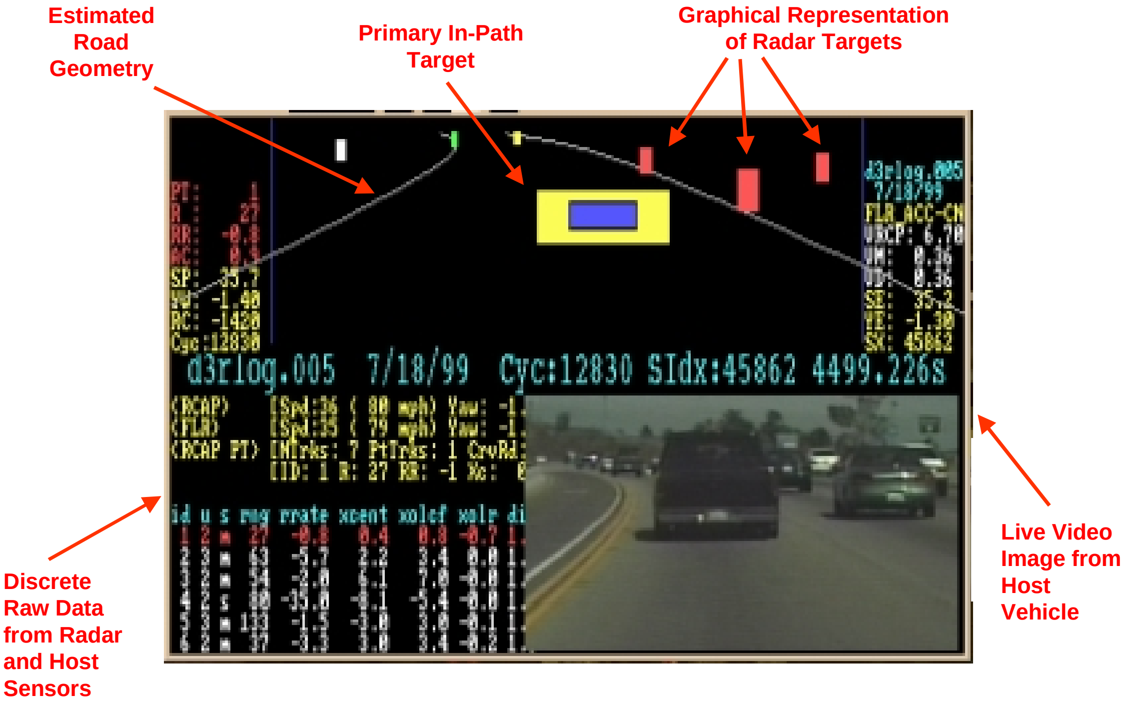


Figure 10.3 Tracking and Identification Validation and Refinement Process

Delphi's custom utilities and tools are used to dynamically record and time stamp internal performance results and interfaces for various key ACC/FCW subsystems and to graphically depict the target environment and road geometry in front of the ACC/FCW vehicle. The Vector Canalyzer™ CAN bus utility is used to dynamically record/collect and time stamp all of the system's CAN bus messages and events, in real-time. The data recorded by both the Canalyzer™ and the custom Delphi tools, as well as by Delphi's Matlab™ based road scenario generator are used to build up a scenario database that can be back through the real time hardware in a laboratory setting for more detailed post processing engineering investigations. The scenario database can also be replayed through the Delphi's Target Tracking and Identification sub-systems to refine and iterate the key algorithm components.

Figure 10.4 depicts the Delphi graphical target display in a split screen video format. The middle and lower left portion of the display contains text describing the radar, target selection, and optionally the ACC controller status. The target features of the primary in-path target are highlighted in red. The upper portion of the figure depicts a real-time graphical representation of the detected radar scene targets (i.e.: synthetically generated by the laptop computer). The Host vehicle's perceived lane boundaries, based on the predicted road model, are also graphically drawn. The exterior color of the rectangles is based on relative target speed. For example, green rectangles denote targets “moving away” from the Host vehicle, red rectangles denote targets that the Host vehicle is “closing on”, magenta rectangles denote “oncoming” targets, yellow rectangles denote targets that are “matched in speed” to the Host, and white rectangles depict “stationary” targets. The relative size of the rectangular-shaped “targets” is based on the target range and in-path target status. The “narrow” rectangle boxes denote “non-primary in-path” targets. The “large” rectangle with the dark blue center denotes the “primary in-path target”.



```
PT:      1
R:      27
RR:   -0.8
RC:    0.5
SP:   35.7
YW:  -1.40
RC:  -1420
Cyc:12830

d3rlog.005
 7/18/99
FLR ACC-CN
VRCP: 6.70
UM:   0.36
UD:   0.36
SE:   35.2
YE:  -1.30
SX:  45862

d3rlog.005  7/18/99  Cyc:12830 SIdx:45862 4499.226s
(RCAP)    [Spd:36 ( 80 mph) Yaw: -1.
(FLR)     [Spd:35 ( 79 mph) Yaw: -1.
(RCAP PT) [NTrks: 7 PtTrks: 1 CrvRd:
          [ID: 1 R: 27 RR: -1 Xc: 0

id u s rng rrate xcent xolef xolr di
 1 2 m  27  -0.8   0.4   0.8 -0.7 1.
 2 3 m  63  -5.7   2.2   3.4  0.0 1.
 3 2 m  54  -2.0   6.1   7.0 -0.0 1.
 4 2 s  80 -35.0  -0.1  -5.4 -0.0 1.
 5 3 m 133  -1.5  -3.0   3.0 -0.1 1.
 6 2 m  37  -3.3   3.0   3.4 -0.2 1.
```

Figure 10.4 Delphi Diagnostic Tracking and Identification Display

The lower right portion of the figure is used to display real-time video imagery of the roadway environment ahead of the Host vehicle. This video-based diagnostic system is extremely useful tool. It provides a mechanism to review lengthy time segments of “on-road” data, and to isolate those time segments which had marginal or questionable performance. Once identified, voluminous files of more detailed sensor and system data, recorded together with the video, can be more carefully investigated, to determine the precise cause of any observed anomalies or unusual results.

Integration and Test

A preliminary design review of all of the Tracking and Identification sub-systems was held in June 2000. The sub-system interfaces between the Tracking and Identification sub-systems and the other vehicle sub-systems (i.e.: radar, data fusion, threat assessment, etc.) have been defined and they will be mimicked and implemented on EDV test vehicles.

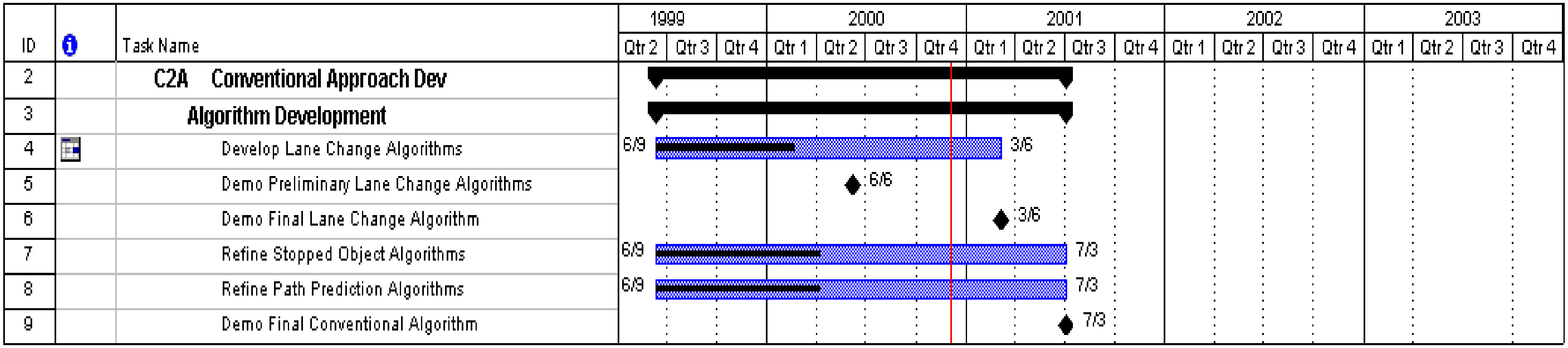
In addition, Delphi has developed a radar tracking and target selection test plan with over 15 distinct scenarios. The scenarios include moving and stationary roadway and roadside objects, executing normal both normal driving and lane change maneuvers on straight, curved, and curve/entry exit type roadways. The scenarios include varying types of test vehicles (sedans, SUVs, trucks, motorcycles, bridges, and roadside clutter). The performance of the HEM ACC2 radar tracker and Delphi's target selection algorithms has been evaluated against real and simulated sensor and system performance data that matches many of the critical test scenarios.

During the first part of the year, a three-day field test held on Los Angeles area freeways and at the Camarillo airport. The collected data was analyzed to track down software bugs and identify performance problems. The target selection algorithms were refined and iterated off-line by replaying the collected data through the target selection simulation. The HEM tracker algorithms were also enhanced.

During the Spring of 2000, another three-day field test was held to collect real time sensor and system performance data and to evaluate both ACC2 radar tracker and target selection algorithm improvements. Significant improvements were observed in the ACC2 radar tracker's performance against stopped objects. In addition, improved target selection performance during host lane change and curve entry/exit maneuvers was observed when additional road and host state data was used (i.e.: from scene tracking or lane tracking).

Plans through December 2000

During the next six months, the development of all of the key target selection algorithms will continue (i.e.: path algorithms, distributed stationary object clustering, truck grouping, and host lane change detection). In addition, the ACCA sensor will be integrated on the Delphi EDV Cadillac test vehicle. The ACCA sensor and Target Selection subsystems performance will then be benchmarked against the Target Selection test scenarios. Key areas for algorithm improvement will be identified, and algorithm refinements will be made via simulation and bench tests. Furthermore, correlated ACCA sensor, vehicle sensor, vision, target selection, and high accuracy GPS data will be collected to support the development of the Target Selection, Scene Tracking, and Data Fusion tasks, and to provide ground truth.



ID		Task Name
2		**C2A Conventional Approach Dev**
3		**Algorithm Development**
4	▦	Develop Lane Change Algorithms
5		Demo Preliminary Lane Change Algorithms
6		Demo Final Lane Change Algorithm
7		Refine Stopped Object Algorithms
8		Refine Path Prediction Algorithms
9		Demo Final Conventional Algorithm

Figure 10.5 Task C2A Schedule

10.2 Scene Tracking Approach Development (Task C2B)

Objectives

Scene tracking is an enhancement to the conventional path prediction process in which preceding vehicles are classified as being in-lane or not in-lane. The conventional yaw rate based road estimation approach cannot reliably predict changes in road curvature ahead of the host, since the road curvature is assumed to be constant. Moreover, the conventional yaw rate based approach also assumes that the host is not weaving in lane or changing lanes. In the scene tracking approach the paths of the preceding vehicles are observed in order to estimate the upcoming forward road curvature. This approach assumes that most of the preceding vehicles are staying in their lanes, and that there are reasonable constraints on the rate at which the road curvature can change. In addition to estimating the upcoming road shape, the scene tracking approach also estimates the angular orientation of the host vehicle in its lane, thereby accounting for in-lane weaving or lane changing by the host.

Approach

Two scene tracking approaches are currently under consideration: (1) the original ‘parallel’ approach; and (2) the newer ‘unified’ approach.

In the parallel approach, separate target tracking filters estimate the curvature of the trajectory of each target, along with the target’s heading angle. The curvature-at-range information from all of the targets is then combined in a road curvature estimation filter, in which parameters in a road curvature model are estimated. A host path angle filter combines all of the targets’ heading angle information and the road curvature estimates to estimate the host vehicle’s path angle, which is the angle between the host’s longitudinal axis and the local lane tangent. Finally, the path angle and road curvature estimates are used, along with the target coordinates, to estimate the lateral lane position of each target relative to the host’s lane.

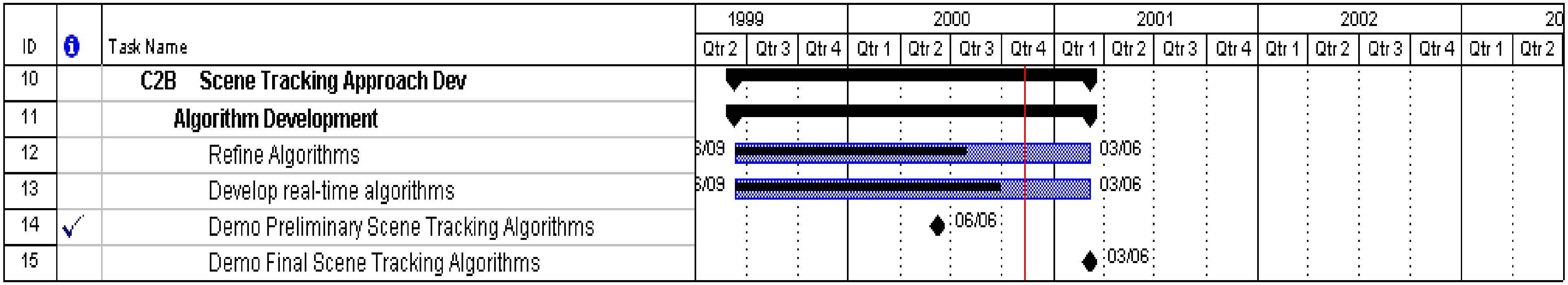
In the unified approach, a single unified filter estimates all of the quantities above. Separate determination of target lane changes may be necessary in order to keep those targets from corrupting the road shape estimates.

Work Accomplished

The primary accomplishments to date include: (1) development of the core part of the unified approach; (2) experimentation with rules to identify and reject maneuvering targets and outliers in the unified approach; (3) conversion of the scene tracking algorithm from Matlab™ to the C language; (4) implementation of a real-time scene tracking algorithm on a PC104 computer; (5) integration of scene tracking software with baseline RCAP path algorithms; and (6) evaluation and tuning of algorithms with real world radar target data.

Plans through December 2000

Work is proceeding on several fronts: (1) improving the rejection of maneuvering targets in the unified approach, particularly without adding parallelism, (2) improving the performance of the unified approach when the host changes lanes, and (3) developing a new way of combining target information in the parallel approach.



ID	ℹ	Task Name
10		**C2B Scene Tracking Approach Dev**
11		**Algorithm Development**
12		Refine Algorithms
13		Develop real-time algorithms
14	✓	Demo Preliminary Scene Tracking Algorithms
15		Demo Final Scene Tracking Algorithms

Figure 10.6 Task C2B Schedule

10.3 Enhanced GPS Approach Development (Task C2C)

Objectives

The objectives of this task are to develop and implement a path prediction system capable of aiding the radar in eliminating irrelevant targets, and assisting in classifying detected targets as obstacles/non-obstacles, using dead reckoning, differential GPS and digitized roadway map database.

Approach

In this approach, path prediction is achieved by continuously estimating the location of the vehicle on the road, matching the vehicle location to a point on a road in the stored roadway map, tracking the path traversed by the vehicle and extracting the upcoming road geometry from the map. The objectives of this task are met using several sensors such as DGPS, dead reckoning and a digitized road map. The overall functional block diagram of this subsystem is shown in Figure 10.7.

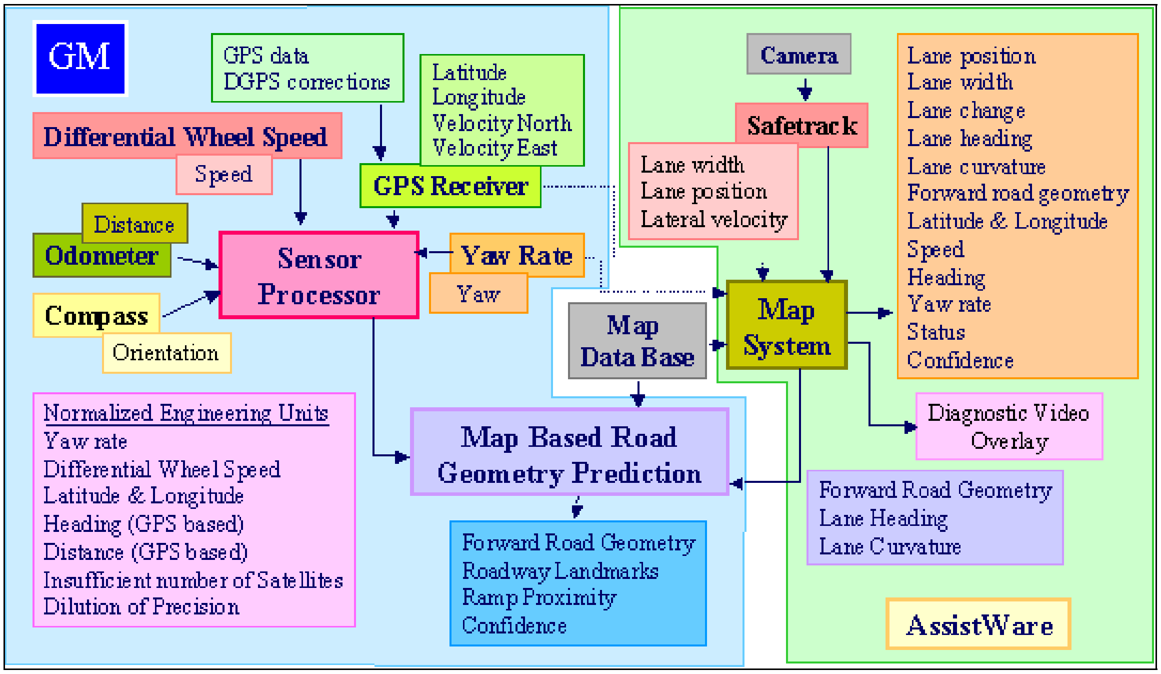


Figure 10.7 Functional Diagram of the Map Based Path Prediction System

DGPS is used to compute the heading and distance traversed by the vehicle. The accuracy in determining the heading and distance is further enhanced by computing the heading angle and distance relative to the previous position of the host vehicle. Apart from the benefits that DGPS based systems offer, they are seriously plagued by outages in GPS signals that occur in the presence of tunnels and tall buildings, among other things. In order to overcome this shortcoming, the developed approach is augmented with dead reckoning sensors, where wheel speed sensors and odometer are used for distance measurement and yaw rate sensor, compass and differential wheel sensors are used for angle measurement.

The combination of dead reckoning and DGPS with the map database has been explored to obtain a map based path prediction system. DGPS, when used in conjunction with the map database, can provide fairly accurate path prediction except in situations of GPS signal outages. At such times, the dead reckoning is expected to carry forward the task of path prediction.

The above discussion has assumed the availability of accurate map database (a major component of the discussed system) that meets the design specifications. It should be noted that such a database is not commercially available at the present time. Within the limited scope of the ACAS-FOT project, AssistWare has been contracted to aid in the development of maps that are superior to those commercially available.

The AssistWare system (Figure 10.8) is an integrated forward road geometry measurement system consisting of two parts – a vision system and an enhanced map development system. The vision system is a version of AssistWare's commercial Safe-Trac lane tracking product, and is meant as the fallback vision system for the ACAS FOT project. It differs from the other three vision systems in that it uses a short-range visual field (39 deg. field of view), which provides the ability to obtain highly robust measurements of lane width, and vehicle position and orientation in the lane under a wide range of ambient conditions. It is expected to give the highest performance of the vision systems for the limited scope in which it is performing. This expectation is for two reasons. First, the short range gives a resolution and contrast advantage over the long-range systems. Second, the system has been in development for several years and has thousands of hours of testing behind it.

Figure 10.8 AssistWare System Components

As part of the development of superior maps, AssistWare is in the process of developing a digital mapping module along with on-the-fly map generation and refinement that allows the creation of more accurate maps by multiple traversals over the route. A software module will be developed to facilitate the integration of AssistWare's map matching method with the General Motors developed map-matching scheme.

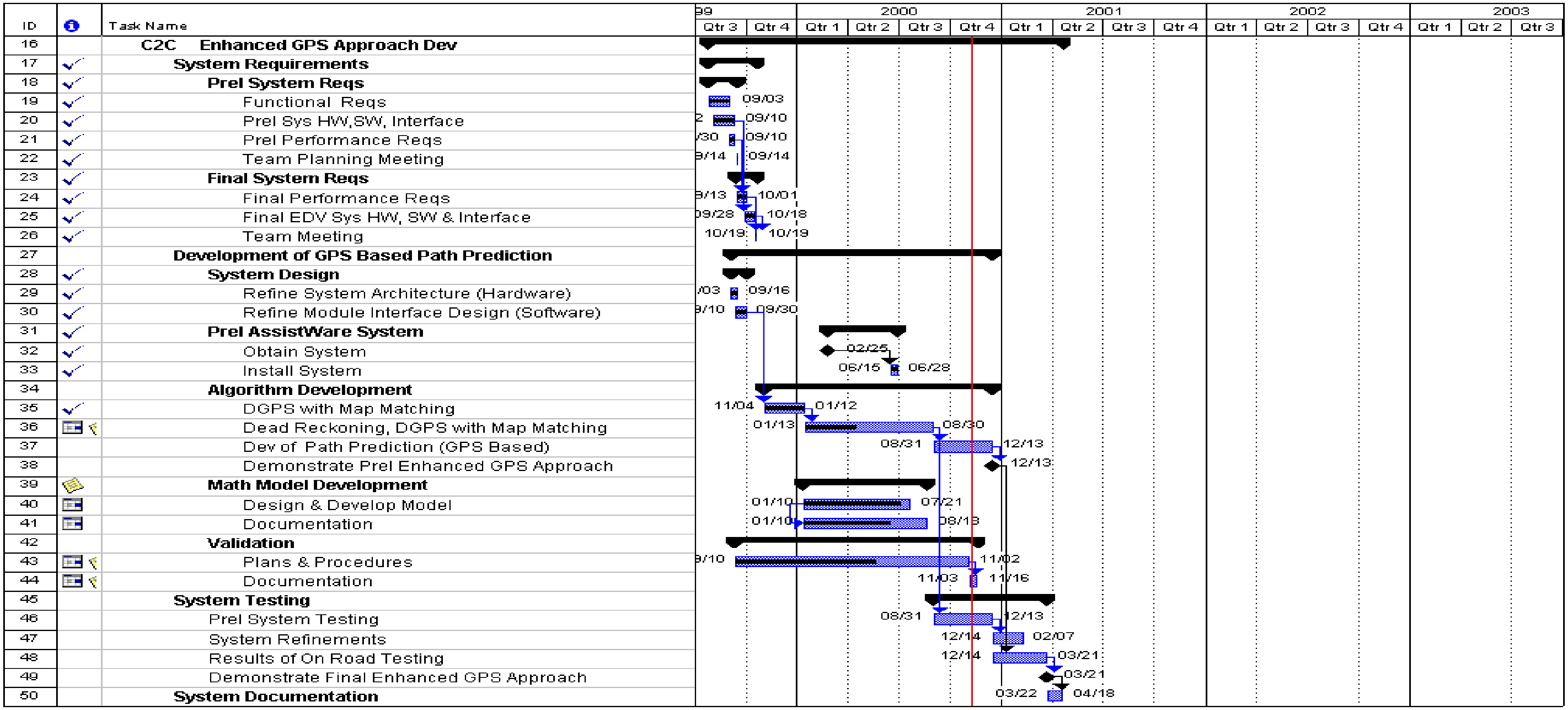
Work Accomplished

The system specification of the processor hardware, software, signal interface and CAN messages between sensors and the processor, signal interface and CAN messages between this subsystem and other subsystems, CAN messages for fault diagnostics and subsystem status, sensors (DGPS and dead reckoning) and roadway map database has been completed. All the subsystem components including a preliminary version of the AssistWare system have been integrated into the GM Engineering Development Vehicle.

Software development of the sensor drivers is complete and sensor tests have yielded satisfactory performance results. The development and implementation of the algorithms that integrate DGPS and digitized roadway maps that form the basis of retrieving forward road geometry is complete. Limited testing of this implementation has been conducted and the results are very promising. In order to enable continuous improvement of algorithms, a laboratory setup for testing and tuning of algorithms is available for use.

Math based path prediction models using DGPS, dead reckoning and roadway maps have been designed and developed for incorporation into the simulation of the overall system model being developed by UC Berkeley-PATH. These models have been provided to PATH along with parameters for error estimates of standard GPS signals, DGPS and map databases obtained from realistic situations.

The initial integrated AssistWare system was delivered to GM in late February 2000. The vision portion of this system is complete and for the most part is unchanged from the commercial Safe-Trac system. The major development for this system is in the map processor. The CAN interface hardware is located in this processor. All CAN hardware and message protocol development for this system is complete. The enhanced map system development is currently in progress. The system is installed on the GM engineering development vehicle. A second system remains at AssistWare where further development is taking place.



ID	ℹ	Task Name
16		**C2C Enhanced GPS Approach Dev**
17	✓	**System Requirements**
18	✓	**Prel System Reqs**
19	✓	Functional Reqs
20	✓	Prel Sys HW,SW, Interface
21	✓	Prel Performance Reqs
22	✓	Team Planning Meeting
23	✓	**Final System Reqs**
24	✓	Final Performance Reqs
25	✓	Final EDV Sys HW, SW & Interface
26	✓	Team Meeting
27		**Development of GPS Based Path Prediction**
28	✓	**System Design**
29	✓	Refine System Architecture (Hardware)
30	✓	Refine Module Interface Design (Software)
31	✓	**Prel AssistWare System**
32	✓	Obtain System
33	✓	Install System
34		**Algorithm Development**
35	✓	DGPS with Map Matching
36		Dead Reckoning, DGPS with Map Matching
37		Dev of Path Prediction (GPS Based)
38		Demonstrate Prel Enhanced GPS Approach
39		**Math Model Development**
40		Design & Develop Model
41		Documentation
42		**Validation**
43		Plans & Procedures
44		Documentation
45		**System Testing**
46		Prel System Testing
47		System Refinements
48		Results of On Road Testing
49		Demonstrate Final Enhanced GPS Approach
50		**System Documentation**

Figure 10.9 Task C2C Schedule

11 CW FUNCTION (TASK C3 AND C5)

11.1 Threat Assessment Simulation Development (Task C3A and 5A)

Objectives

The objective of this task is to develop and document a computer simulation of ACAS threat assessment performance during forward collision scenarios. The product of this effort, the TASIM (Threat Assessment SIMulation), will be a 'user-friendly' computer code – to be run on a PC, with three-dimensional graphics available for use on a Silicon Graphics, Inc. (SGI) workstation – with appropriate models and fidelity to accurately gauge the effectiveness of unique user-defined ACAS threat assessment algorithms. In order to accomplish this, an important sub objective of the simulation development is to integrate ACAS-specific or relevant 'reusable' sensor, fusion, vehicle, and roadway models into a useable and reasonable simulation of ACAS performance.

A key component to 'useable' will be the provision of additional tools to provide a graphical user interface for setting up simulations based on scenario definitions, observing the effect of various threat assessment algorithms, and analyzing output data. Additionally, an annotated example of a forward collision scenario with ACAS operation will be provided to GM, plus the provision of a tutorial at Warren, Michigan by February 28, 2001.

Approach

The block diagram for TASIM is shown in Figure 11.1. It shows the integrated architecture of TASIM, with constituent blocks representing discrete modules. Note that the block diagram is divided at the top level into a "simulated world" and a "sensor & hardware model". The modules within the "simulated world" primarily draw from the UC Berkeley PATH Program's SmartAHS model (http://www.path.berkeley.edu/smart-ahs/index.html) with ACAS-specific upgrades recently provided in the *Host Vehicle States* block (and described later in this report under Work Accomplished).

The modules within the "sensor & hardware model" block are provided by other members of the ACAS team, GM *(In-Vehicle Sensors, Vision System, GPS/Map-Based Road Geometry, Radar Target Detection, Target Selection, Threat Assessment*), Delphi (*Driver Visual Interface*) and HRL (*Data Fusion*). For the most part, these modules are provided in pseudo-code or block diagram form, and PATH developers have written them into C-language. Figure 11 2 illustrates how the configuration control is implemented.

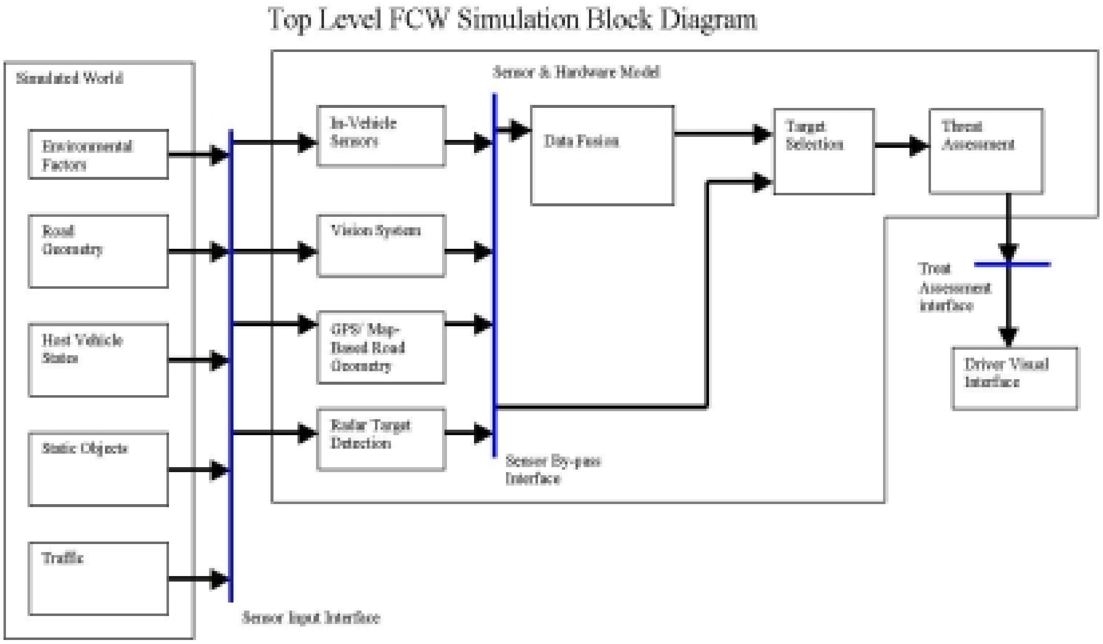
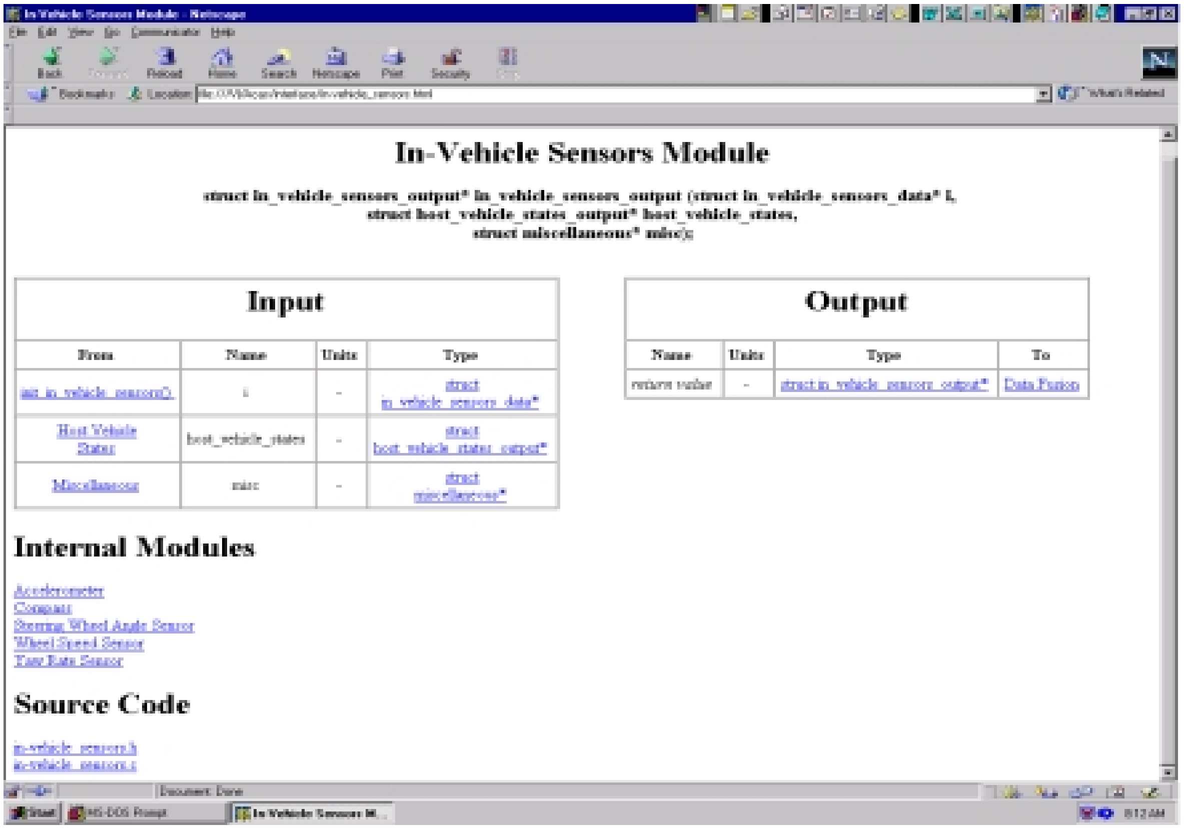


Figure 11.1 Integrated Architecture for TASIM



In-Vehicle Sensors Module

struct in_vehicle_sensors_output* in_vehicle_sensors_output (struct in_vehicle_sensors_data* i,
struct host_vehicle_states_output* host_vehicle_states,
struct miscellaneous* misc);

Input

From	Name	Units	Type
init_in_vehicle_sensors()	i	-	struct in_vehicle_sensors_data*
Host Vehicle States	host_vehicle_states	-	struct host_vehicle_states_output*
Miscellaneous	misc	-	struct miscellaneous*

Output

Name	Units	Type	To
return value	-	struct in_vehicle_sensors_output*	Data Fusion

Internal Modules

Accelerometer
Compass
Steering Wheel Angle Sensor
Wheel Speed Sensor
Yaw Rate Sensor

Source Code

in-vehicle_sensors.h
in-vehicle_sensors.c

Figure 11.2 Example HTML Interface: In-Vehicle Sensors Module

Consistency and control is maintained by defining input and output variable definitions via HTML scripting, wherein hyperlinks to summon these definitions can be called. For example, the In-Vehicle Sensors Module in Figure 11.1 can be double-clicked to show Figure 11.2. From Figure 11.2, variable declarations, internal modules, or source code can be accessed. Hence, with the module interfaces frozen, multiple developers at PATH can (and have) translated pseudo-code and block diagrams of the modules in Figure 11.1 into C-language code, with the primary formal interface enforced through a controlled check-in and check-out registry.

The TASIM tool development integrates:

1. SHIFT[3] models of vehicles, highways and controllers
2. Uniform interfaces between the C and the SHIFT codes to support independent development and re-coding of C-code modules should new or refined models be added in the future
3. GUI supporting testing and evaluation.

In essence, and as illustrated in Figure 11.3, the TASIM development integrates user-provided C-code with a simulation kernel implemented in the SHIFT programming language, with 2-D visualization implemented in tcl/tk (in a version called TkSHIFT, with point-of-departure look and feel shown in Figure 11.4), and 3-D visualization implemented in SGI Performer software (with point-of-departure look and feel shown in Figure 11.5). The software will compile with MSVC 6 and run under Windows. This strategy allows:

1. Use of considerable legacy investment in SmartAHS
2. Simplified user interaction
3. In implementation, avoids delays and inefficiencies due to interprocess communication; and
4. Simplified programming, especially the task of porting from Unix to Windows.

---

[3] The expressive power of SHIFT provides a compact notation for modeling spatial and logical relationships and for analyzing control strategies governing interactions of complex systems. The application domain – multiple interacting vehicles and drivers – is modeled as a dynamic network of hybrid automata using the SHIFT formalism and specification language. Information on the SHIFT simulation language is available at: <http://path.berkeley.edu/~SHIFT>. To use TASIM, however, does not require any prior knowledge of SHIFT.

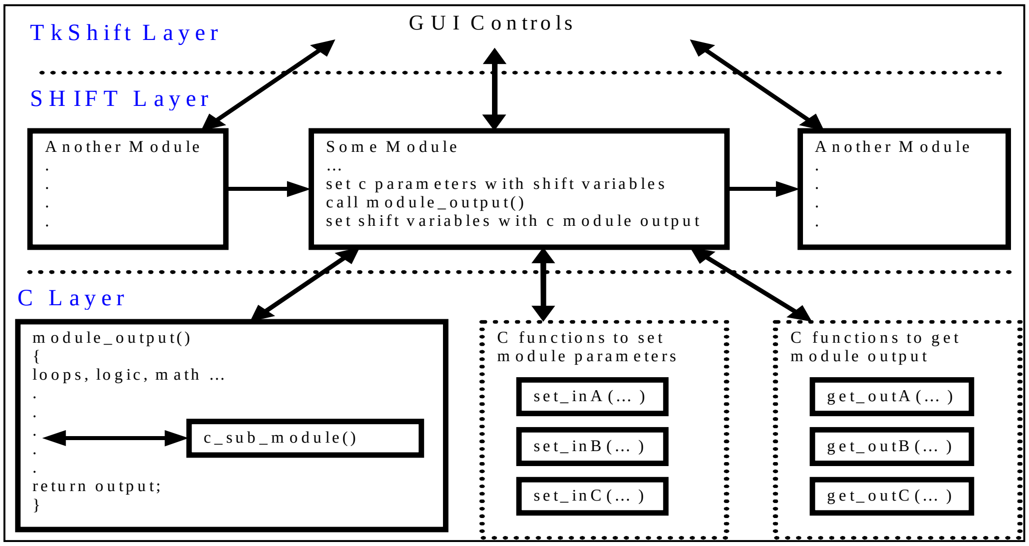


Figure 11.3 TASIM Layers: TkSHIFT, SHIFT and C

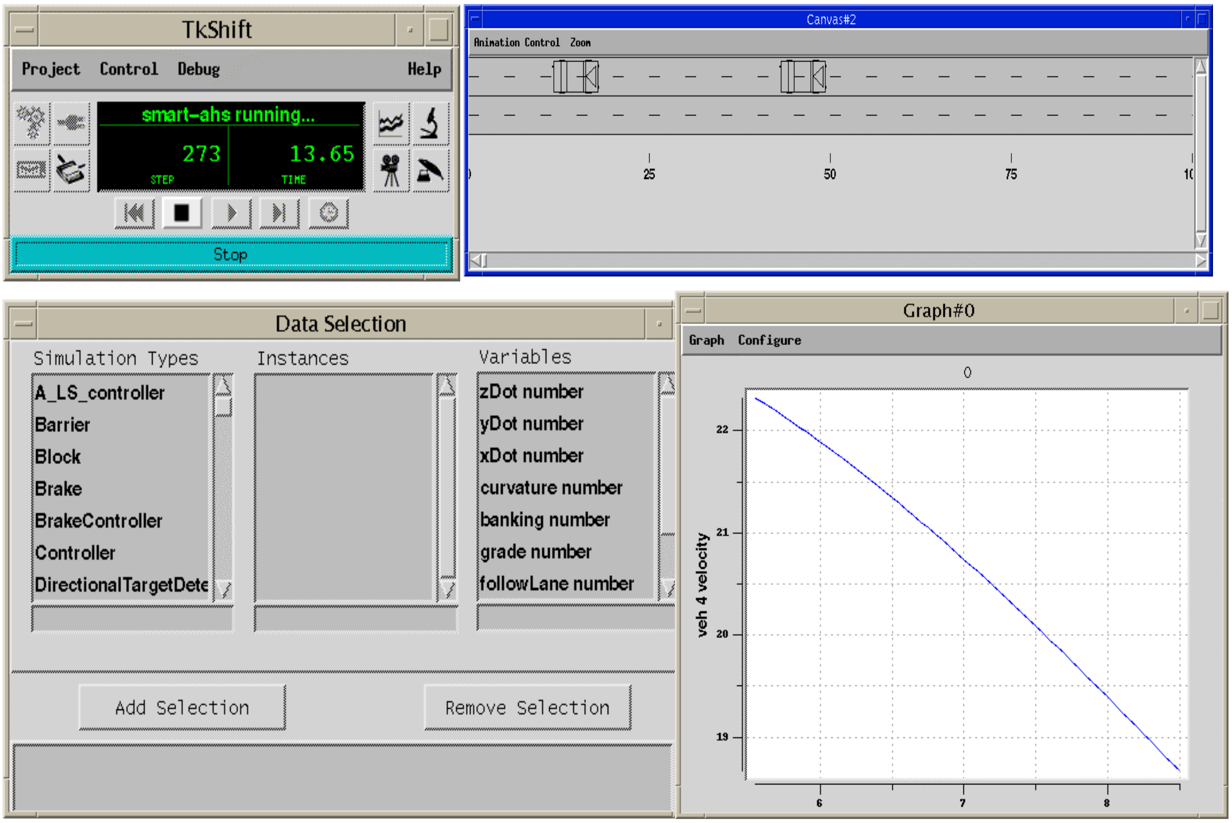


Figure 11.4 Starting Point of 2-D GUI for TASIM

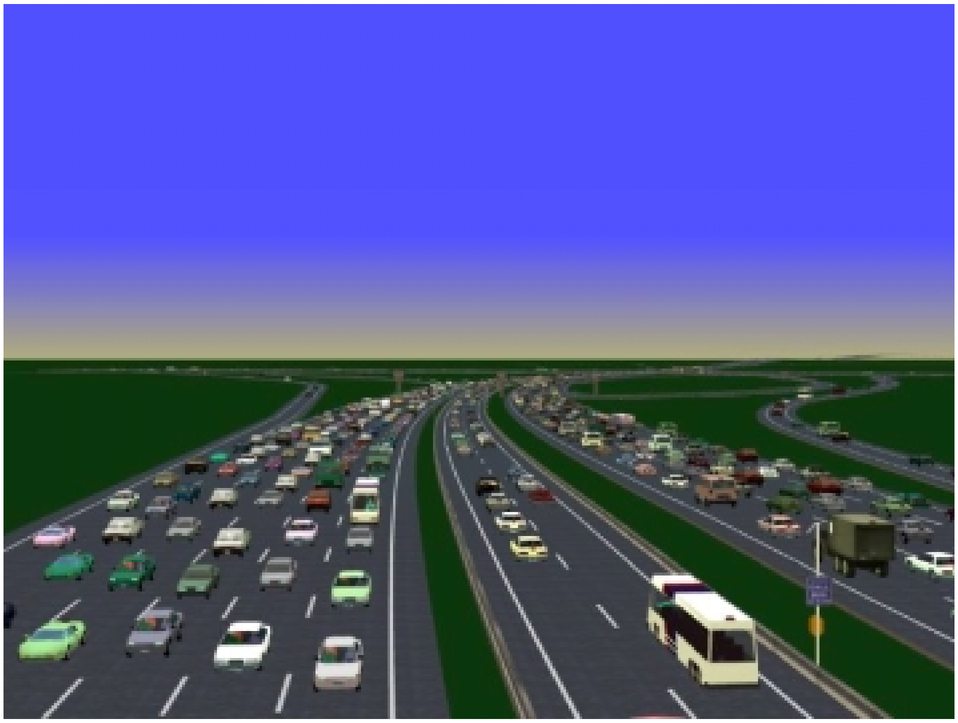


Figure 11.5 Starting Point of 3-D Visualization for TASIM

<u>Work Accomplished</u>

1. Conducted module and code architecture tradeoff study
2. Conducted detailed TASIM interface/specification meeting with GM
   a. Achieved consensus on module and code architecture
   b. Defined level of vehicle host simulation fidelity
   c. Received preliminary definition of simulation scenarios
3. Received preliminary TASIM modules from GM
   a. In-Vehicle Sensors
      Accelerometer
      Compass
      Wheel Speed Sensor
      Yaw Rate Sensor
      Steering Wheel Angle Sensor
   b. Vision System
   c. GPS/Map-Based Road Geometry
   d. Radar Target Detection
   e. Data Fusion
   f. Target Selection
   g. Threat Assessment
   h. Driver Visual Interface
4. Coded in-vehicle sensor models
   Coded vision system model

Coded the radar model (field of view test and target report generator) for a single target
Developed preliminary host and target vehicle models

Coding of GM Modules

Coding was underway with the set of TASIM modules received from GM, with an anticipated completion of August 2000. Some testing was conducted to eliminate memory and compilation mistakes. At this junction, there was no testing done to ensure the correctness of the model, but this is planned as a major component to the TASIM development effort, as discussed in Plans for Next Six Months.

Development and Implementation of PATH Modules

The new PATH modules, host vehicle dynamics and controllers and target vehicle kinematics, have been integrated into the SHIFT-based world simulation, although there are a few remaining host vehicle lateral and longitudinal features (e.g., lateral dynamics under slip or wet conditions) that are not yet implemented; expected completion is September 2000.

The vehicle host dynamics models are designed to provide sufficient granularity and fidelity inputs to the in-vehicle sensors which later effect the threat assessment. Specifically, the host vehicle dynamics interface with the road geometry, environment and path planning modules. In order that the vehicle follows a pre-defined trajectory, a controller is also designed. The task internal to the vehicle model is following a reference trajectory such that the test scenario definitions are satisfied. The models are written such that in the closed loop mode, the vehicle will follow a desired trajectory while obeying its physical dynamics.

3-D Visualization

The existing SmartPath 3.2 animation suite is the basis for the TASIM 3-D visualization. In the current period, it was investigated for suitability for development and/or delivery as under x86 Linux and IRIX 6.4. Since SGI released Performer under Linux, it is possible to port SmartPath to Linux without rewriting the entire program to use another scene graphing package. This will allow a high performance, cost effective and stable platform (PC) for graphics and visualization.

Specific accomplishments include:

1. Compilation and running of SmartPath 3.2.1 on IRIX 6.4.
2. Installation and running of Performer for Linux at ~60 and ~120fps on TNT2 and GeForce2 GTS, respectively.
3. Compilation of running of SmartPATH 3.2.1 on Linux operating system underway; currently in the debugging process, particularly with overcoming need for SGI widgets.

Synchronous Video Images

Several tasks were accomplished with displaying synchronous video images:

1. In conjunction with GM, defined data specifications for:
   - File transfer
   - Video files (MJPEG, 320 x 240 pixels)
   - Date file display headers (time counter, frame number)
   - Playback controller functions
2. Using these specifications, digitized test files and generated MJPEG clips.
3. Implemented software utility created by GM to convert .log files into MJPEG files
4. Played back GM-created .log files at PATH (using Microsoft Media Player using MJPEG codec distributed by Pegasus Imaging (http://www.jpeg.com)

Scenario Definition

ACAS scenarios provided by GM and shown in Table 1 were examined and decomposed into constituent atomic maneuvers with the goal that each of these maneuvers can automatically be instantiated in SHIFT and that the user could therefore build the current or a similar expanded (or more complex) set of maneuvers.

Table 11.1 Nominal ACAS Scenarios

	SV	POV	Coordination	Roadway	Environment
	Maneuver	Maneuver	Inter-vehicle	segments	
C1	constant v straight	stopped middle of the lane	none	straight	night (no direct lighting)
C2	constant v straight	constant v straight	"	unpaved or poorly paved	-
C3	constant v straight	braking moderately	"	-	-
C6	constant v (curvature)	stopped middle of the lane	"	straight+transition (<20m)+curve(r,speed(SV))	wet
C8	constant v (curvature)	constant v (curvature)	"	tight curve	-
C9	constant v straight	constant v cuts in front of SV	TBD	straight	-
C10	change lanes	stopped	none	straight	-
C12	SV follows POV	(10+5s) follow lane+braking	TBD	straight	-
C13	constant v straight	constant v straight	none	straight	-
		constant v straight	"		
		constant v straight	"		
C14	constant v straight	constant v straight	"	straight	-
		constant v straight	"		
C16	=C6	=C6	"	=C6+poor lane markings	-
A7	Highway speeds tailgating a lead vehicle				
V8	Lead-follower, curve, leader decelarates				

Two types of atoms are conceived:

1. Open loop with the following parameters:
   - Modality: straight, turn left, turn right

- Duration
- Speed

2. Feedback (in increasing order of difficulty)
   <u>Follow center of the lane</u>. Parameters:
   - Speed
   - Duration

   <u>Landmark based navigation</u>. Follow center of lane until the detection of a static feature. Parameters:
   - Static feature
   - Time-out

   <u>Closed-loop based navigation</u>. Examples:
   - Follow a car, while following the center of the highway
   - Upon detection of a certain-event invoke a certain behavior

From this, subject vehicle atomic maneuvers listed in Table 11.2 are conceived.

Table 11. 2 Maneuvers for Subject Vehicle

2a. *Total Set:*

Maneuver	Description
Constant v straight	Constant longitudinal speed on a straight line
Constant v following center lane	Constant longitudinal speed following center of lane
Change lanes	
Follow a leader at a prescribed distance	Follow a designated vehicle at a prescribed distance
Emergency braking	Brake according to a defined brake pattern
Start	Start motion from the side of the highway

2b. *Required for Maneuvers Shown in Table 1:*

Maneuver	Description
Constant v straight	Constant longitudinal speed on a straight line
Constant v following center lane	Constant longitudinal speed following center of lane
Change lanes	
Emergency braking	Brake according to a defined brake pattern
Start	Start motion from the side of the highway

Undertaking a similar exercise, the set of atomic maneuvers for the target vehicle is listed in Table 11.3.

Table 11.3 Maneuvers for Target Vehicle

Maneuver	Description
Follow lane	Follow lane with a certain longitudinal speed profile
Changetoadjacent lane	Move from the current lane to the line crossing between this lane and the adjacent one (left or right as a parameter)
Follow a leader at a prescribed distance	Follow a designated leader vehicle within a prescribed distance
Brake	Initiate and maintain a braking profile
Startfromside	Start moving from the side of the highway till the center of the highway
Null	Do nothing

Table11. 4 lists the preliminary codification of inputs to these atomic maneuvers, while Table11. 5 lists the outputs. The internal state and termination conditions to these maneuvers are provided in Tables 11.6 and 11.7, respectively. The termination conditions, which will be user input, are the conjunction of the main condition and the enabling condition. Maneuver commands are to be recalculated at each time step. All these computations will be encapsulated in C functions that take the inputs to determine

the current value of the commands. The acceleration and braking profiles are encapsulated in these functions, and they can be re-coded by the user.

Table 11.4 Inputs to Atomic Maneuvers

Input	Description
Idriverc	Category of driver
Imaneuverc	Category of maneuver
	Termination conditions:
imaxdistance	• Distance to travel
itime_out	• Duration of the maneuver
idesired_lspeed	• Speed to attain
idesired_lane	• Lane to cross to
	Initial error conditions:
Ilspeed	• The maximum tolerable error in the initial longitudinal speed
Ixt	• The maximum tolerable error in the distance from the center of the lane
	Feedback info:
Ixcenter_of_lane	• X position of the center of the lane
ixvehicle	• x position of the vehicle
ispeedl_of_leaderv	• longitudinal speed of leader (if any)
iypos_of_leader	• y position of the leader
icurvature	• curvature of the lane
i_lspeed;	• longitudinal speed

Table 11.5 Outputs from Atomic Maneuvers

Output	Description
	Commands to the longitudinal controller
Longspeed	
Long acell	
Offset from the lane center	Command to the lateral controller

Table 11. 6 Internal State of Atomic Maneuvers

State	Description
Slenght	Distance traveled
Sduration	Elapsed time

Table 11. 7 Termination Conditions

Condition/event	Enabling condition (set to true or false)
slenght >= imaxdistance	enlenght
olong_speed >= idesired_lspeed	endesired_lspeed
sduration >= itime_out	entime_out
Event Reachnextlane	enlane
Event Abort	-

Plan for Next Six Months

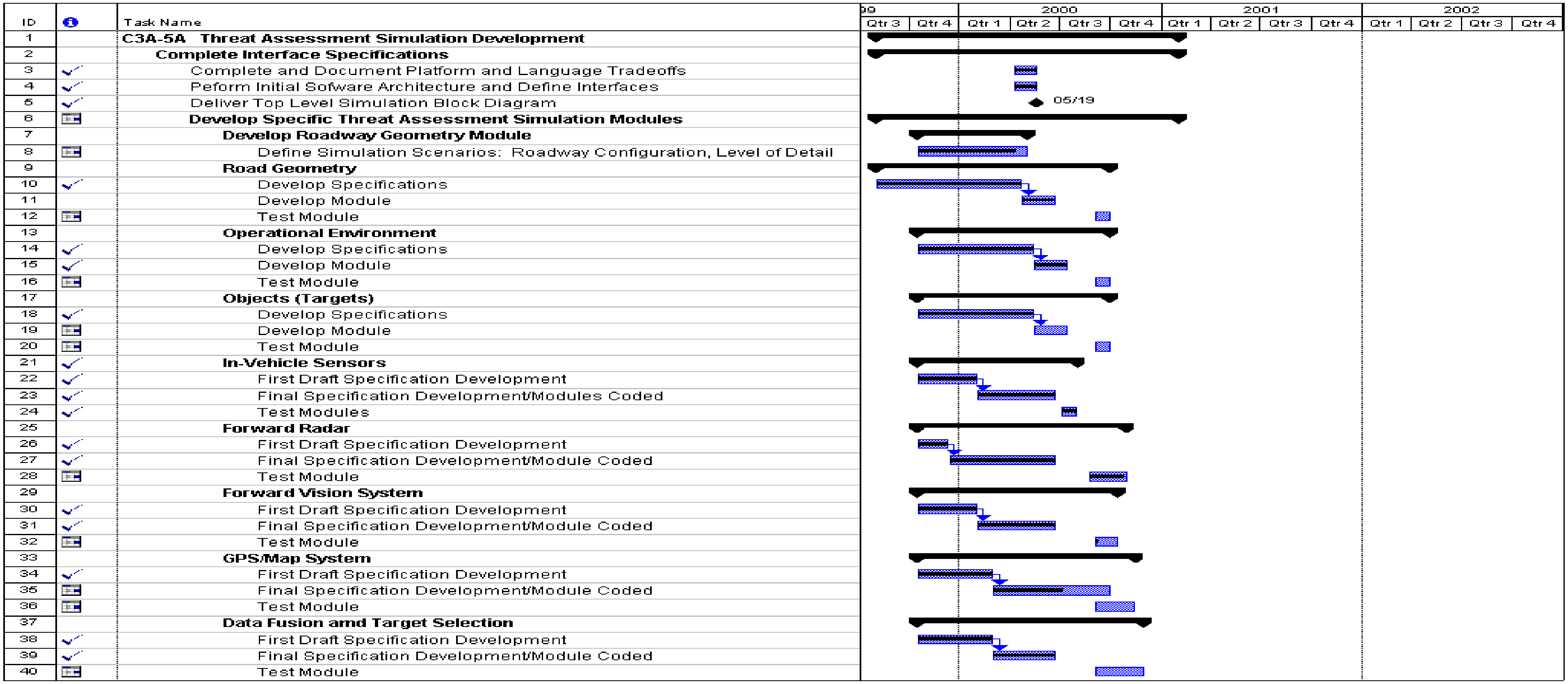
The critical focus will be to continue work on the combined simulation application, extending the user interface to support features desired for TASIM. Specifically, we will:

1. Develop 2-D GUI
2. Integrate legacy 3-D visualization
3. Integrate synchronized video playing into the application, to include GM road test files anticipated to be provided to PATH Oct – Nov 2000
4. Connect world simulation to threat assessment by way of vehicle sensors
5. Perform module- and system-level tests.

Testing in particular will be emphasized, with the philosophy of testing from “bottom to top”, that is, all modules are tested individually first, then they are tested as part of the system. In the next 6 months, individual models will be tested separately. In doing so, test data for each of the models will be taken from the developer of the model. Alternatively, the tester will suggest test data. In both cases the developer of the model should approve test results in a checklist manner. Further discussion is warranted on the radar detection module testing for several reasons: at this writing it is the furthest along, and it is also a pivotal module within TASIM; its veracity will likely most affect that threat assessment algorithm.

The radar detection module is designed so that it can be tested in two ways: either test the probability of detection for a specific radar cross-section and type of weather, or test the whole radar detection for a specific scenario. The user can choose the target cross-section, the targets fluctuation model, the atmospheric conditions, and turn on or off multipath effects.

The basic radar detection model test plan is for five scenarios, ranging from one target to three targets in 3 lanes. The basis for verification is probability of detection for different cross-sections and different weather conditions per GM data set. Three additional test items supplement the basic test plan: a non-flat road, a sixth scenario (one target on a curved lane) and the sorting of track ID numbers in the target tracker. The target tracker could also be tested in the case of more than 15 targets in the field of view. Additionally, in the target discrimination test, an enhanced test plan could consider the case when the range is more than 2 m and the range rate more than 3 m/s. Also, the merged target could be put back into the oldest index. In the target tracker, the azimuth could be predicted in the case when the targets are not going straight down their lanes.



ID	❶	Task Name
1		**C3A-5A Threat Assessment Simulation Development**
2		**Complete Interface Specifications**
3	✓	Complete and Document Platform and Language Tradeoffs
4	✓	Peform Initial Sofware Architecture and Define Interfaces
5	✓	Deliver Top Level Simulation Block Diagram
6	▦	**Develop Specific Threat Assessment Simulation Modules**
7		**Develop Roadway Geometry Module**
8	▦	Define Simulation Scenarios: Roadway Configuration, Level of Detail
9		**Road Geometry**
10	✓	Develop Specifications
11		Develop Module
12	▦	Test Module
13		**Operational Environment**
14	✓	Develop Specifications
15	✓	Develop Module
16	▦	Test Module
17		**Objects (Targets)**
18	✓	Develop Specifications
19	▦	Develop Module
20	▦	Test Module
21	✓	**In-Vehicle Sensors**
22	✓	First Draft Specification Development
23	✓	Final Specification Development/Modules Coded
24	✓	Test Modules
25		**Forward Radar**
26	✓	First Draft Specification Development
27	✓	Final Specification Development/Module Coded
28	▦	Test Module
29		**Forward Vision System**
30	✓	First Draft Specification Development
31	✓	Final Specification Development/Module Coded
32	▦	Test Module
33		**GPS/Map System**
34	✓	First Draft Specification Development
35	▦	Final Specification Development/Module Coded
36	▦	Test Module
37		**Data Fusion amd Target Selection**
38	✓	First Draft Specification Development
39	✓	Final Specification Development/Module Coded
40	▦	Test Module

Figure 11.6 Task C3A & 5A Schedule, Page 1

ID	●	Task Name
41		**Threat Assessment**
42	✓	First Draft Specification Development
43	▦	Final Specification Development/Module Coded
44	▦	Test Module
45		**DVI Warning Cues**
46	✓	First Draft Specification Development
47	▦	Final Specification Development/Module Coded
48	▦	Test Module
49		**Scene Visualization**
50	✓	First Draft Specification Development
51		**Final Specification Development/Module Coded**
52	✓	Define Simulation Language (SHIFT) and GUI Communication
53	▦	Add New Windows (Vehicle on Highway, Host Vehicle, TA Algorithm,
54	▦	Adding Additional GUI Functionality (Data Logging, Playback)
55	▦	Tuning and Polishing
56		**Math Model Report**
57	▦	Assemble Report
58		**Complete Threat Assessment Simulation Software**
59		**Complete Definition ofSimulation Architecture**
60	✓	Partition Simulation System: Different Languages/Simulations
61	✓	Define File Format for Data Exchange
62	▦	Deliver Final Simulation Block Diagram
63		**Develop Threat Assessment Simulation**
64	▦	Develop Code for Simulation Integration, Including File I/O Functions
65	▦	Implement "Atomic" Maneuvers in SHIFT
66	▦	Integrate Modules with SmartAHS Legacy Code
67	▦	Integrate On-Board Sensors with Simulation
68	▦	Implement Prototypical Trajectories
69		Packaging and Installation
70	▦	Documentation
71		**Perform Simulation Testing/Provide Examples**
72	▦	Conduct End-to-End Simulation Tests
73	▦	Develop and Perform Example Simulations
74	▦	Deliver, Document and Teach Simulation Tool
75	▦	Deliver Phase I Interim Program Report Inputs/Effort Final Report
76		**Provide Synchronized Visualization of Sensor Data and Visual Input**
77	✓	Initially Define Data Specifications for File Transfer
78	✓	Define External Output Specification
79	✓	Digitize Test Video Files and Generate MPEG Video Clips
80	✓	Define Data to be Displayed on User Interface
81	▦	Collect Video Files
82	▦	Develop Playback Controller
83	▦	Integrate Video Files into Program
84	▦	Test Visualization System
85		**Data Collection**
86	▦	Final Specification Development
87	▦	Math Model Report (minus data collection)

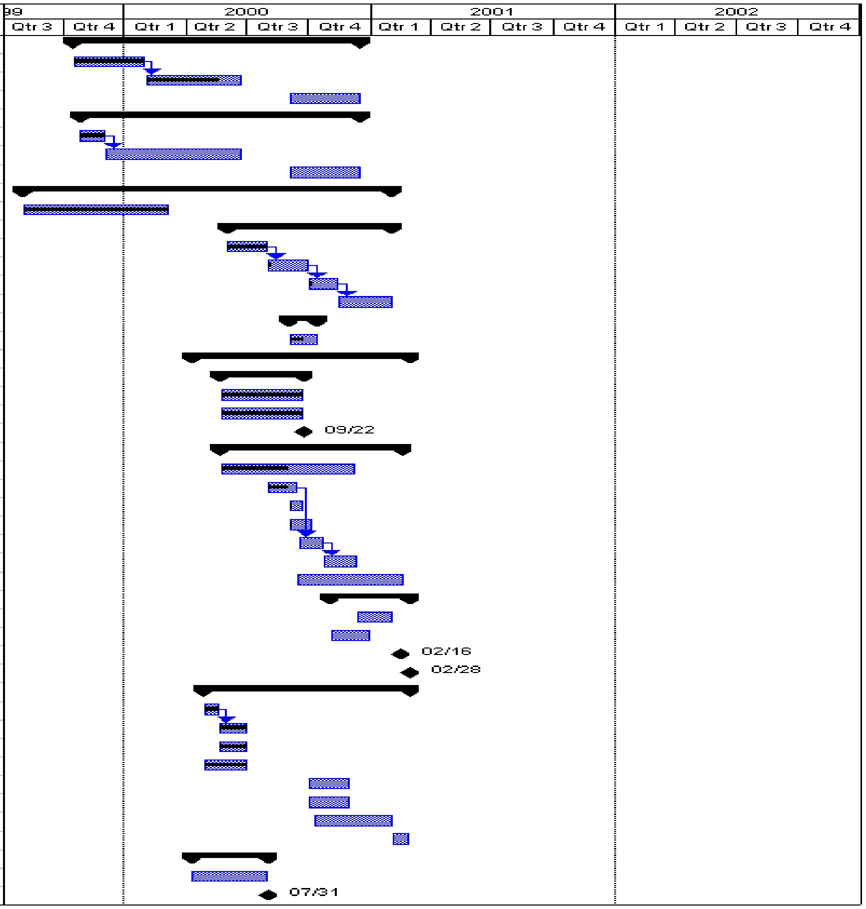


Figure 11.7 Task C3A & 5A Schedule, Page 2

11.2 Threat Assessment In-Vehicle Development (Task C3B and 5B)

Objectives

The objectives of these tasks are to:

1. Develop threat assessment algorithms through analysis and simulation
2. Test the threat assessment algorithms in an instrumented vehicle on test tracks and real traffic
3. Coordinate the implementation of the NHTSA Algorithm on the GM EDV and Prototype vehicles.

Approach

The usefulness of the driver alert warning depends on the robustness of the threat assessment algorithm. The threat assessment algorithm must determine the probability of a collision with a vehicular target that is in the forward path of motion of the Host vehicle. This estimation is determined from the Host vehicle’s and target’s velocity and deceleration, the distance between the vehicle and object, and the driver’s reaction time. The time of collision could be determined from these parameters if these parameters were deterministic. However, in real-world traffic scenarios, these parameters are confounded by multiple traffic lanes, roadway curvature, multiple vehicles, roadside obstacles, and driver attentiveness and reaction times. Because of these non-deterministic occurrences, modeling techniques must be developed to assist in the selection of the algorithm or algorithms with the highest chance of success. Several iterations of algorithm candidates will have to be simulated and analyzed.

The threat assessment algorithms will be integrated into a project vehicle for real-time evaluation and assessment. This project vehicle will be driven in various traffic conditions and on test track situations, which simulate potential crash situations, to determine hit and nuisance rates for the various combinations of threat and path prediction algorithms. Six threat algorithms will be evaluated with each of the path prediction methods (e.g., conventional approach, scene tracking approach, vision sensor, and enhanced GPS approach). The six candidate algorithms are called GMR1, GMR2, NHTSA, CAMP, HW and TTC.

To measure the driver’s vigilance, selective subsystems of the instrument panel (e.g., windshield wiper control, HVAC & radio adjustments, etc.) will be monitored and used to further enhance the threat assessment processing by attempting to anticipate the attentiveness and potential reaction time to an imminent alert. For example, application of the windshield wipers would suggest rain, and adjustment of the radio would suggest momentary inattention/distraction of the driver. In these two cases, additional warning time might be provided to compensate for slippery roadway or slower driver reaction time.

Since these parameters are non-deterministic for the future state, only an estimate of a collision event can be provided. The algorithm development of the threat assessment process was initiated during the ACAS program. Further development of these threat assessment algorithms will continue based on the findings initiated during the ACAS Program. These algorithms will be evaluated in the collision warning simulation tool and project vehicles. They will be evaluated for collision warning usefulness and for nuisance alert potential. As previously discussed, minimization of nuisance alerts is paramount to the successful acceptance of this warning approach. Based on previous experience, many modeling, simulation, analysis, and vehicle test iterations will be required to obtain an alert system robust enough for field operation test drivers.

The algorithm development team will collaborate with the other subsystem development teams in order to provide both algorithm performance refinements and subsystem integration capabilities during the integration phase of the program. Additionally, this team will provide the appropriate support required to address any CW system anomalies experienced during the FOT phase.

Milestones and Deliverables

A joint Team/NHTSA collaborative meeting was conducted in order to develop a detailed work plan for securing access to relevant Government-sponsored studies/data.

Work Accomplished

The following threat assessment activities have been accomplished in the last year:

1. Characterization and first delivery of GM R&D Algorithms 1 and 2
2. Received Time to Collision and Time Headway Algorithms from GM
3. Have provided in software provisions for CAMP and NHTSA Algorithms
4. Hosted four of six algorithms (GMR1, CAMP, HW and TTC) on FCW Processor
5. Provided support for NHTSA Algorithm implementation
6. Started development of algorithm MOE’s
7. Made significant progress on FCW Simulation
8. Have almost completed GM EDV Hardware and Software

Research Findings

Research findings to date have been primarily in the areas of analytical development. Once completed, these results will be implemented in the simulation described in Section 11.1 and the vehicles described in Section 13. The following describes a summary of the GM Research threat assessment algorithm that is being readied for simulator and vehicle testing.

Threat Assessment Description

The I/O data to/from Threat Assessment are taken from and put onto the CAN bus by the system modules. The Threat Assessment process is as follows:

1. Target Selection inputs, to the FCW Processor (via the CAN bus), certain radar track data of selected radar track with the following criteria:
   a. The closest in-path moving vehicle (CIPV)
   b. The closest in-path stationary object (CIPS)
   c. All moving vehicles that are projected to enter the host vehicle's path (PIHP)
2. The FCW Processor collects (for the Threat Assessment Algorithms) the required radar track data (see Table 11.8) sent over by Target Selection, from the CAN bus.
3. The FCW Processor also collects the other required Threat Assessment input data (see Table 11.9), from other modules, from the CAN bus.
4. Threat Assessment then calculates an Alert Level and determines other messages (see table 11.10). The FCW Processor outputs this data to the CAN bus.

Table 11.8 Radar Track Data

	Alert Parameter	Source
a.	Radar Track ID, Radar Scan Number, Range, Relative Range Rate, and Relative Acceleration of the closest in-path moving target (CIPV)	Target Selection
b.	Radar Track ID, Radar Scan Number, Range, Relative Range Rate, and Relative Acceleration of the closest in-path stationary target (CIPS)	Target Selection
c.	Radar Track ID, Radar Scan Number, Range, Relative Range Rate, Relative Acceleration, Lateral Offset, and Lateral Offset Rate of all target projected to be in the host vehicle path in the near future (PIHP)	Target Selection

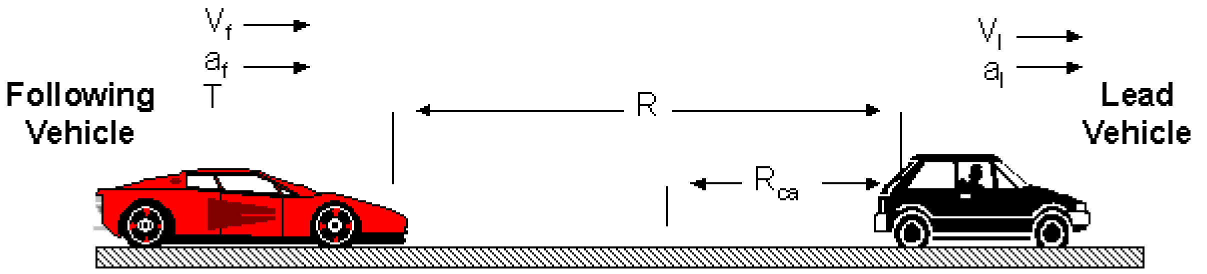
Table 11.9 Threat Assessment Input Data

	Alert Parameter	Source
a.	Following (host) vehicle speed	Class 2 bus
b.	Following (host) longitudinal acceleration	Vehicle sensors
c.	Required following vehicle acceleration	ACC Controller
d.	Distraction Level	Data Fusion
e.	Road Surface Condition	Data Fusion
f.	Rain Rate	Data Fusion
g.	Brake Applied	Vehicle sensors
h.	ACC On/Off	DVI
i.	FCW Sensitivity/	DVI

Table 11.10 FCW Processor Output Data

	FCW Output	Message
a.	Alert Level: a number between 0 and 1 which results in an indication to the driver of the potential for a rear-end collision with the most threatening (CIPV, CIPS, or PIHP) vehicle	Max_AL
b.	Indicates alert being inhibited	FCW_Inactive
c.	Indicates that Threat Assessment is limited by operational or environmental factors	System_Limitation
d.	Indicates that the FCW Processor is not operational	FCW_Fault

Figure 11.8 below defines the terms in the discussions to follow.



V_f = Following Vehicle velocity
a_f = Following Vehicle acceleration
V_l = Lead Vehicle velocity = V_f + Rdot
a_l = Lead Vehicle acceleration
T = delay time (before Following Vehicle starts to decelerate after Lead Vehicle starts to decelerate (at t = 0)

R = range (measured by the radar) between Lead and Following Vehicle
Rdot = relative range rate (measured by the radar) between Lead and Following Vehicle
R_{ca} = collision avoidance range

Figure 11.8 Definition of Threat Assessment Algorithm Terms

The collision avoidance range, R_{ca} is the closest possible range that a driver can make a decision to stop, using the normal equations of motion, and still avoid a collision for parameters V_f, V_l, a_l, a_f and T. These parameters may be measured, assumed or a combination of measured or assumed values.

$$R_{ca} = f(V_f, V_l, a_l, a_f, T)$$

where

V_f = is a measurement from vehicle sensors
$V_l = V_f + R\_rate$
$a_f = \gamma(\alpha + \beta V_f)$
$\gamma = f(\textbf{Road\_Surface})$
$a_l = -0.2\text{ g for } a_r > -0.4g$
$a_l = a_{f\_m} + a_r$ for $a_r \leq -0.4g$
$T = f(\textbf{Distraction})$

The alert onset range R_o is determined as follows.

$$R_O = R_{ca} + (V_f - V_l)(n-1)\tau$$

where

n = number of alert levels

τ = time between alert level changes

However, when $V_f - V_l \leq 1.12$ m/s,

$$R_o = V_f\,Th$$

where

Th = the desired time headway

The first expression for R_o is used for the case when the following vehicle is closing on the lead vehicle (algorithm 1). The second expression for R_o is used for the case when the following vehicle is "tail-gating" the lead vehicle at the same speed (algorithm 2). Algorithm 2 is automatically selected when $V_f - V_l$ is less than 1.12 m/s.

The Alert Level, AL, is a number between 0 and 1 that is output to the Driver-Vehicle Interface. AL is an indicator to the driver of the potential for a rear-end collision, and is intended to drive a gradient display.

$$AL_i = 0, \textbf{ for } (R > R_o) \textbf{ or } (V_l > V_f)$$

$$AL_i = 1 - \frac{R - R_{ca}}{R_o - R_{ca}}, \text{ for } R_c \geq R \geq R_{ca}$$

$$AL_i = 1, \textbf{ for } R < R_{ca}$$

The above concepts form the basis of the GM R&D threat assessment algorithm.

Target Projected to be in Host Vehicle Path

When Target Selection determines that a vehicle is changing lanes and will be in the host vehicle's path in the future, Threat Assessment must use the projected range of the lead vehicle to calculate the Alert Level. Figure 11.9 below shows the geometry and definition of terms for a lead vehicle changing lanes into the following vehicle's path.

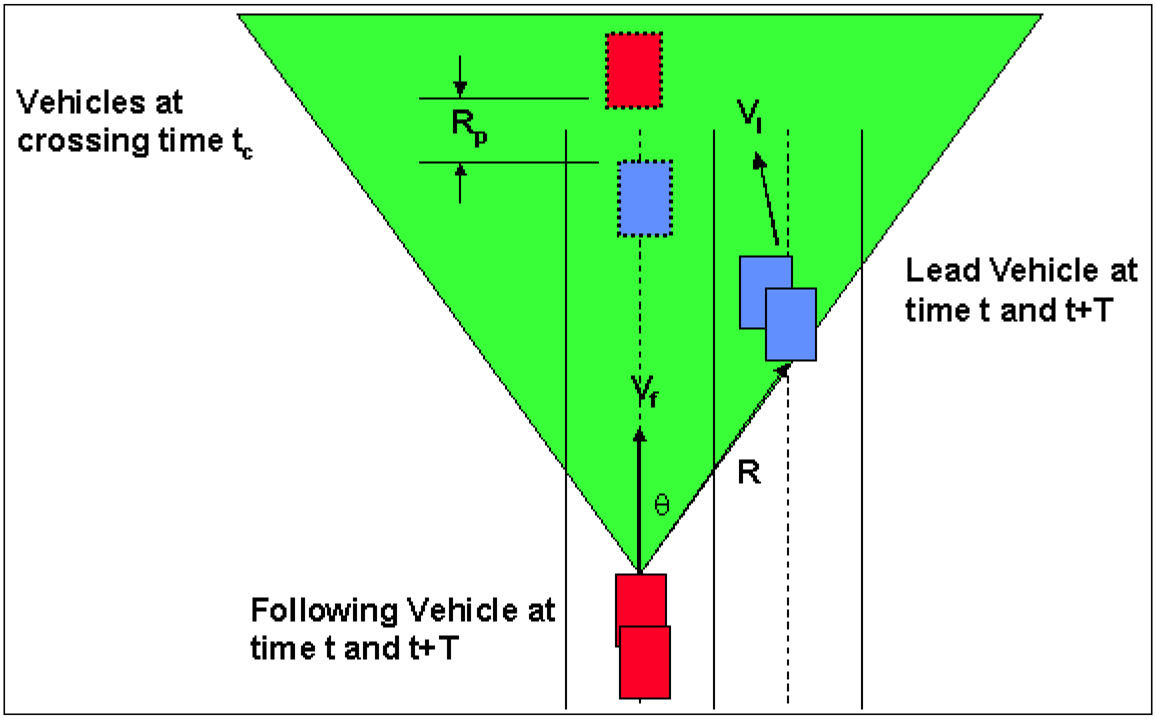


Figure 11.9 Geometry and Definition of Terms for the PIHP Vehicle

Target Selection provides the offset X and offset rate Xdot to the threat assessment algorithm as seen in Figure 11.10.

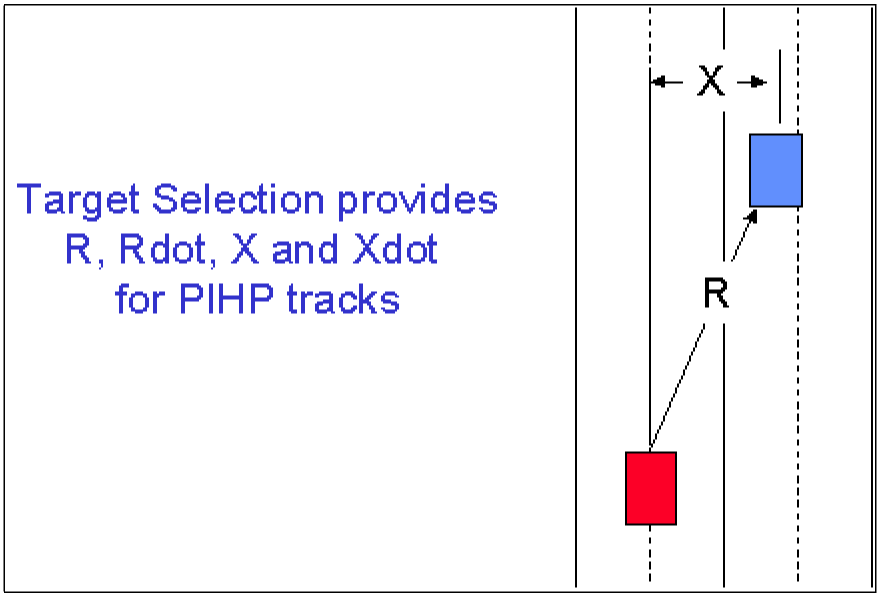


Figure 11.10 Offset X and Offset Rate Xdot

The time for path crossing, t_c is determined from X and Xdot as shown in Figure 11.11. From t_c and other known lead and following vehicle data, the projected range R_p is calculated. R_p is used in place of R in the threat assessment algorithm.

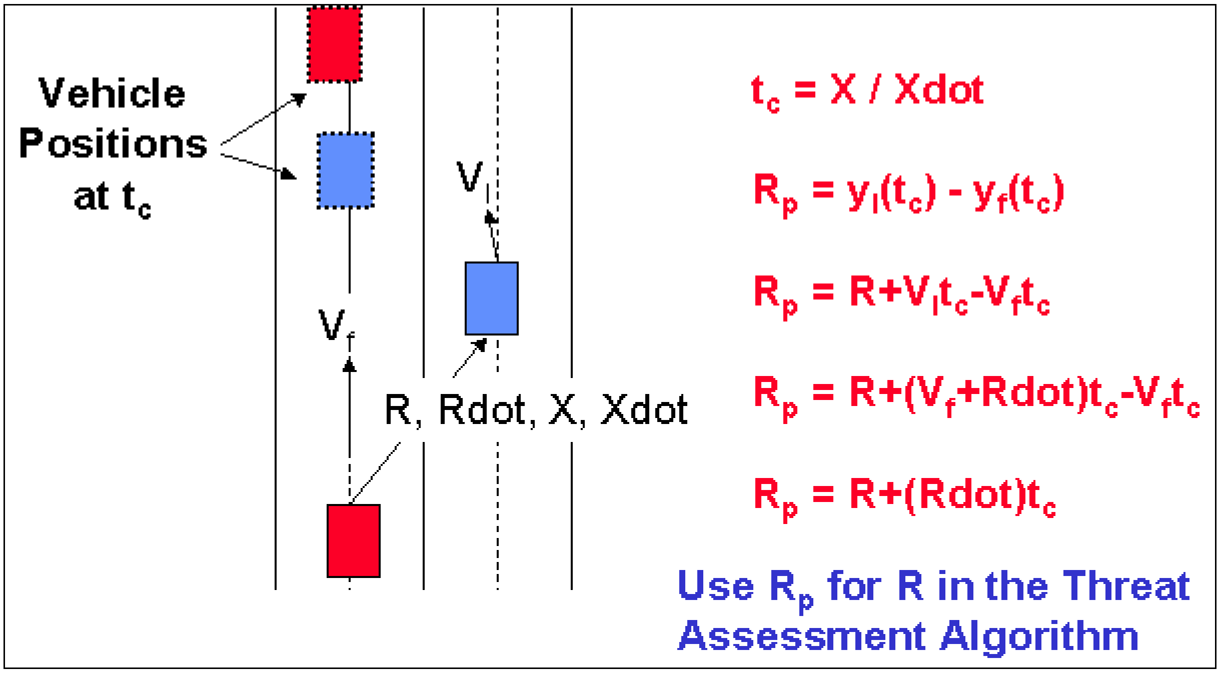


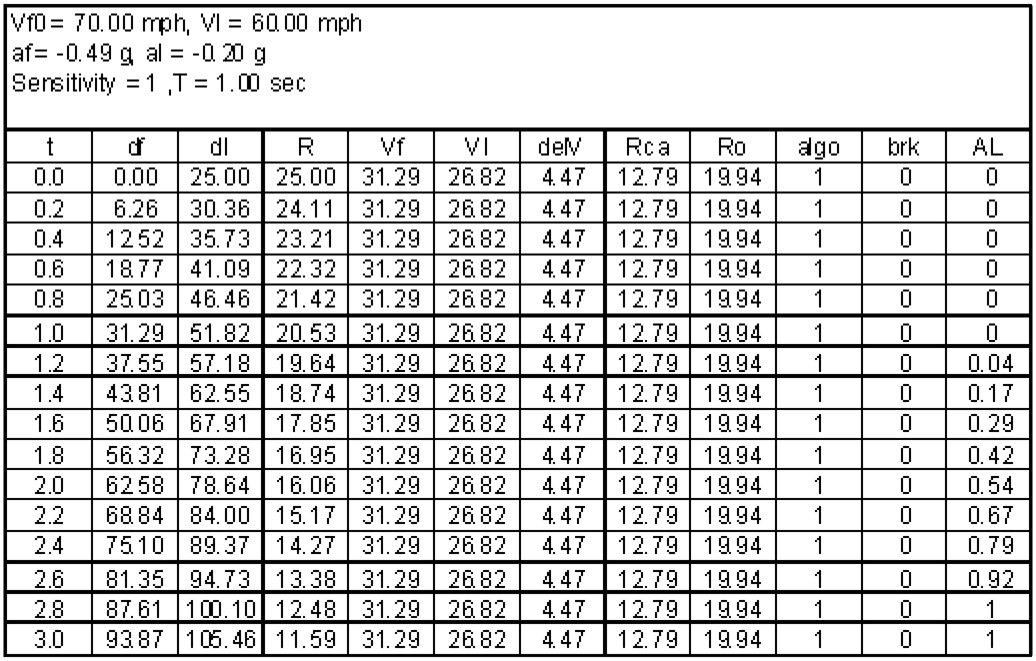
Figure 11.11 Determination of t_c and R_p

Alert Characterization

The following two scenarios illustrate how the alert algorithm would perform. Algorithm parameters have not yet been optimized. This will wait until the CW Simulation is available. Table 11.10 shows various vehicle parameters vs. time.

In Scenario 1, the following and lead vehicles are traveling at constant speeds of 70 and 60 mph respectfully. It is assumed that the following vehicle does not brake. Algorithm 1 is always in effect because $V_f - V_l$ is always above 1.12 m/s. The last three columns of Table 11.11 shows the algorithm used, the brake status and the alert level vs. time. Figures 11.12 and 11.13 below show graphically the information in Table 11.11.

Table 11.11 Scenario 1



Vf0 = 70.00 mph, Vl = 60.00 mph
af= -0.49 g, al = -0.20 g
Sensitivity = 1 ,T = 1.00 sec

t	df	dl	R	Vf	Vl	delV	Rca	Ro	algo	brk	AL
0.0	0.00	25.00	25.00	31.29	26.82	4.47	12.79	19.94	1	0	0
0.2	6.26	30.36	24.11	31.29	26.82	4.47	12.79	19.94	1	0	0
0.4	12.52	35.73	23.21	31.29	26.82	4.47	12.79	19.94	1	0	0
0.6	18.77	41.09	22.32	31.29	26.82	4.47	12.79	19.94	1	0	0
0.8	25.03	46.46	21.42	31.29	26.82	4.47	12.79	19.94	1	0	0
1.0	31.29	51.82	20.53	31.29	26.82	4.47	12.79	19.94	1	0	0
1.2	37.55	57.18	19.64	31.29	26.82	4.47	12.79	19.94	1	0	0.04
1.4	43.81	62.55	18.74	31.29	26.82	4.47	12.79	19.94	1	0	0.17
1.6	50.06	67.91	17.85	31.29	26.82	4.47	12.79	19.94	1	0	0.29
1.8	56.32	73.28	16.95	31.29	26.82	4.47	12.79	19.94	1	0	0.42
2.0	62.58	78.64	16.06	31.29	26.82	4.47	12.79	19.94	1	0	0.54
2.2	68.84	84.00	15.17	31.29	26.82	4.47	12.79	19.94	1	0	0.67
2.4	75.10	89.37	14.27	31.29	26.82	4.47	12.79	19.94	1	0	0.79
2.6	81.35	94.73	13.38	31.29	26.82	4.47	12.79	19.94	1	0	0.92
2.8	87.61	100.10	12.48	31.29	26.82	4.47	12.79	19.94	1	0	1
3.0	93.87	105.46	11.59	31.29	26.82	4.47	12.79	19.94	1	0	1

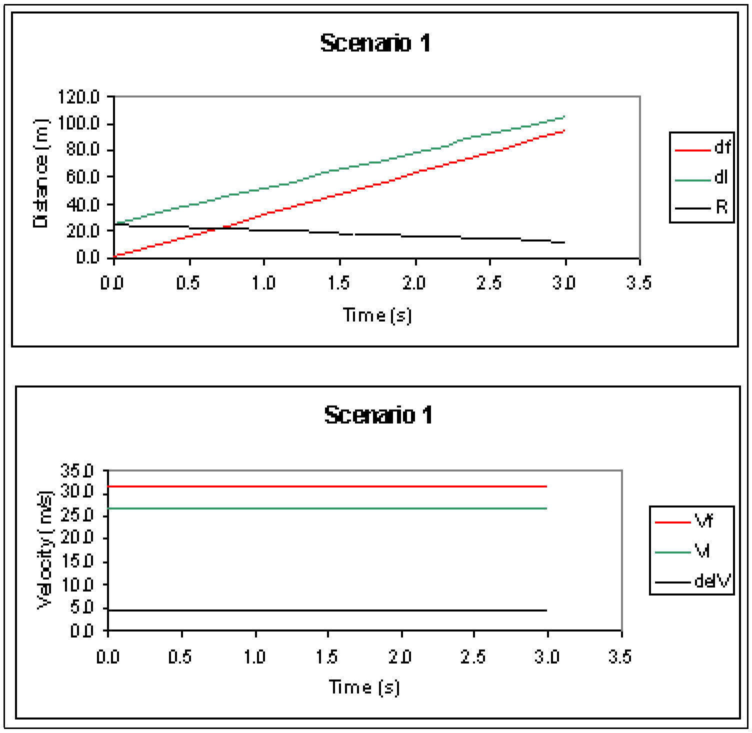


Figure 11.12 Scenario 1 Shown Graphically

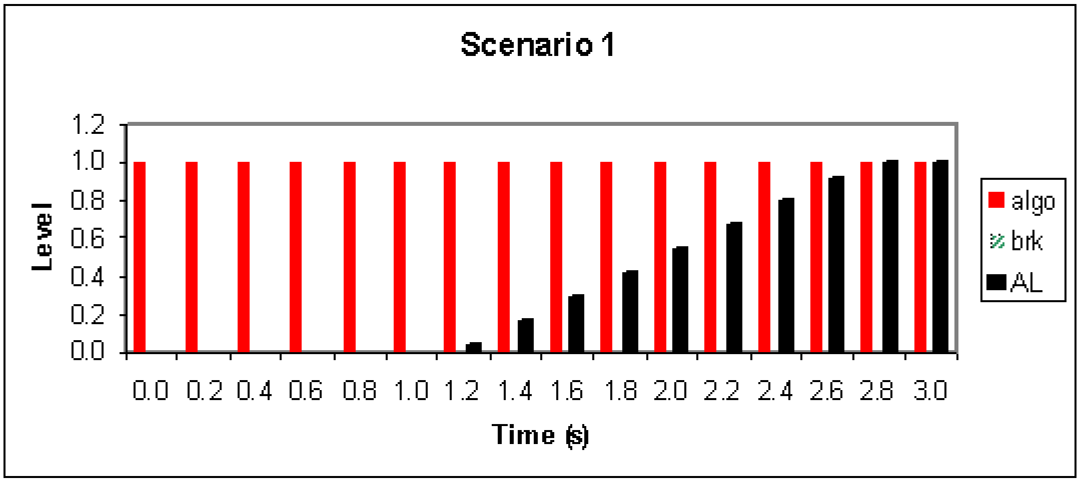


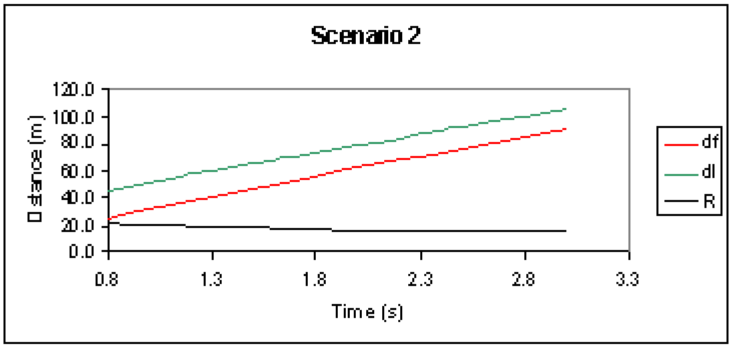
Figure 11.13 Scenario 1 Output Alert Level

In Scenario 2, the following and lead vehicles are initially traveling at constant speeds of 70 and 60 mph respectfully. But as soon as the Alert Level exceeds 0.3, the following vehicle brakes until $V_f = V_l$. Algorithm 2 is in effect as soon as $V_f – V_l$ is below 1.12 m/s. The last three columns of Table 11.12 shows the algorithm used, the brake status and the alert level vs. time. Figures 11.14 and 11.15 below show graphically the information in Table 11.12.

Table 11.12 Scenario 2

Vf0 = 70.00 mph, Vl = 60.00 mph
af = -0.49 g, al = -0.20 g
Sensitivity = 1 ,T = 1.00 sec

t	df	dl	R	Vf	Vl	delV	Rca	Ro	algo	brk	AL
0.8	25.03	46.46	21.42	31.29	26.82	4.47	12.79	19.94	1	0	0
0.9	28.16	49.14	20.98	31.29	26.82	4.47	12.79	19.94	1	0	0
1.0	31.29	51.82	20.53	31.29	26.82	4.47	12.79	19.94	1	0	0
1.1	34.42	54.50	20.08	31.29	26.82	4.47	12.79	19.94	1	0	0
1.2	37.55	57.18	19.64	31.29	26.82	4.47	12.79	19.94	1	0	0.04
1.3	40.68	59.87	19.19	31.29	26.82	4.47	12.79	19.94	1	0	0.10
1.4	43.81	62.55	18.74	31.29	26.82	4.47	12.79	19.94	1	0	0.17
1.5	46.94	65.23	18.30	31.29	26.82	4.47	12.79	19.94	1	0	0.23
1.6	50.06	67.91	17.85	31.29	26.82	4.47	12.79	19.94	1	0	0.29
1.7	53.19	70.59	17.40	31.29	26.82	4.47	12.79	19.94	1	0	0.35
1.8	56.30	73.28	16.98	30.81	26.82	3.99	11.26	17.65	1	1	0
1.9	59.36	75.96	16.60	30.33	26.82	3.51	9.81	15.44	1	1	0
2.0	62.37	78.64	16.27	29.86	26.82	3.04	8.45	13.31	1	1	0
2.1	65.33	81.32	16.00	29.38	26.82	2.56	7.16	11.26	1	1	0
2.2	68.24	84.00	15.76	28.90	26.82	2.08	5.96	9.29	1	1	0
2.3	71.11	86.69	15.58	28.42	26.82	1.60	4.84	7.40	1	1	0
2.4	73.93	89.37	15.44	27.95	26.82	1.13	3.80	5.60	1	1	0
2.5	76.70	92.05	15.35	27.47	26.82	0.65	2.84	27.47	2	1	0
2.6	79.42	94.73	15.31	26.99	26.82	0.17	1.96	26.99	2	1	0
2.7	82.10	97.41	15.31	26.82	26.82	0	1.66	26.82	2	0	0.46
2.8	84.79	100.10	15.31	26.82	26.82	0	1.66	26.82	2	0	0.46
2.9	87.47	102.78	15.31	26.82	26.82	0	1.66	26.82	2	0	0.46
3.0	90.15	105.46	15.31	26.82	26.82	0	1.66	26.82	2	0	0.46



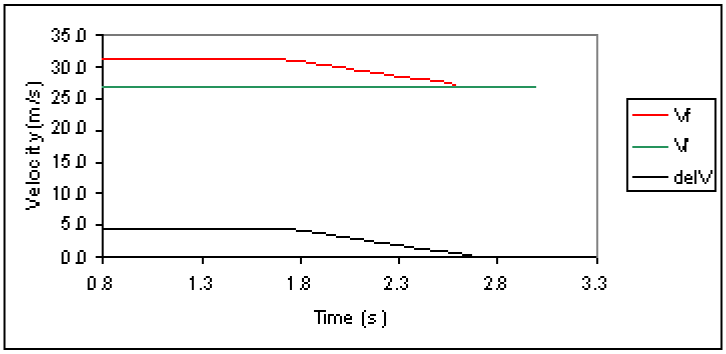


Figure 11.14 Scenario 2 Shown Graphically

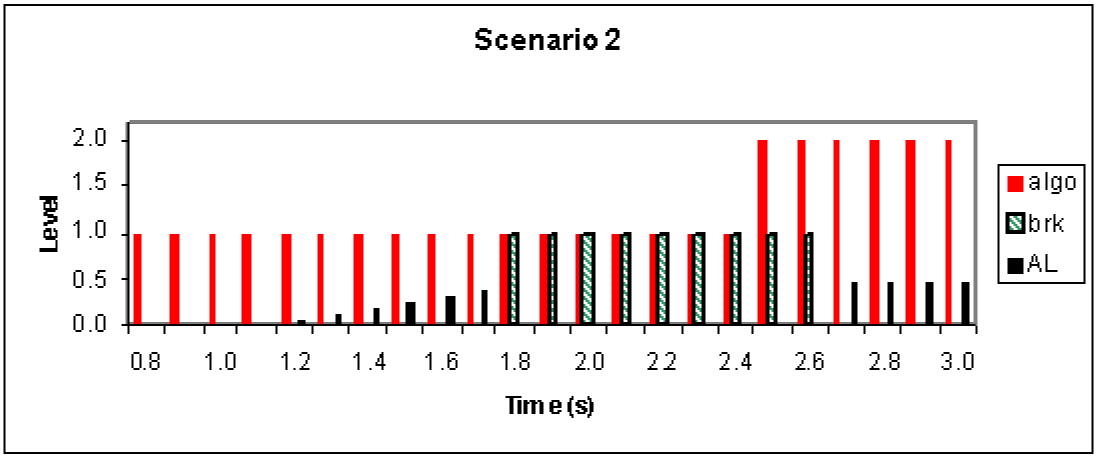
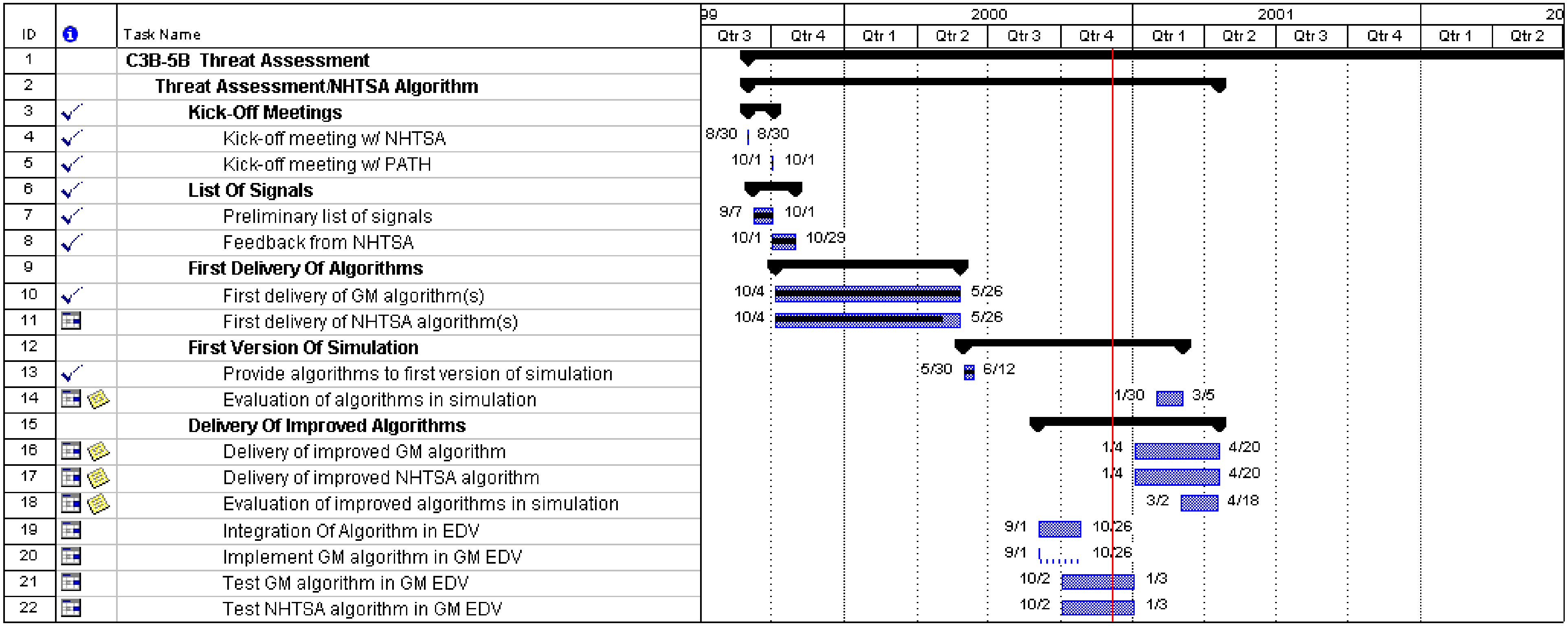


Figure 11.15 Scenario 2 Output Alert Level

Plans through December 2000

1. Optimize choice of Algorithm Parameters by analysis, simulation, and in-vehicle tests.
2. Develop MOE's for judging alternate Threat Assessment Algorithms.
3. Start in-vehicle testing.



ID	ℹ	Task Name
1		**C3B-5B Threat Assessment**
2		**Threat Assessment/NHTSA Algorithm**
3	✓	**Kick-Off Meetings**
4	✓	Kick-off meeting w/ NHTSA
5	✓	Kick-off meeting w/ PATH
6	✓	**List Of Signals**
7	✓	Preliminary list of signals
8	✓	Feedback from NHTSA
9		**First Delivery Of Algorithms**
10	✓	First delivery of GM algorithm(s)
11	▦	First delivery of NHTSA algorithm(s)
12		**First Version Of Simulation**
13	✓	Provide algorithms to first version of simulation
14	▦ ✎	Evaluation of algorithms in simulation
15		**Delivery Of Improved Algorithms**
16	▦ ✎	Delivery of improved GM algorithm
17	▦ ✎	Delivery of improved NHTSA algorithm
18	▦ ✎	Evaluation of improved algorithms in simulation
19	▦	Integration Of Algorithm in EDV
20	▦	Implement GM algorithm in GM EDV
21	▦	Test GM algorithm in GM EDV
22	▦	Test NHTSA algorithm in GM EDV

Figure 11.16 Task C3B & 5B Schedule

12 ACC Function (Task C4)

Objectives

The objectives of this task are to:

1. Provide an Adaptive Cruise Control (ACC) Subsystem for the 2000 Buick LeSabre
2. Determine the interface requirements to the other vehicle subsystems
3. Provide support to development and deployment groups.

Approach

The approach is to utilize the ACC subsystem that is part of a future production program. The ACC subsystem is a complete control system that uses an integral radar to detect objects in front of the vehicle, and provide throttle and brake control to maintain a safe distance to the car ahead. The radar will also detect objects for the Forward Collision Warning system to be designed into the vehicle. Since the ACC will be used as received, the design work will focus on the interfaces between the ACC system and the rest of the vehicle.

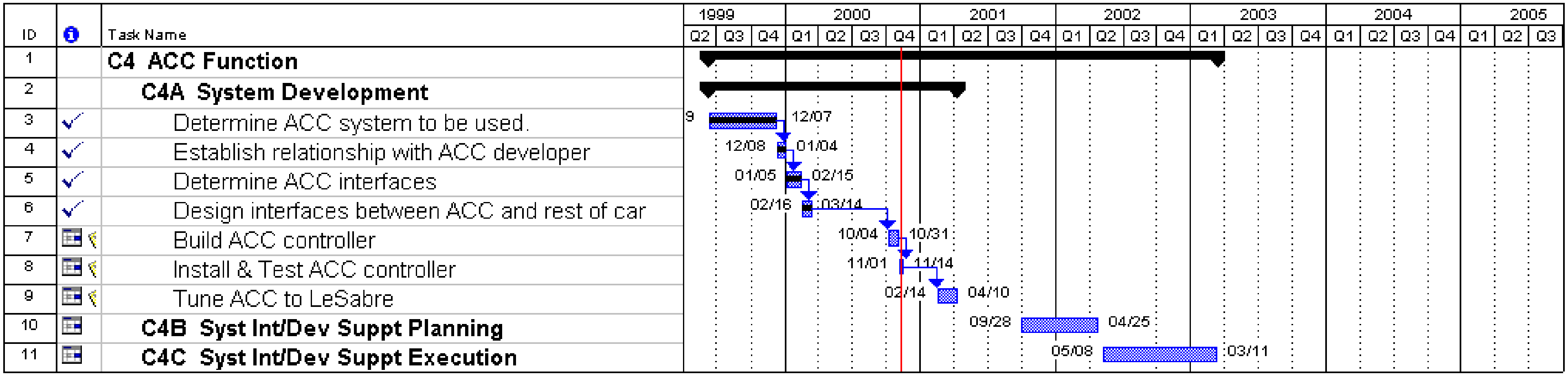
Work Accomplished

Initial interface designs have been completed. It has been determined that the ACC subsystem will communicate to the DBC 7.2 brake subsystem over a Class 2 bus, and to the throttle stepper motor cruise control (SMCC) over an 8192 baud serial link. Preliminary tests using the ACC radar have provided knowledge about the instrumentation interface requirements for the radar.

Communicating to the ACC system by the other subsystems will be over a CAN interface using an instrumentation protocol. This interface must be established each time the radar is powered up. This will be accomplished by initializing the radar's instrumentation messages to send object data to the other subsystems after each radar scan.

Plans through December 2000

The plans for the next 6 months are to install an ACC-A radar on a test vehicle and evaluate the interface and performance of this radar.



ID		Task Name
1		**C4 ACC Function**
2		**C4A System Development**
3	✓	Determine ACC system to be used.
4	✓	Establish relationship with ACC developer
5	✓	Determine ACC interfaces
6	✓	Design interfaces between ACC and rest of car
7		Build ACC controller
8		Install & Test ACC controller
9		Tune ACC to LeSabre
10		**C4B Syst Int/Dev Suppt Planning**
11		**C4C Syst Int/Dev Suppt Execution**

Figure 12.1 Task C4 Schedule

13 FLEET VEHICLE BUILD (TASK D)

13.1 GM Engineering Development Vehicle

<u>Objectives</u>

The objective of General Motors Engineering Development Vehicle (GM EDV) is to develop, design, implement and investigate a subset of technologies that will be available on the deployment vehicles to be used in the ACAS/FOT Program. These technologies will be evaluated on this vehicle and will go through a down selection process with other technologies being investigated by the partners in the program. The basic technologies being focused on at this time on this vehicle are:

1. Threat assessment
2. GPS/Map based path prediction
3. Evaluating the performance of the Assistware System
4. Human factors

These technologies are elaborated in different sections of the report and will also be summarized later in this section.

<u>Approach</u>

The GM EDV is a 2000 model year Buick LeSabre that has gone through a significant modification to accommodate all the required instrumentation to investigate the intended technologies. Our approach in building this vehicle consisted of three major steps.

1. Defining the architecture - This important step consisted of analyzing various architectures and configurations, and finally determining the best approach for this task. Important factors in this determination were:
    a. simplicity and ease of implementation
    b. compatibility with our partners' architectures
    c. ease of debugging the system
    d. ease of collecting data
2. Implementing the architecture in the laboratory - However well the test vehicle is designed and built, it is still a very cumbersome and inconvenient environment to debug a system. For this reason, the first step taken in this task was to implement the architecture in the laboratory. The configuration that was intended for the vehicle was implemented on the bench with exactly the same computers, communications scheme, and add-on sensors. However, integrating the vehicle sensors on the bench system is not possible in a laboratory environment.

Work Accomplished
The following has been accomplished on the GM Engineering Vehicle (EDV).

System Hardware

The system hardware was debugged on the bench and made operational. Initially, rudimentary software for the functions performed by each module was integrated with the communications software, to make sure the communications software and processor hardware were working properly. Then, the operation of sensors was verified, although the data provided is not meaningful in this environment.

Before instrumenting the vehicle, necessary electrical and mechanical infrastructure was built to support the system. Electrical upgrades consist of installing a high output alternator in addition to wiring, power and signal, terminals, fuses and various relays. Mechanical upgrades consist of various brackets for computers and sensors, wire and cable routing, modifications to various parts of the vehicle to install subsystems/devices.

The instrumentation was installed in various parts of the vehicle. The grille and the engine compartment contain the radar sensor. The passenger compartment contains the yaw rate sensor, accelerometer, and compass, which are underneath the console. A high head down display (HHDD) is immediately in front of the driver embedded in the dashboard. A speaker for audio feedback is under the instrument panel and is driven by an amplifier in the trunk. Haptic feedback, which consists of a seat vibrator, is embedded into the driver's seat in the lumbar area. The engineering terminal is in the back seat immediately behind the front passenger. This consists of a liquid crystal display and keyboard. A single display and keyboard will support multiple computers in the vehicle. An electronic switch box is installed in the opening between the trunk and the passenger compartment. By pushing the selector switch on this box, it will connect the terminal to the next computer in round-robin fashion.

The trunk is where the majority of the computers and devices are installed. A number of computers with a dedicated floppy disk drive for program loading are permanently installed. A panel with all the signals serves the purpose of a breakout box for observing the sensor signals. The Assistware system, differential global positioning system (DGPS), Class 2 bus to serial converter, and a soundboard with amplifier are all laid out on a baseboard in the trunk. In addition, there is a data acquisition system, which resides in the trunk but will be used on demand in conjunction with a laptop, when needed.

The exterior of the vehicle is used for antennas. The antenna for the compass is hidden in the headliner. The antenna for the DGPS of the Assistware system and the road geometry processor are mounted on the trunk lid. A second DGPS antenna for data truthing in certain tests will be temporarily mounted on the trunk lid.

EDV Architecture

The architecture and block diagram of the GM EDV is shown in Figure 13.1. This architecture is being implemented and built into the vehicle.

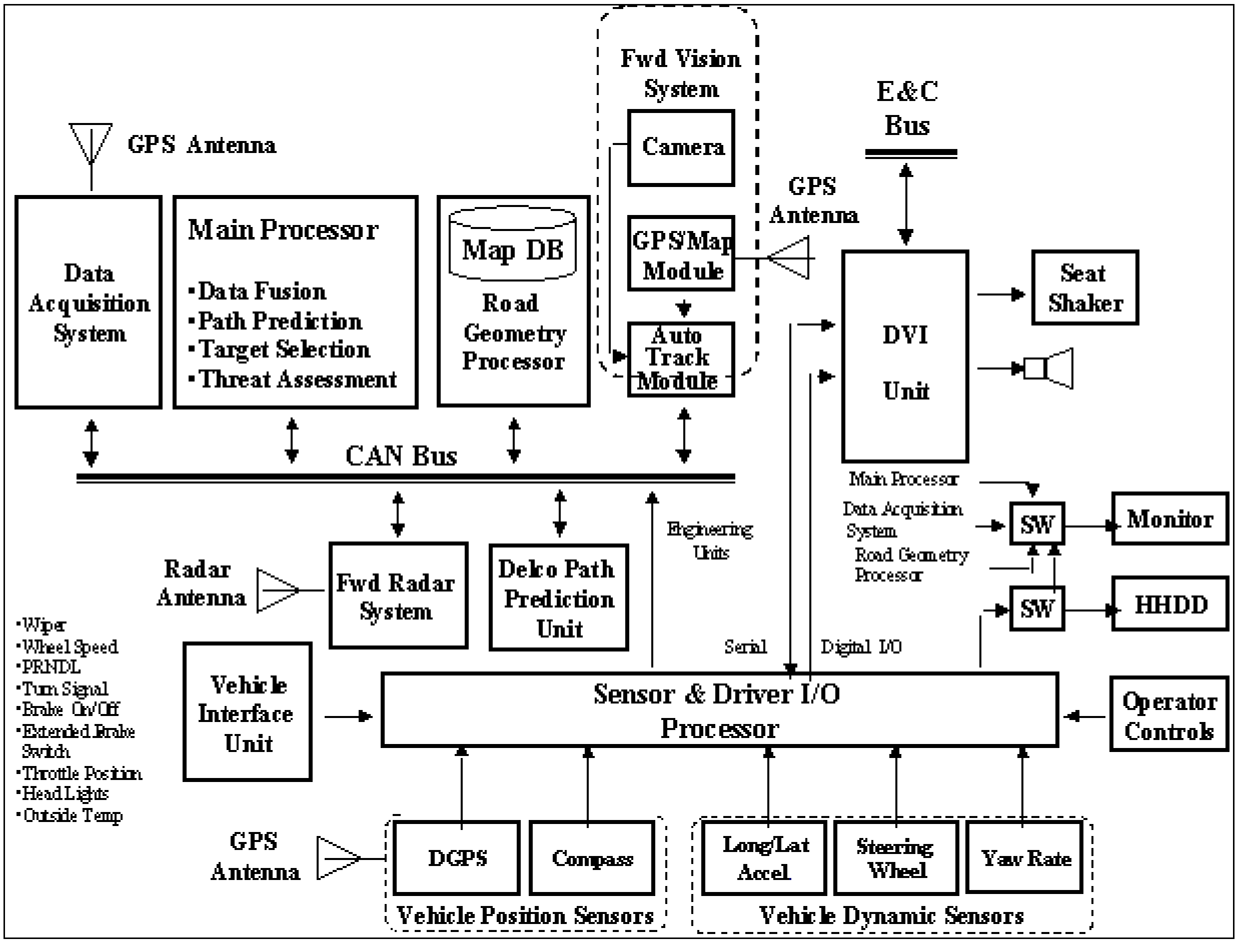


Figure 13.1 Architecture of GM Engineering Development Vehicle

The backbone of the system is a CAN bus for communicating between various subsystems in the vehicle. The bus is operating at 500 Kbaud rate and uses an 11-bit identification code for messages. One end of the bus is terminated at the radar, which is at an extreme location physically. The other end is terminated at the Sensor and Driver I/O Processor.

There are a number of processors that share the tasks to be accomplished. Sensor and Driver I/O Processor is the interface between the vehicle, the driver and the system. It is interfaced to in-vehicle production sensors and devices. This is accomplished via two separate paths. First is the Class 2 bus; any sensor information of use to the GM EDV on this bus is monitored and captured. Then interface electronics convert Class 2 messages to RS232 format. Any sensor or device parameter not available on Class 2 bus is directly interfaced. This information is gathered through either discrete digital inputs or an analog to digital converter. Non-production sensors are installed on the vehicle. These are the differential global positioning system (DGPS), compass, longitudinal/lateral accelerometer, steering wheel position sensor, yaw rate sensor. The driver inputs are captured through the steering wheel buttons. The Driver Vehicle Interface (DVI) Unit, consists of a High Head Down Display (HHDD), a soundboard, and seat vibrator.

The Road Geometry Processor is used to determine the road geometry ahead of the vehicle based on DGPS data and maps. It receives the DGPS data periodically through the Sensor Processor and the CAN bus. The maps are permanently stored on the hard disk media in this processor. It generates a data record which defines the path of the road ahead, and this information is placed on the CAN bus to be picked up by the Main Processor.

The Main Processor performs many functions: data fusion, path prediction, target selection, and threat assessment. It receives the data from the radar via the CAN bus, which contains target tracks and additional pertinent information, related to detected targets. It receives vehicle sensor data and road geometry processor output for data fusion to predict the vehicle path. Based on the radar targets and predicted path, it selects the most threatening target. The threat assessment algorithm(s) are performed on this target based on the kinematics of the vehicle, which is monitored by the sensor processor and the target, which is determined from target information.

The radar is directly interfaced to the CAN bus. At power up it requires an initialization message which will be sent automatically by the Delphi Delco Path Prediction Unit. This initialization message configures the radar main processor to transmit the requested data periodically, at a 10 Hz rate.

The Delco Path Prediction Unit, as the name implies, is a stand-alone box which predicts the vehicle path based on vehicle dynamics sensors. In addition, it initializes the radar to the proper mode.

Assistware is a forward vision system that has two functions. First, it has a forward-looking camera and a vision processor to determine the lane marker positions and the attitude of the vehicle within the lane, specifically, offset from the centerline, and the heading. Second, it has a GPS/map module which is capable of building maps as the vehicle is driven around.

The Driver Vehicle Interface (DVI) Unit consists of several devices that alert the driver. A High Head Down Display (HHDD) is directly in front of the driver on the dashboard and, displays various graphics and icons as well as text data. The speaker generates various tones to get the attention of the driver under certain conditions. A seat shaker is the haptic output, which is another mode for alerting the driver.

All processors are connected to a switch box which enables them to share a common monitor and keyboard. The monitor and keyboard are mounted on the back seat for the engineer to control the overall system. Not shown in the block diagram are floppy disk drives for each processor. These features enable easy debugging in the field and downloading of software to the system.

Software Development

An initial version of all the software components of the Engineering Development Vehicle has been designed and coded, and tested in the lab. Currently it is in the process of being installed in the Engineering Development Vehicle for testing and data logging. The software components are:

1. Program Loader - from solid state non-volatile memory
2. Real Time Multi-Threading Functions
   a. Interrupt service routines
   b. Resource locking
   c. Time slicing
   d. Pre-emption
   e. Timer services
   f. Intra processor communication functions
   g. Functions to copy data structures between program modules.
   h. CAN bus message definitions and functions.
3. Asynchronous Serial Communication with External Sensors
   a. GPS
   b. Yaw rate sensor
   c. Compass
   d. Accelerometer
   e. Class 2 gateway for vehicle OEM data
   f. Audio output device.
4. Map Road Geometry **-** Extracts forward road geometry from map database**.**
5. Data Fusion - Combines instantaneous yaw rate with predicted Map Road Geometry
6. Target Selection **-** Selects a target from the Radar target tracks based on host vehicle path and radar track data.
7. Threat Assessment - Uses vehicle and radar data to compute alert level based on the most threatening target in the host vehicle path.
8. Driver-Vehicle Interface - Presents the alert level to the driver in visual, audio and haptic form.

Plans through December 2000

1. Complete the vehicle build
2. Collect data for individual components / subsystems
3. Develop and integrate algorithms and software.
4. Perform system level tests and collect data
5. Evaluate the system
6. Enhance functionality, especially time latency of the algorithms

13.2 Prototype Vehicle

Objectives

The objective of building the Prototype Vehicle is to integrate all the technologies developed by the partners in the Program as a precursor to the Pilot Vehicle and finally to the Deployment Vehicles. This vehicle will have the full functionality as required to support the FOT.

Approach

The Prototype vehicle will also be a development vehicle in the sense that all the subsystems that have been verified in a number development vehicles will be integrated. This is not a straightforward task, and will require significant collaboration among the partners to complete.

The approach is similar to that undertaken in the GM EDV, however bench development in the laboratory will be limited because this vehicle has Adaptive Cruise Control (ACC). The emphasis will be on integration rather than development of individual subsystems. In addition, this vehicle will contain a full data acquisition system.

The software system is designed such that most of the software components of the Prototype Vehicle will have been installed and tested on the Engineering Development Vehicle. The exceptions are:

1. Road geometry from the Vision System
2. Road geometry from Radar Scene Tracking
3. Driver-Vehicle Interface with the HUD

Work Accomplished

The architecture and block diagram of the Prototype Vehicle is shown in Figure 13.1. This architecture will be implemented and built into the Prototype Vehicle.

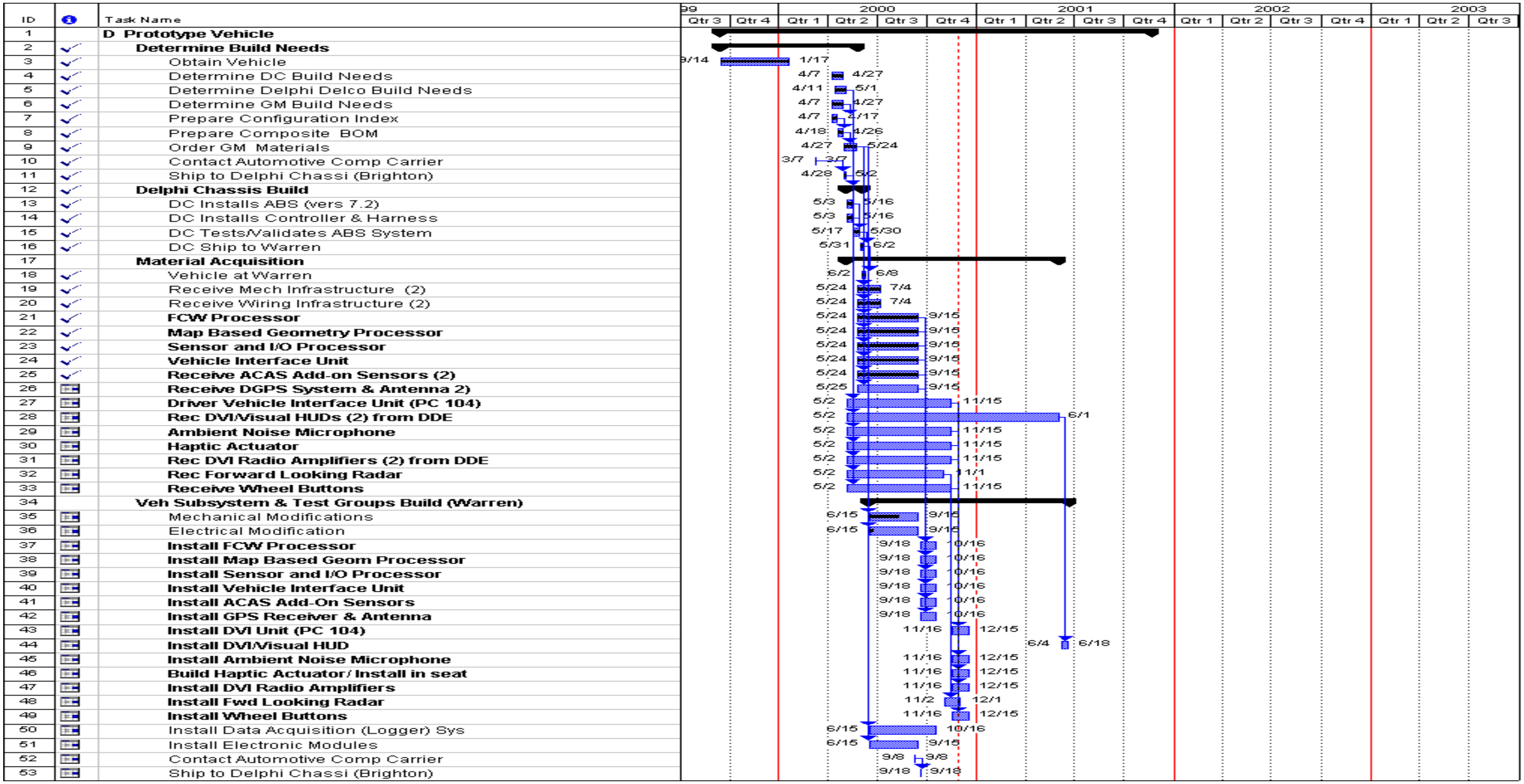
As of June 2000, the following has been accomplished on the Prototype Vehicle:

1. Obtain the vehicle
2. Finalize bill of materials
3. Order components / subsystems
4. Modify the brake system (first phase)

This architecture is an extension of the GM EDV. The major difference is the addition of the Adaptive Cruise Control, which involves throttle and brake control. The Driver Vehicle Interface is different, mainly in the use of Head-up Display. In addition, the functional mapping of tasks to hardware is unlike the EDV because partners are delivering some of the functions already implemented in hardware modules as black boxes.

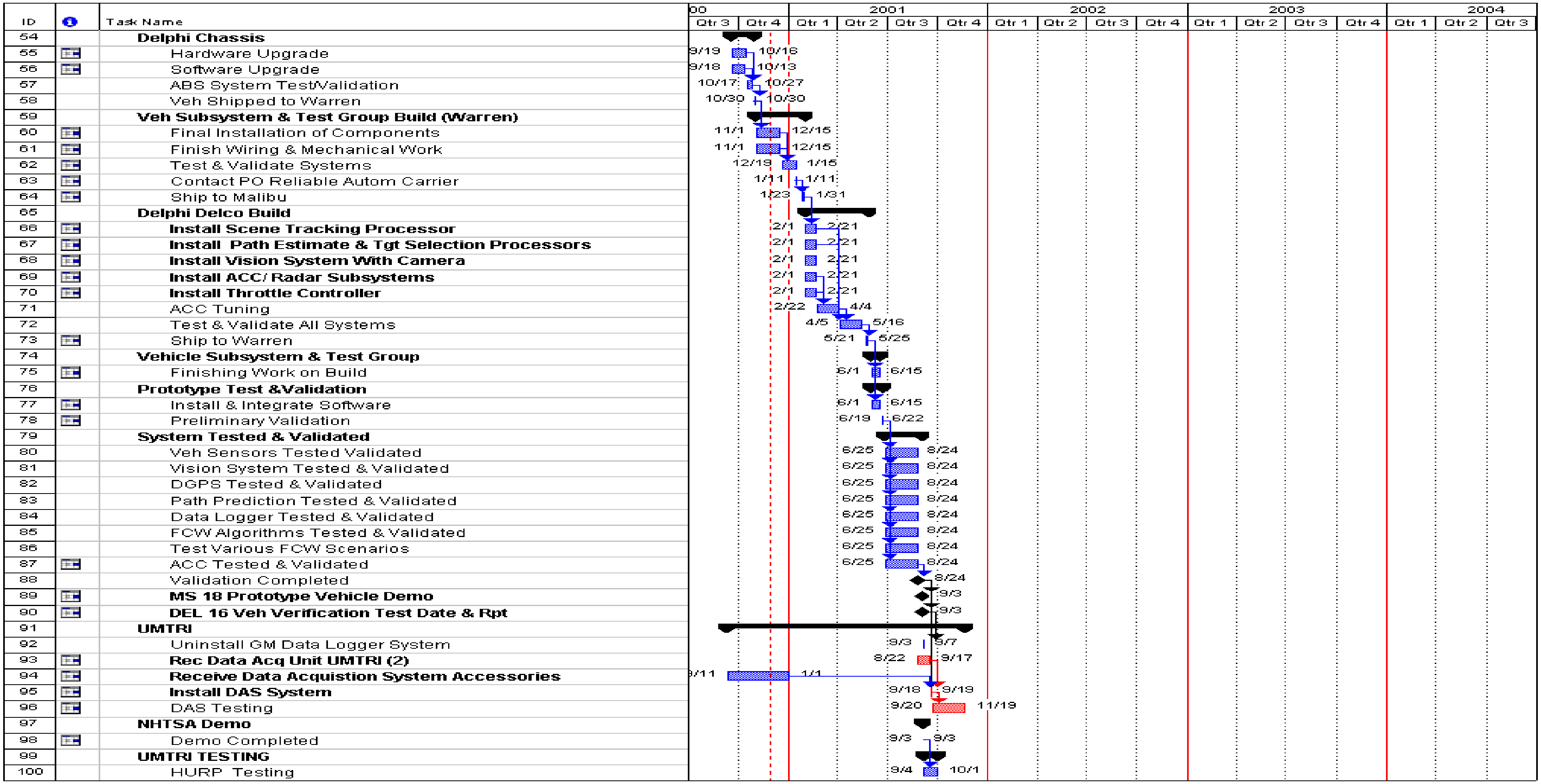
Plans through December 2000

1. Modify the vehicle with mechanical and electrical infrastructure.
2. Complete the brake control system (second and final phase).
3. Install add-on sensors.
4. Install GM computers and subsystems.



ID	ⓘ	Task Name
1		**D Prototype Vehicle**
2	✓	**Determine Build Needs**
3	✓	Obtain Vehicle
4	✓	Determine DC Build Needs
5	✓	Determine Delphi Delco Build Needs
6	✓	Determine GM Build Needs
7	✓	Prepare Configuration Index
8	✓	Prepare Composite BOM
9	✓	Order GM Materials
10	✓	Contact Automotive Comp Carrier
11	✓	Ship to Delphi Chassi (Brighton)
12	✓	**Delphi Chassis Build**
13	✓	DC Installs ABS (vers 7.2)
14	✓	DC Installs Controller & Harness
15	✓	DC Tests/Validates ABS System
16	✓	DC Ship to Warren
17		**Material Acquisition**
18	✓	Vehicle at Warren
19	✓	Receive Mech Infrastructure (2)
20	✓	Receive Wiring Infrastructure (2)
21	✓	**FCW Processor**
22	✓	**Map Based Geometry Processor**
23	✓	**Sensor and I/O Processor**
24	✓	**Vehicle Interface Unit**
25	✓	**Receive ACAS Add-on Sensors (2)**
26	▦	**Receive DGPS System & Antenna 2)**
27	▦	**Driver Vehicle Interface Unit (PC 104)**
28	▦	**Rec DVI/Visual HUDs (2) from DDE**
29	▦	**Ambient Noise Microphone**
30	▦	**Haptic Actuator**
31	▦	**Rec DVI Radio Amplifiers (2) from DDE**
32	▦	**Rec Forward Looking Radar**
33	▦	**Receive Wheel Buttons**
34		**Veh Subsystem & Test Groups Build (Warren)**
35	▦	Mechanical Modifications
36	▦	Electrical Modification
37	▦	**Install FCW Processor**
38	▦	**Install Map Based Geom Processor**
39	▦	**Install Sensor and I/O Processor**
40	▦	**Install Vehicle Interface Unit**
41	▦	**Install ACAS Add-On Sensors**
42	▦	**Install GPS Receiver & Antenna**
43	▦	**Install DVI Unit (PC 104)**
44	▦	**Install DVI/Visual HUD**
45	▦	**Install Ambient Noise Microphone**
46	▦	**Build Haptic Actuator/ Install in seat**
47	▦	**Install DVI Radio Amplifiers**
48	▦	**Install Fwd Looking Radar**
49	▦	**Install Wheel Buttons**
50	▦	Install Data Acquisition (Logger) Sys
51	▦	Install Electronic Modules
52	▦	Contact Automotive Comp Carrier
53	▦	Ship to Delphi Chassi (Brighton)

Figure 13.2 Task D Schedule, Page 1



ID	ℹ	Task Name
54		**Delphi Chassis**
55	▤	Hardware Upgrade
56	▤	Software Upgrade
57		ABS System Test/Validation
58		Veh Shipped to Warren
59		**Veh Subsystem & Test Group Build (Warren)**
60	▤	Final Installation of Components
61	▤	Finish Wiring & Mechanical Work
62	▤	Test & Validate Systems
63	▤	Contact PO Reliable Autom Carrier
64	▤	Ship to Malibu
65		**Delphi Delco Build**
66	▤	**Install Scene Tracking Processor**
67	▤	**Install Path Estimate & Tgt Selection Processors**
68	▤	**Install Vision System With Camera**
69	▤	**Install ACC/ Radar Subsystems**
70	▤	**Install Throttle Controller**
71		ACC Tuning
72		Test & Validate All Systems
73	▤	Ship to Warren
74		**Vehicle Subsystem & Test Group**
75	▤	Finishing Work on Build
76		**Prototype Test &Validation**
77	▤	Install & Integrate Software
78	▤	Preliminary Validation
79		**System Tested & Validated**
80		Veh Sensors Tested Validated
81		Vision System Tested & Validated
82		DGPS Tested & Validated
83		Path Prediction Tested & Validated
84		Data Logger Tested & Validated
85		FCW Algorithms Tested & Validated
86		Test Various FCW Scenarios
87	▤	ACC Tested & Validated
88		Validation Completed
89	▤	**MS 18 Prototype Vehicle Demo**
90	▤	**DEL 16 Veh Verification Test Date & Rpt**
91		**UMTRI**
92		Uninstall GM Data Logger System
93	▤	**Rec Data Acq Unit UMTRI (2)**
94	▤	**Receive Data Acquistion System Accessories**
95	▤	**Install DAS System**
96	▤	DAS Testing
97		**NHTSA Demo**
98	▤	Demo Completed
99		**UMTRI TESTING**
100		HURP Testing

Figure 13.3 Task D Schedule, Page 2

14 FIELD OPERATIONAL TEST (TASK E)

Objectives

The objectives of this task center on the preparations for and execution of the field operational test. In Phase I of this project, the objectives include:

1. Planning the pilot testing series
2. Conducting Stage One and Stage Two pilot tests
3. Development of a Data Acquisition System, and
4. Development of procedures, software, and a plan for executing the FOT.

Approach

The general approach has been to apply as much of UMTRI's prior methodology and learning from the ICC FOT as possible, adapting the field-testing techniques to the ACAS platform. The approach also involves advancing the state of practice with updated hardware and software for data acquisition and updated procedures to bring about an efficient and highly informative field test of ACAS. Noting that the ACAS system is much more complex than was the ICC system tested in 1997 and that much more of the system function is being developed in the course of the ACAS project, as opposed to simply testing a mostly pre-developed ICC system, UMTRI's approach has included significant engagement in technical discussions with the ACAS team. Thus, UMTRI staff have become increasingly knowledgeable on the makeup and operation of the entire system, while also giving critique and trial test results by way of feedback on system design to GM and Delphi team members.

From the viewpoint of an architecture for data acquisition, processing, and analysis, UMTRI has undertaken a top-down review of the approach, resulting in a major reconfiguration and upgrade of the data handling system. The intent is that the largest portion of this system plan will be confirmed through implementation of the data acquisition system and the associated database tools that are used for testing Stage 1 Pilot vehicles and the Prototype Phase Vehicle. Experience from these preliminary rounds of application will help in guiding a highly efficient and productive approach for the later field test of the ACAS fleet of vehicles.

Milestones and Deliverables through June 2000

The FOT Pilot Test Plan was delivered to NHTSA in January 2000.

Work Accomplished

The work accomplished will be summarized in three sections as follows:

1. Work on the Data Acquisition System (DAS)
2. Work on the larger architecture for a "Data System" (i.e., including the provisions for a database and all its associated tools.)
3. Work on testing the Opel Vectra EDV.

The Data Acquisition System

Figure 14.1 shown below is the conceptual layout of the ACAS test vehicle, showing the points at which it is to be interfaced with the DAS unit. Work on DAS development has included a substantial effort to understand the complete ACAS system and the proper means for interfacing with it. While various ancillary signals from the ACAS vehicle are given an interface with the DAS to support power control functions, the primary datalink is via the CAN bus. The DAS package interfaces with the UMTRI lab facility both via logic control and data link mechanisms. The DAS also supports data collection outside of the domain of the CAN interface by means of a concern button, video cameras, and a microphone/speaker provision for driver comment.

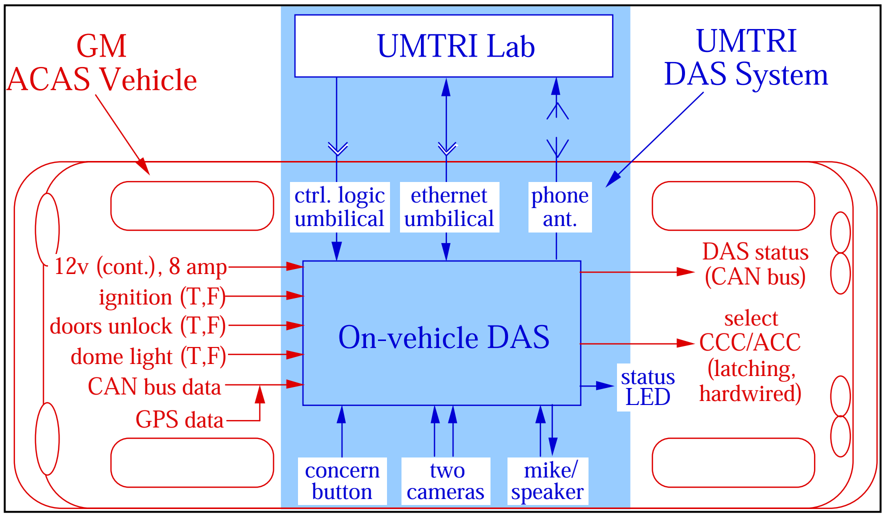


Figure 14.1 Vehicle Interfaced With the DAS

The operation of the DAS is depicted in Figure 14.2, indicating that objective, quantitative data and audio/video data are handled separately. The primary control of the data collection process is vested in the computer that handles objective data, yielding time-stamped and stored samples of more than a hundred selected variables as well as transition files that identify when certain logical states have been satisfied. Among these states are those matching certain criteria that trigger the storage of audio and video files that have been temporarily buffered in a loop-&-store memory.

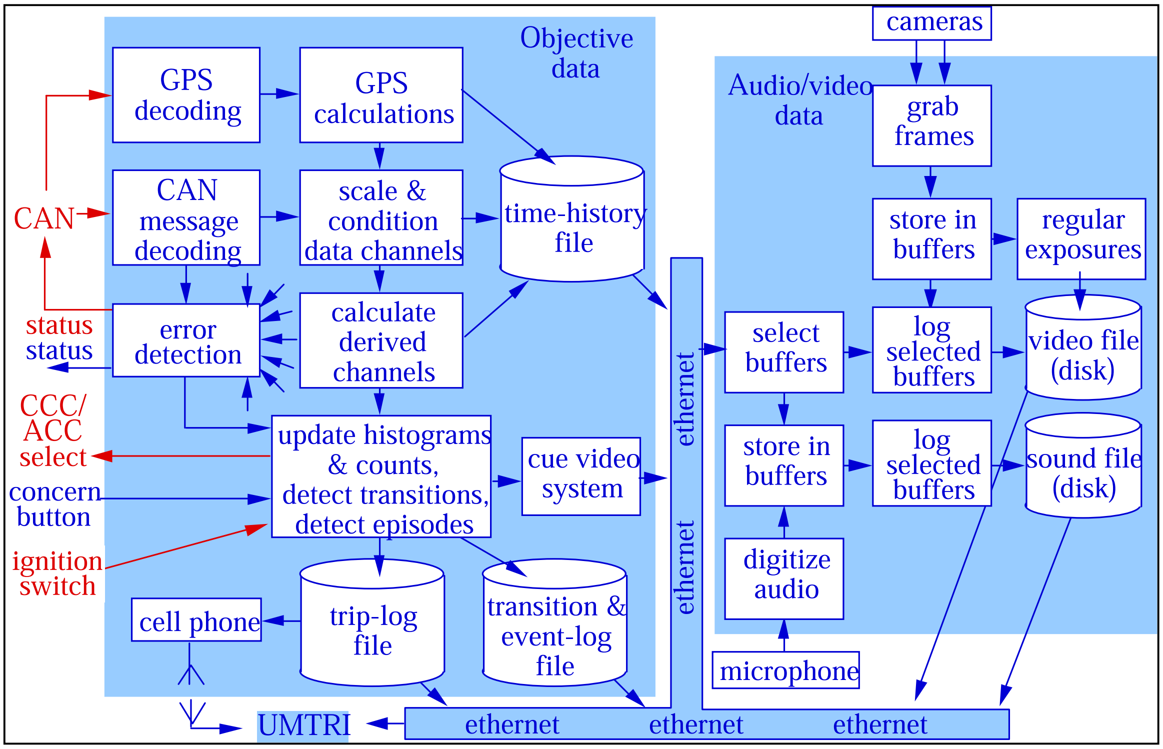


Figure 14.2 Objective, Quantitative Data And Audio/Video Data

The DAS communicates both between its two primary units and, upon return of the test car, directly with UMTRI's main archival computers via Ethernet connections. When a subject returns the vehicle to the UMTRI building, an Ethernet cable connection is patched to the DAS in order to recover the full data set. Throughout the test operation, cell modem connections to UMTRI are made at the end of each ignition-off cycle of the vehicle to download a trip summary that affords a means of monitoring progress in the field.

Figure 14.3 shows the basic hardware plan for the DAS. Two single-board computers support the respective "main" and "video" (including audio) storage modules. The link with GPS, aside from the recovery of GPS coordinates via the CAN bus, is to support the synchronism of DAS records with the Pulse-Per-Second (PPS) signal that allows GPS to serve as the master clock. The link to a box labeled "ignition, door locks, dome light" is a provision for accelerating the start-up of the DAS in order to minimize the time delay of DAS availability at the start of each new trip.

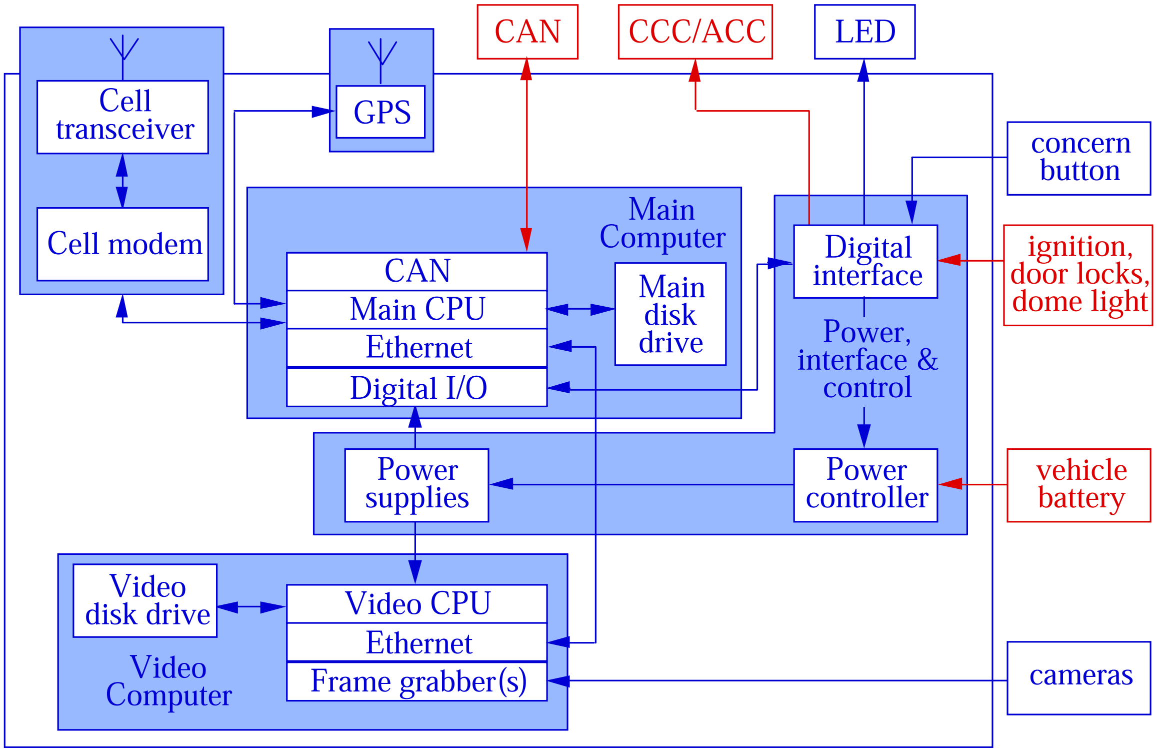


Figure 14.3 Basic Hardware Plan for the DAS

The Larger Architecture for a "Data System"

Figure 14.4 depicts the overall architecture of the data system, which supports research on FOT data. Included are elements that provide for the creation of test data via the DAS package, investigation of data based upon browsing and analyzing the contents of the database, appending analytical results as an augmentation of the test-derived database, high-level examination of reduced or aggregated data using data mining and visualization tools, and sharing data with others via a Web server. This overall architecture provides for an integrated multi-use of software that may be downloaded onto an individual DAS package in a vehicle as well as installed as part of the archival record of FOT results within the database.

The diagram shows that data are stored in each of three forms: namely as metadata, the database, and a data warehouse. Metadata serve to store objective attributes of the test design, test conditions, measured variables, real-time computations conducted on board the DAS package, etc., as well as corresponding attributes which define post-test analyses and simulations that were performed on test data drawn from the database. In general, metadata constitute instructions within the DAS package as well as a permanent bookkeeping record accompanying all measured and analyzed data elements.

The database represents one or more relational databases in which the FOT data and analytical derivations are stored. The most detailed study of the FOT results will involve exercise of the indicated “Explorer” and “Cruncher” tools, shown at the upper right, as specialized utilities for accessing and operating upon the relational database.

The data warehouse provides for convenient study by many researchers of results aggregated for high-level analysis. Significant response “FACTS” are defined for aggregating the data—for example, warning events, ACC interventions, driver-cited “miss” events, etc. Each FACT has “click-able” dimensions such as driver, road, time, cruise state, etc., and each dimension has attributes such as driver age, gender, driving style, velocity range, etc. A so-called “Pivot table”, then, provides a query engine that is optimized for immediate analysis of the multiple dimensions of the FACT. The practical result is that the insight process is better stimulated by richer initial displays of data whose study can be better sustained, once the researcher gets on a good discovery track, because the pursuit process has been made so efficient.

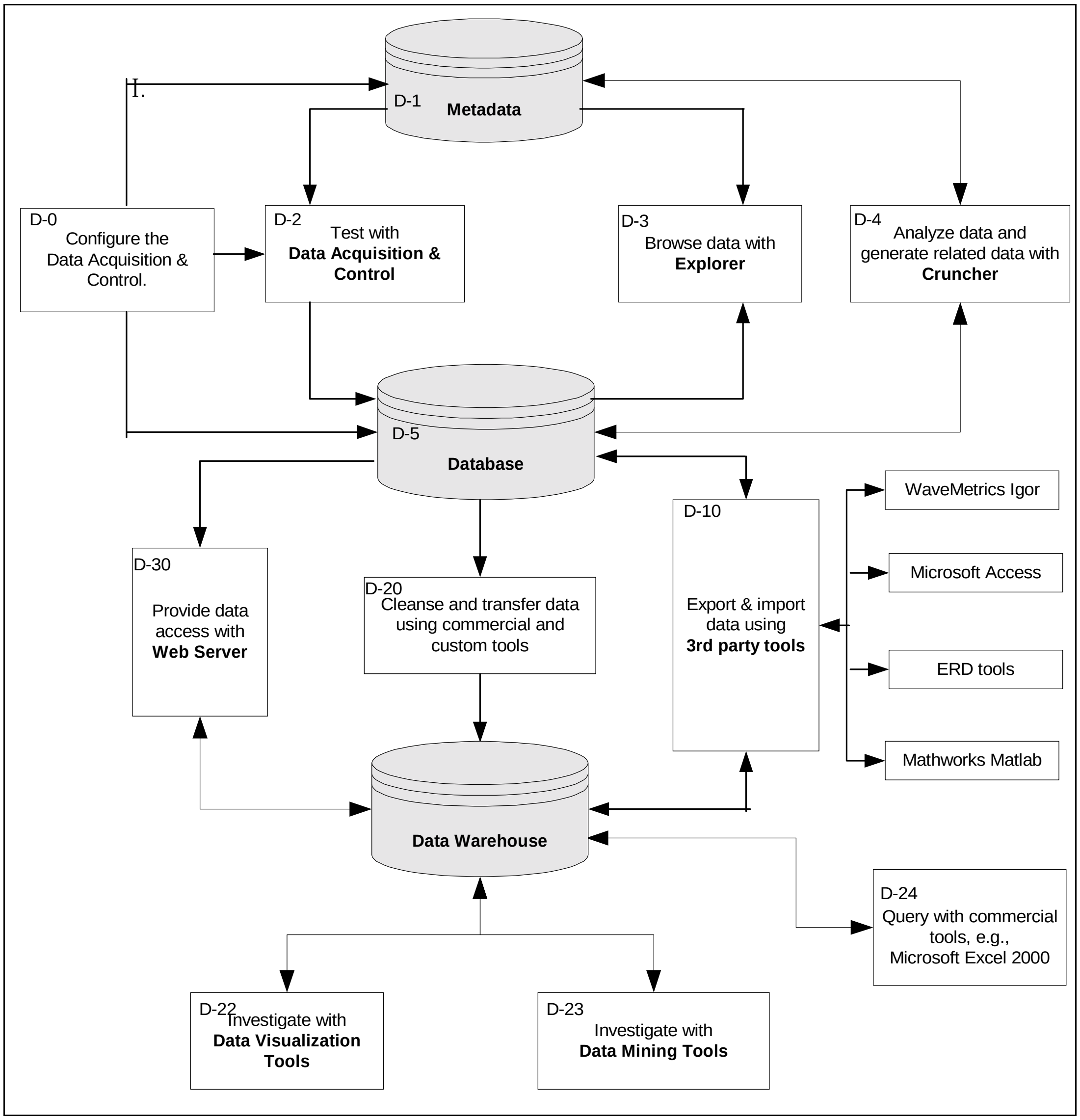


Figure 14.4 Overall Architecture of the Data System

Testing the Opel Vectra Engineering Development Vehicle

Eight UMTRI staff members drove the Opel ACC vehicle over a 94-mile route during June of 2000. Each of these individuals was experienced in developing and testing ACC vehicles, some for as many as seven years and some for as little as one year. Prior to beginning the route, each person was given an orientation drive of approximately twenty minutes in order to learn system operation.

The route originated in Ann Arbor, proceeded along mostly freeway segments into Southfield, went south on freeways and a 24-mile segment of Telegraph Road to Flat

Rock, and proceeded back to Ann Arbor on mostly freeways. Each person who drove the route filled out a 21-point questionnaire and the results were compiled and summarized for informing later stages of the ACAS activity.

The intent of this exercise was to gain first-hand experience that would guide the development of UMTRI and GM Institutional Review Board (IRB) and NHTSA Human Use Review Panel (HURP) applications required under the ACAS study. Additional collection of quantitative data from the Opel also facilitated the planning of UMTRI's data acquisition system, as well.

The Opel package afforded a brake-assisted ACC functionality and multi-target radar that was seen as reasonably approximating those which will support the ACC features of the ACAS system, albeit an earlier generation of the same having various differences in calibration of its ACC controller. Since the test drivers were encouraged to get as much ACC driving experience as possible along the route, they each took a special effort to maximize engagement while also maintaining reasonable safety margins. As a brief indicator of the scope of this pilot testing activity, Figure 14.5 presents the utilization results covering four cases defined as follows:

1. Segments of the Opel route, as it was actually driven,
2. An estimate of the utilization level that each person said they would expect to employ after a month of ACC usage, under the same road and traffic conditions as were driven,
3. A benchmark value for ACC utilization as obtained in UMTRI's prior ICC Field Operational Test (where the intelligent cruise system had only throttle control plus a transmission downshift)
4. Another benchmark from the prior field test pertaining to subject engagement of conventional cruise control (CCC), when it was the only cruise modality available.

Both the actual and estimated (month-later) Opel utilization results are shown as bars whose width represents +/- one standard deviation about the reported mean value for eight drivers. The ICC FOT and CCC benchmark results are shown only as the average values obtained across the 108 test subjects in the earlier field test. Road types are distinguished by freeways, two kinds of surface streets, and the overall set of roads that were driven.

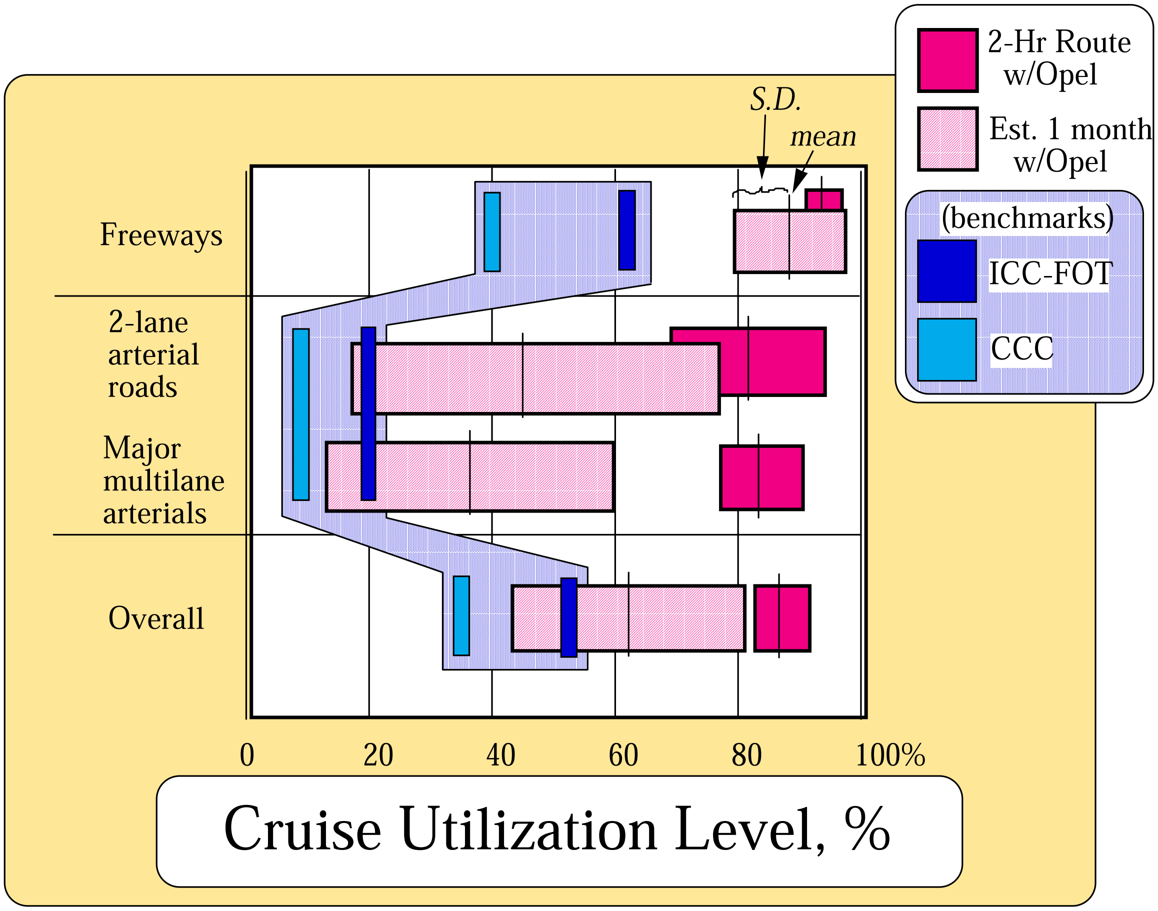


Figure 14.5 Cruise Utilization Level

Figure 14.6 shows that this rather motivated group of professionals drove with ACC engaged as much as possible on each leg of the route. Thus we see 80% to 90% utilizations of the Opel's ACC system across the entire route. While utilization on freeways is projected to remain within the 80 to 90% range in normal usage after a month's experience, the corresponding utilization values on surface streets would drop typically in half, or less. That is, UMTRI's drivers were pushing it during the 2-hr test drive in order to gain the operational experience, but they anticipate that a lesser utilization level—perhaps in the vicinity of 40%—might be adopted as normal behavior on surface streets, once a substantial level of familiarity prevails.

Against the ICC-FOT and CCC system utilization benchmarks, it is clear that the brake-assisted ACC system will be more heavily utilized. On surface streets, especially, the higher deceleration authority is expected to induce much higher utilizations than the two benchmark cases, presumably exposing users to the more complex conflicts that such environments present.

ACC utilization during the ACAS FOT is expected to lie above 60%, overall, whenever the vehicle is being operated above the minimum speed needed for ACC engagement.

Research Findings
Research findings fall into two categories: those associated with usage of a pilot version of the DAS package and those deriving from subjective evaluation of the Opel's ACC system.

Regarding Data Acquisition

A Data Acquisition System that included many but not all of the features and software architecture of the eventual FOT package was successfully constructed and operated on the Opel EDV. The system collected a large set of quantitative variables from the Opel's CAN bus and, among other things, provided UMTRI an early look at the multi-target radar data. A sample summary of such data is shown below in Figure 14.6, presenting a range vs. azimuth histogram that resulted from driving over the same 94-mile route as had been used in the subjective testing series. The figure shows the range/azimuth data for all targets flagged as stationary—and which thus resided outside of the proximate zone of the lane ahead of the vehicle. Thus, there are roadside objects and parked vehicles lying left and right of center at intermediate ranges and, at long range, objects that are assumed to be overhead bridges and signs.

Moreover, the early operation of an UMTRI data acquisition system on the Opel EDV served to confirm readiness for handling the later tasks of data collection in this project.

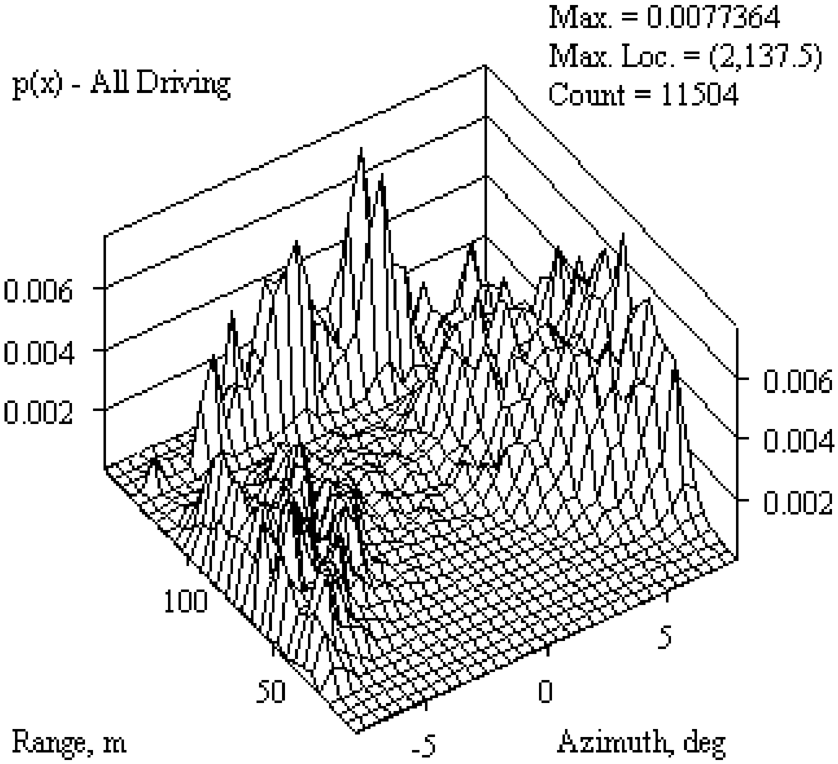


Figure 14.6 Range vs. Azimuth Histogram

Regarding the Opel ACC Evaluation

The Opel ACC system was found to be highly operable and was successfully driven in the Engaged Mode over approximately 90% of its mixed-route miles by eight different individuals. The 80%-and-above utilizations that were achieved with this ACC system on surface streets are acknowledged to be unusually high. Nevertheless, the intent was to explore and identify several of the challenging conflict types that primarily manifest themselves in this roadway environment. Utilization of such an ACC system on major surface streets in normal usage is anticipated to go up into the 40% range, with conflicts accompanying.

Additional conflicts were also observed on freeways due to a peculiar aspect of the Opel's control rule whereby braking was applied to resolve temporary headway incursions, even when no overtaking transient is present. At the same time, drivers observed conflict-mitigating aspects of their own behavior with ACC engaged, operating at longer headways and passing other vehicles less often with ACC engaged than they would have if driving manually.

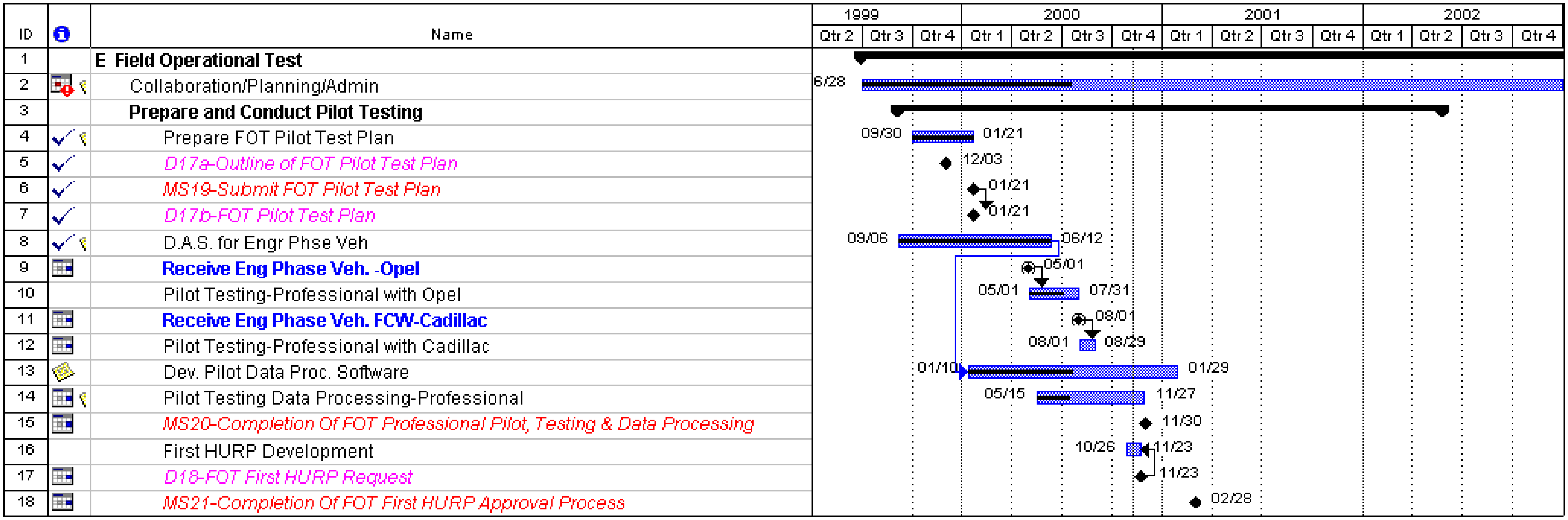
Moreover, the Opel driving tests provide subjective indication that an ACC functionality of this kind calls for careful preparation of test subjects if HURP approval is to be ensured. It also confirms UMTRI's prior experience in the ICC-FOT, which showed that various conflicts would be encountered during ACC operation, some of which are not altogether unlike their occurrence in normal driving. Clearly, a central object of the FOT investigation will be to determine the ability of laypersons to resolve these conflicts and to elect ACC utilization levels and patterns of vigilance that serve to contain the risks.

Plans through June 2000
Shown on the next page is the task schedule covering the first phase of the ACAS FOT project. The schedule shows that all of UMTRI's Task E assignments, including the Pilot Test Plan, the preparation of a DAS package for testing engineering phase vehicles, and pilot testing by UMTRI professionals using the Opel EDV were all on schedule.

Plans through December 2000
Over the next six months, the following important subtasks and milestones will be completed:

1. Completion and submission of the first HURP request by 11/23/00 (i.e., the HURP submission by which to authorize UMTRI's testing of the Prototype Phase vehicle using accompanied laypersons.)
2. Completion of testing and data processing on two EDVs provided to UMTRI by Delphi (note that the Opel ACC system was provided first, to be followed by a Delphi vehicle having an FCW system installed, or alternatively, an implementation of FCW onto the same Opel platform as was tested by UMTRI in June.)

UMTRI is also heavily engaged in advancing the DAS package for use on the Prototype Phase Vehicle during the next six months.



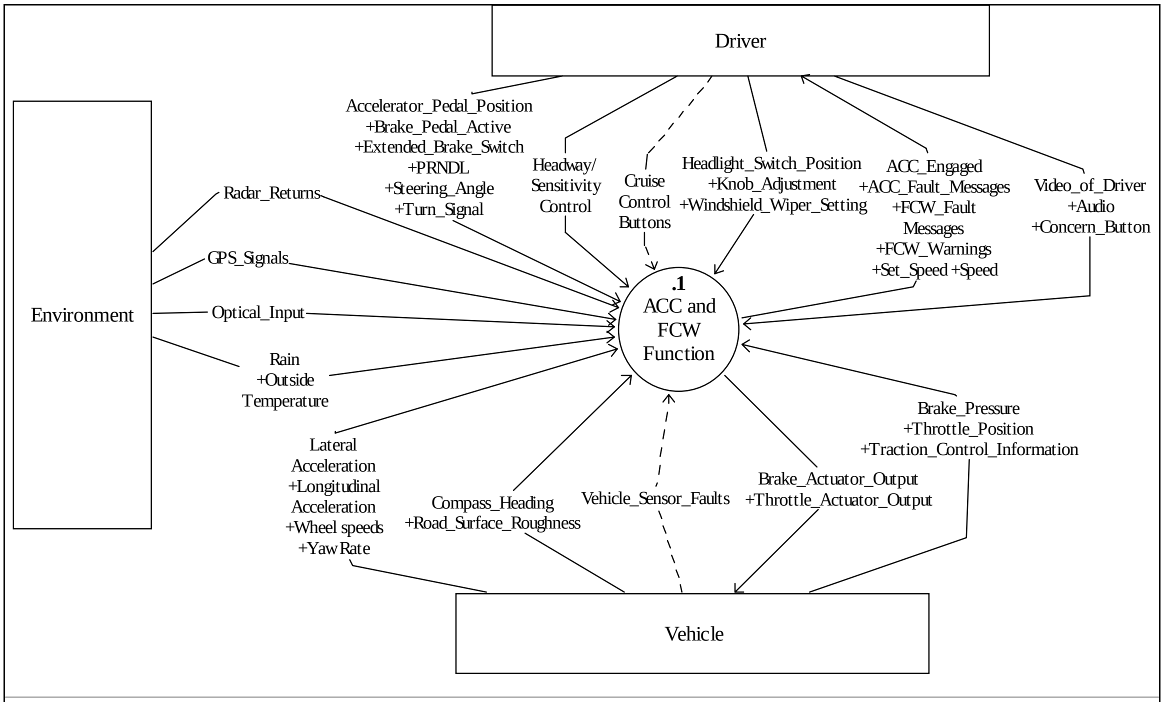
ID	ℹ	Name
1		**E Field Operational Test**
2		Collaboration/Planning/Admin
3		**Prepare and Conduct Pilot Testing**
4	✓	Prepare FOT Pilot Test Plan
5	✓	*D17a-Outline of FOT Pilot Test Plan*
6	✓	*MS19-Submit FOT Pilot Test Plan*
7	✓	*D17b-FOT Pilot Test Plan*
8	✓	D.A.S. for Engr Phse Veh
9		**Receive Eng Phase Veh. -Opel**
10		Pilot Testing-Professional with Opel
11		**Receive Eng Phase Veh. FCW-Cadillac**
12		Pilot Testing-Professional with Cadillac
13		Dev. Pilot Data Proc. Software
14		Pilot Testing Data Processing-Professional
15		*MS20-Completion Of FOT Professional Pilot, Testing & Data Processing*
16		First HURP Development
17		*D18-FOT First HURP Request*
18		*MS21-Completion Of FOT First HURP Approval Process*

Figure 14.7 Task E Schedule

Appendix A Function Diagrams and Descriptions

This Appendix includes the process model for the system that was developed as part of the Functional Description Task (Task A1). The process model shows the functional decomposition of the system through data and control flow diagrams. Each circle in the data and control flow diagrams represents a function performed by the system. Double circles represent primitive functions while single circles indicate there is another diagram that decomposes the function into lower level functions. The solid lines and arrows between the functions indicate flow of information. The dashed lines indicate control signals. Double horizontal lines with a name between them represent data storage. Single vertical lines represent flow into a control specification. Control specifications define the states (operating modes) and state transitions of the system.

The Context Diagram (Figure A1) shows the relationship between the functions provided by the system and the entities that interact with the system. The ACC/FCW System takes inputs from sensors that determine the driving environment, the driver's activities, the host vehicle actuators, and the vehicle dynamics. The ACC/FCW system controls the vehicle speed when ACC is active and produces Forward Collision Warning alerts and warnings for the driver. The ACC maintains a constant speed set by the driver or a set headway if there is a lead vehicle that is going less than the set speed. The FCW produces alerts and warnings based on an assessment of the threat of a crash.



C/DFD -1: Context_Diagram

Figure A1

The ACC and FCW Function diagram (Figure A2) shows the interaction between the top-level functions and the entities that interact with the system. The Sensor Specific Functions include radar processing, vision-based lane tracking, map-based road geometry estimation and yaw-based path estimation. These functions use each sensor to determine the road geometry, to estimate the current relationship between the vehicle and the road, and/or to predict the host vehicle's path. The sensor specific functions also use the radar data to detect, track and classify objects in the forward environment of the host vehicle. Finally the sensor specific functions include vehicle kinematics estimation based upon the GPS data.

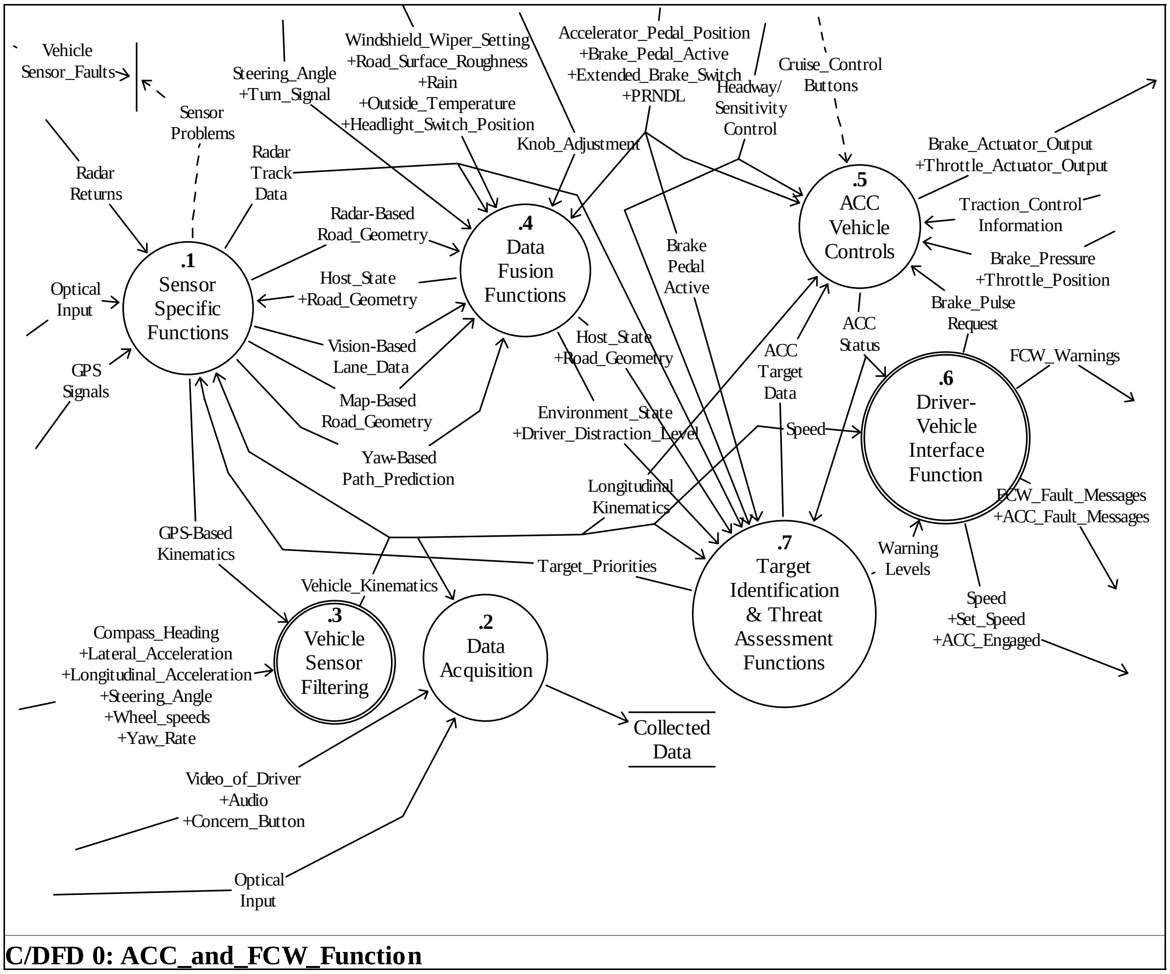


Figure A2

The **Vehicle Sensor Filtering** function filters the vehicle kinematics sensors to provide engineering units and to reduce noise in these measurements.

The **Data Fusion Functions** combine the evidence from the entire sensor suite to develop a higher confidence prediction of the host vehicle's path and to predict the driver/vehicle response in the event of an alert.

The **Target Identification and Threat Assessment Functions** determine which targets are likely to cross the path of the host vehicle, determine if a collision warning should be produced, and select the targets for the ACC functions. They also prioritize the targets to help with resource allocation within the Sensor Specific Functions.

The **ACC Vehicle Controls** maintain the vehicle's speed or headway when the ACC is on and engaged. The controls are similar to those of a conventional cruise control system with the addition of a headway setting. The output includes throttle and brake actuator control signals. The ACC vehicle control also responds to a brake pulse request by controlling the brake actuator control signals. In headway maintenance mode the ACC gets range and range rate data for the primary target from the Target Selection function that is part of the Threat Assessment Functions.

The **Driver-Vehicle Interface Functions** control all of the devices that transmit information to the driver. These include audio, visual, and haptic outputs. The visual display includes a head-up display. The information displayed includes the status of the ACC (on, engaged, set speed, and target detected). The information also includes warnings that indicate maintenance is required or that the vehicle is being operated beyond the range of capability of the ACC/FCW. The warnings may include multiple levels.

The **Data Acquisition** function includes the collection of data from the FOT. These will include the vehicle kinematics, warning levels, and intermediate results from many of the processing functions. It will also include video of the roadway ahead of the vehicle and the driver's head.

The Sensor Specific Functions (Figure A3) include Radar Processing, Vision-Based Lane Tracking, Map-Based Road Geometry Estimation and Yaw-Based Path Estimation.

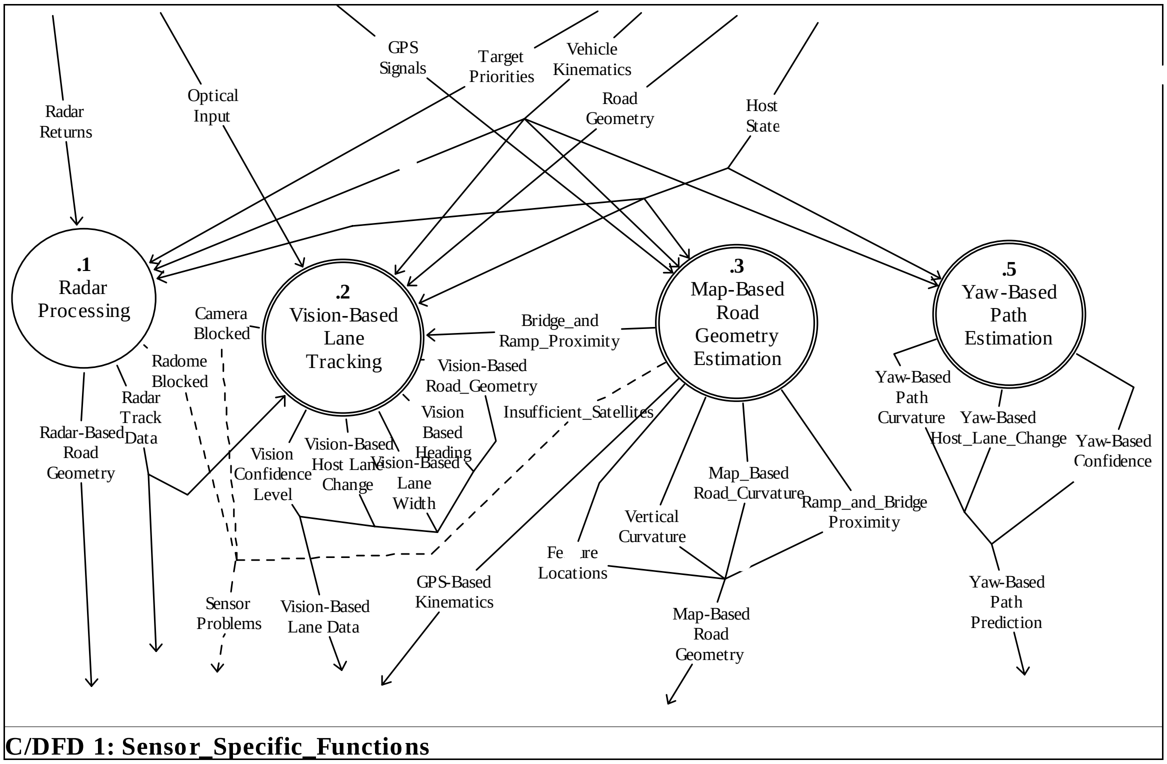


Figure A3

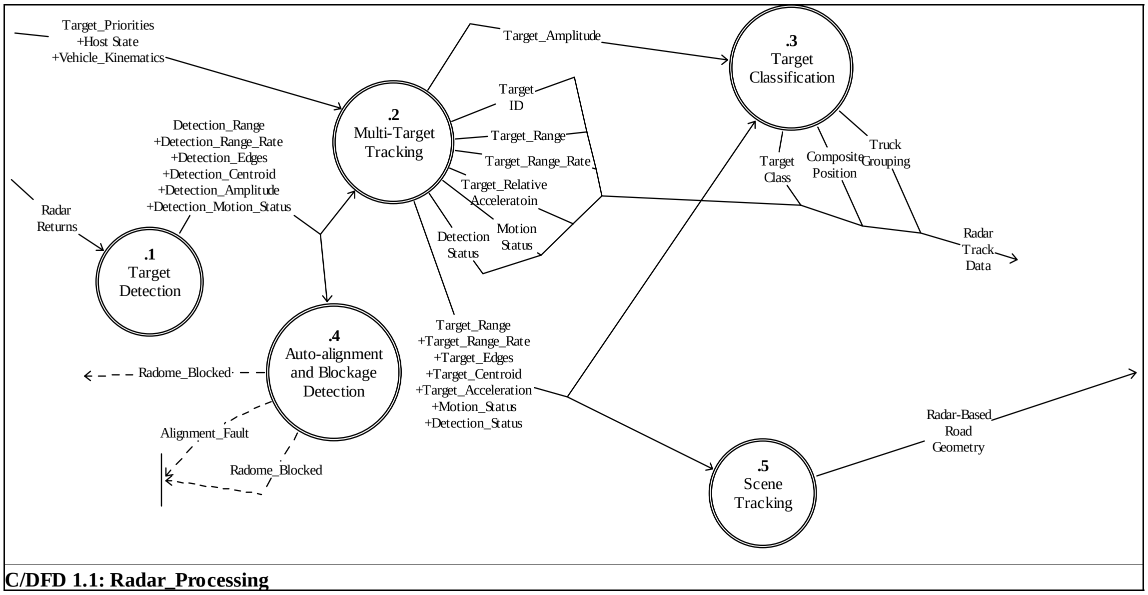
The **Vision-Based Lane Tracking** function determines the geometry of the road ahead of the vehicle and the relationship between the road and the host vehicle. The road-geometry information includes the curvature and/or offset of the road at selected distances ahead of the vehicle. The relationship between the vehicle and the road includes the lateral position in the lane, the heading angle, and whether a lane change is occurring.

The **Map-Based Road Geometry Estimation** function uses a roadmap database, DGPS, and dead reckoning to determine the current map position of the vehicle. It then extracts information from the database indicating the geometry of the road ahead of the vehicle, the relationship of the vehicle to the road, and then the location of significant features along the road. It also produces vehicle kinematics measurements based upon the GPS data.

The **Yaw-Based Path Estimation** function predicts the host vehicles path using yaw-rate sensor input, vehicle speed and acceleration measurements, and steering wheel angle measurements.

The **Radar Processing** function is covered below.

The Radar Processing function (Figure 3.4) includes Target Detection, Multi-Target Tracking, Target Classification, Scene Tracking, Lane Position Estimation, and Auto-Alignment and Blockage Detection.



C/DFD 1.1: Radar_Processing

Figure A4

The **Target Detection** function processes the radar signals to produce estimates of the range, range rate, acceleration, and extent of objects. It also reports the amplitude of the return from each detection.

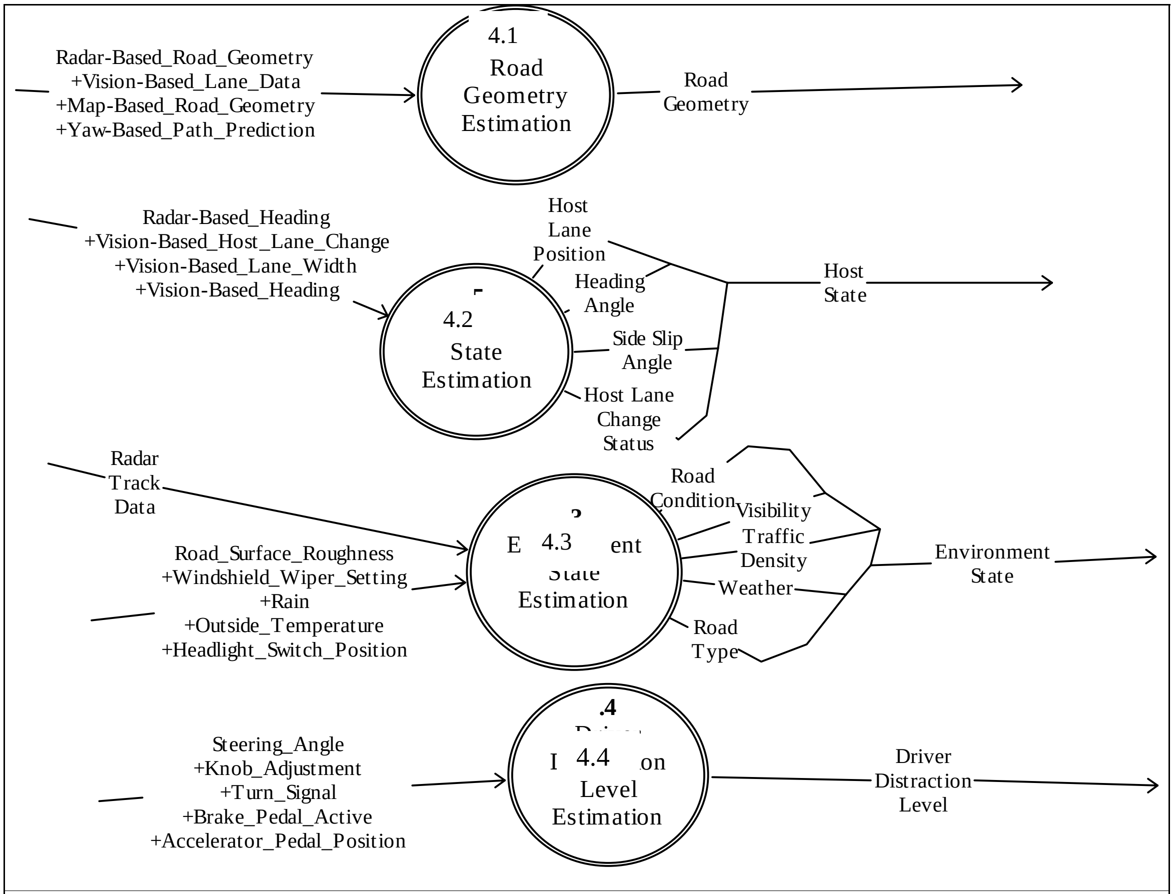
The **Multi-Target Tracking** function associates detections in each new sample with previously observed tracks. It reports whether any currently stationary objects were ever observed to be moving, and can let a target “coast” if it disappears for a short period of time.

The **Target Classification** function looks at the target tracks to determine if any should be associated into a larger object such as a bridge or a truck. If this occurs it indicates which tracks are associated and calculates some composite features of the object.

The **Scene Tracking** function evaluates the target tracks to estimate the geometry of the road ahead of the vehicle and the vehicle’s relationship to the road.

The **Auto-Alignment and Blockage Detection** function evaluates the radar returns to detect when the signal seems to be attenuated by a blocked radome. It also looks at target tracks to produce electronic adjustments of the radar alignment. This function also produces control signals that indicate if the radome is blocked or if the alignment is beyond the range that can be corrected.

Data fusion techniques are used to combine results derived from individual sensors into a composite evaluation of the road geometry, host state, environment state and driver distraction level (Figure A5), shown on following page.



C/DFD 4: Data_Fusion_Functions

Figure A5

The **Road Geometry Estimation** function uses data fusion techniques to produce a road geometry model based upon the sensor specific estimates.

The **Host State Estimation** function uses data fusion techniques to estimate the relationship between the host vehicle and the road based upon the sensor specific estimates. This includes determining if a lane change is occurring.

The **Environment State Estimation** function uses data fusion techniques to estimate the condition of the road, the weather, and the visibility, based upon evidence from several vehicle sensors.

The **Driver Distraction Level Estimation** function keeps track of driver activity to determine if the driver is performing tasks other than driving. It uses this information to derive an estimate of the distraction level of the driver.

The **Target Identification and Threat Assessment Functions** (Figure A6) identify targets that are likely to cross the host vehicle's path, estimate the driver's and vehicle's response to each threat, determine if any of them satisfy the criteria for FCW warnings, and selects the target for ACC.

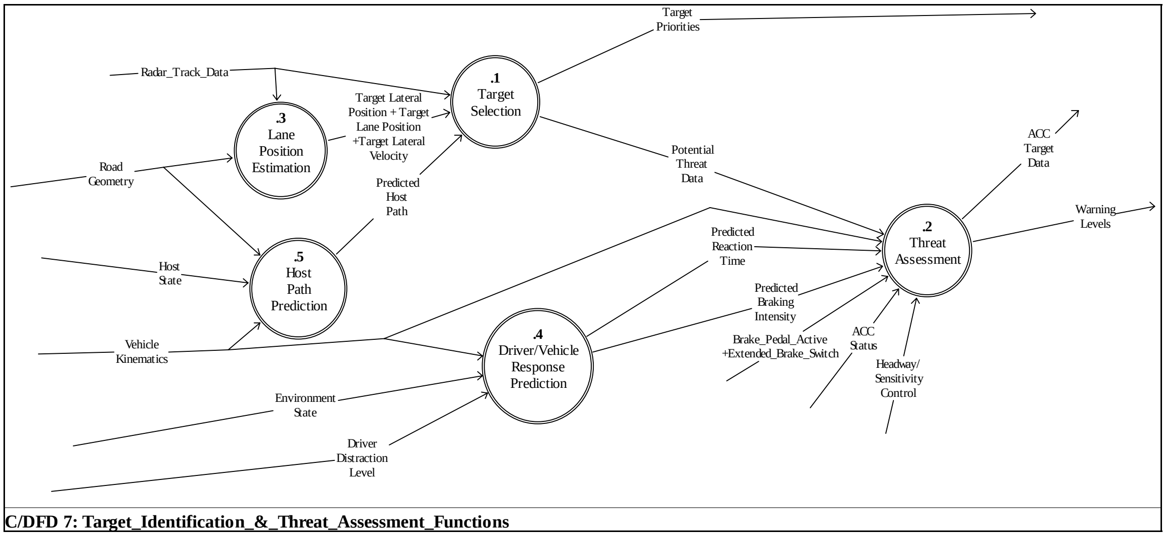


Figure A6

The **Host Path Prediction** function uses the vehicle kinematics, road geometry and host state to predict the path of the host vehicle relative to its current position.

The **Lane Position Estimation** function estimates the relationship of each tracked target to the roadway geometry derived from the tracks. It determines which lane the target is in, its lateral offset, and its lateral velocity in that lane.

The **Target Selection** function evaluates the predicted path of the host vehicle and the objects to determine the threatening targets that will be used for ACC control and for

FCW threat assessment. The FCW targets are those that are in the host vehicle's path or are predicted to cross the host vehicle's path. They may be moving or stationary.

The **Driver/Vehicle Response Prediction** function predicts how fast and how hard a driver is likely to brake if a warning is generated. It assesses the environmental conditions, current speed and headway, and other driving conditions that impact reaction time and the intensity of the response.

The **Threat Assessment** function uses the host vehicle dynamics, the target dynamics, and the expected driver response to determine what level of warning should be generated. The warning algorithm also depends upon whether the ACC is active. When ACC is active a warning is produced if it is predicted that the maximum braking authority will not prevent a collision.

The **Data Acquisition Functions** (Figure A7) record measured and computed values as well as video and audio information. Most variables are recorded continuously. Audio-visual data is recorded in clips at regular intervals and when predefined incidents are detected. The system transmits a summary of the data to a base station at the end of each trip by the host vehicle. The complete set of collected data is offloaded when each subject is finished with the vehicle.

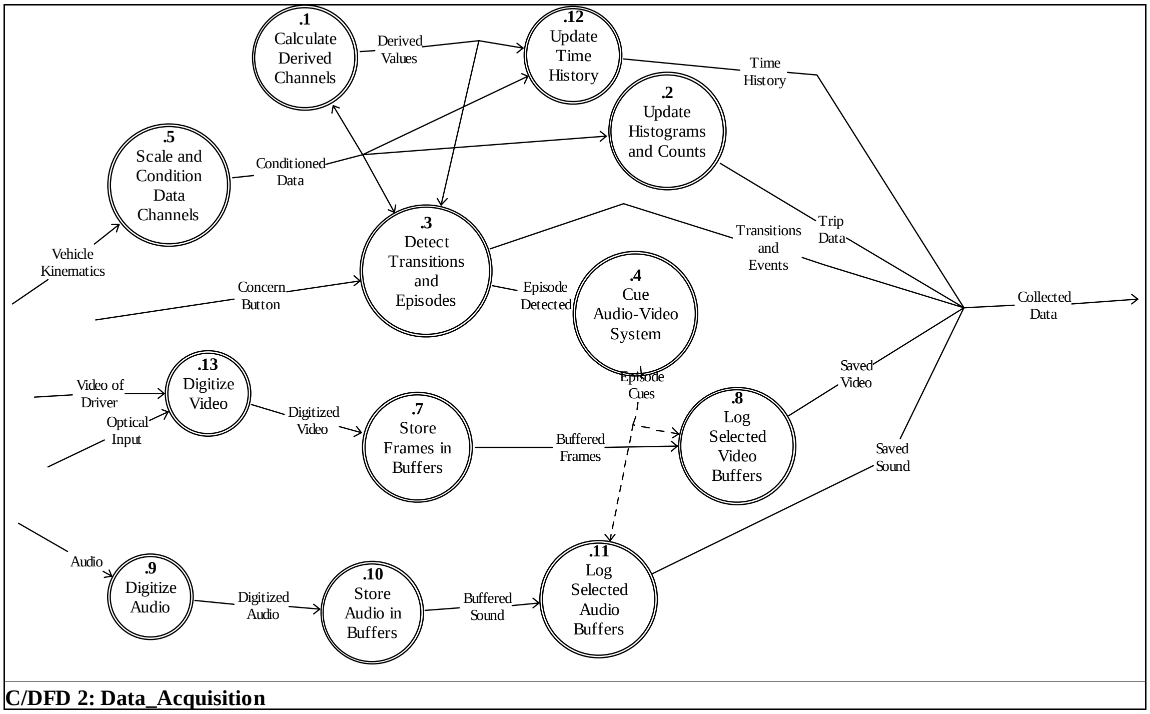


Figure A7

The **Scale and Condition Data Channels** function performs the necessary unit conversions and signal conditioning.

The **Calculate Derived Values** function calculates values from the directly measured values that may be required in real time by other functions.

The **Detect Transitions and Episodes** function looks for pre-defined conditions that trigger storage of audio/video clips. The count of some detected transitions and episodes may also be stored and/or transmitted at the end of each trip.

The **Update Time History** function maintains the log of continuously recorded measurements and derived data.

The **Update Histograms and Counts** functions maintain the histograms of the measured values and counts of events that are transmitted to the base station at the end of each trip.

The **Cue Audio-Video System** is triggered by the detection of an episode. It controls the software that logs audio and video data for a short period before and after each episode. It also causes the audio and video systems to record short clips at regular intervals while the vehicle is operating.

The **Digitize Video** function controls the frame grabber and collects video from cameras that looks out the front window and at the driver.

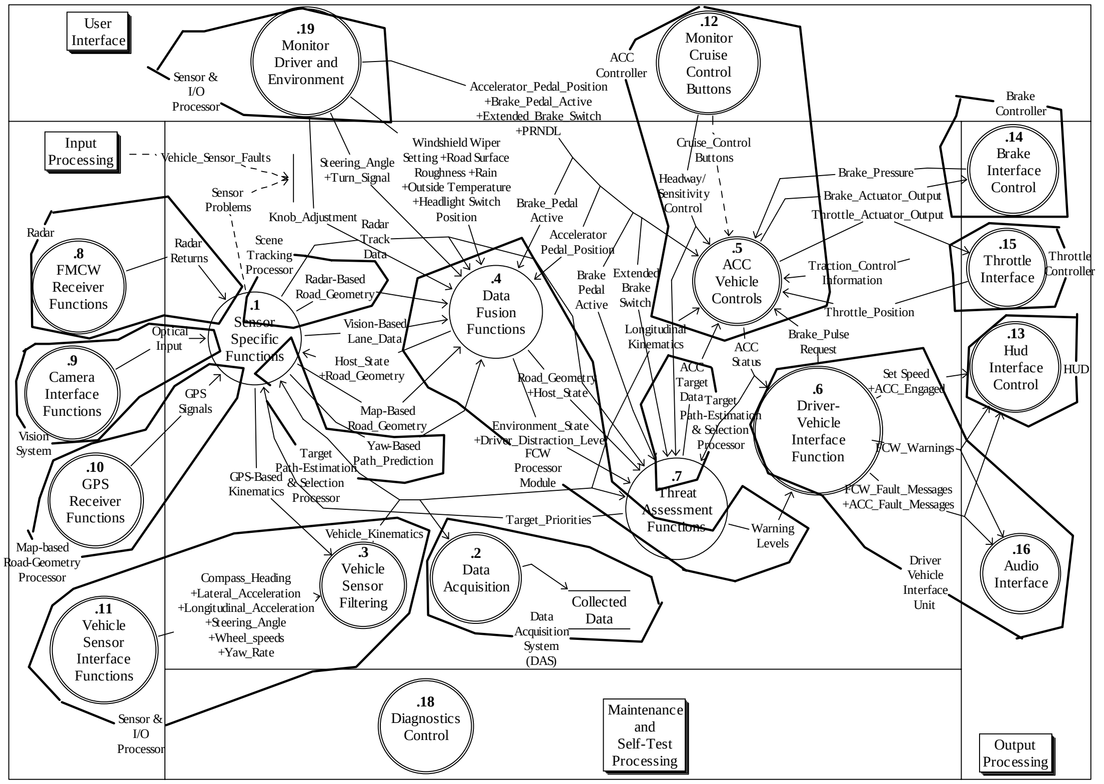
The **Digitize Audio** function controls the audio digitizer for recording sound from the passenger compartment.

The **Store Frames in Buffer** and **Store Audio in Buffers** functions control first-in first-out buffers so that data that precedes the detection of an episode can be recorded.

The **Log Selected Video Buffers** and **Log Selected Audio Buffers** functions transfer data from the first-in first-out buffers when triggered by the Cue Audio-Video System function.

Figures A8 and A9 show the relationship between the function diagrams and the physical modules in the system. Figure A8 is an enhanced version of the ACC and FCW Function. It augments the basic functions with those required to control the interfaces. In addition to the modules listed above, the enhanced functional diagram shows the Brake, Throttle and HUD modules.

The functions performed by each module are enclosed in polygons on the enhanced functional diagram and the subsequent decompositions. Two functions in the top-level diagram have sub-functions assigned to more than one module. Parts of the Sensor Specific Functions are executed in the Radar, Vision Module, Map-based Road Geometry Module, Path Prediction & Target Selection, and Scene Tracking Modules. Parts of the Threat Assessment Functions are executed in the Path Prediction & Target Selection module and in the FCW Processor. The assignment of each of the sub-functions to each of the modules is shown in the subsequent diagrams.



EC/DFD Enhanced_ACC_and_FCW_Function

Figure A8

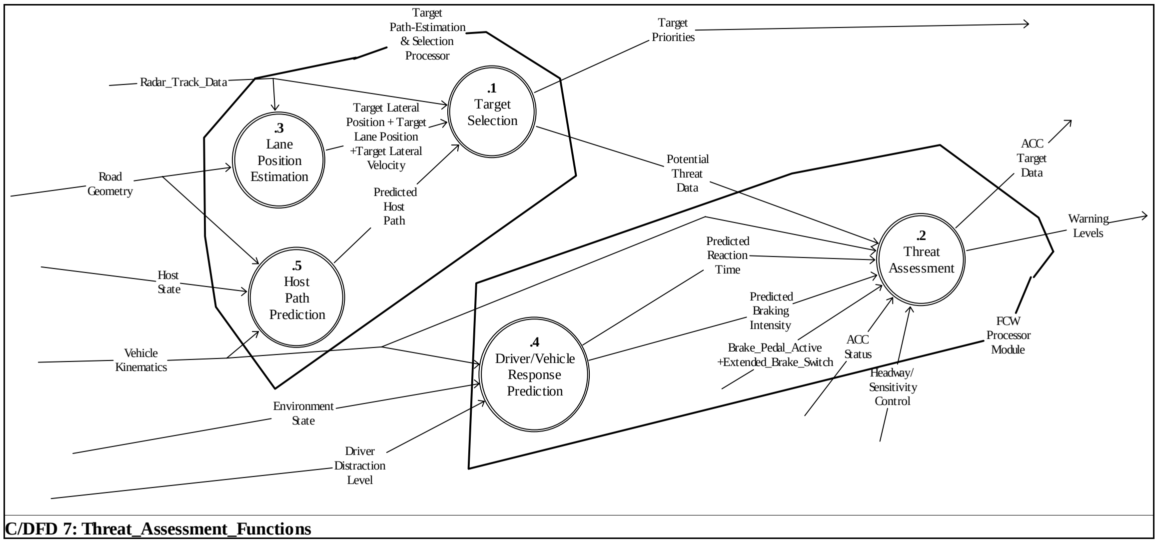
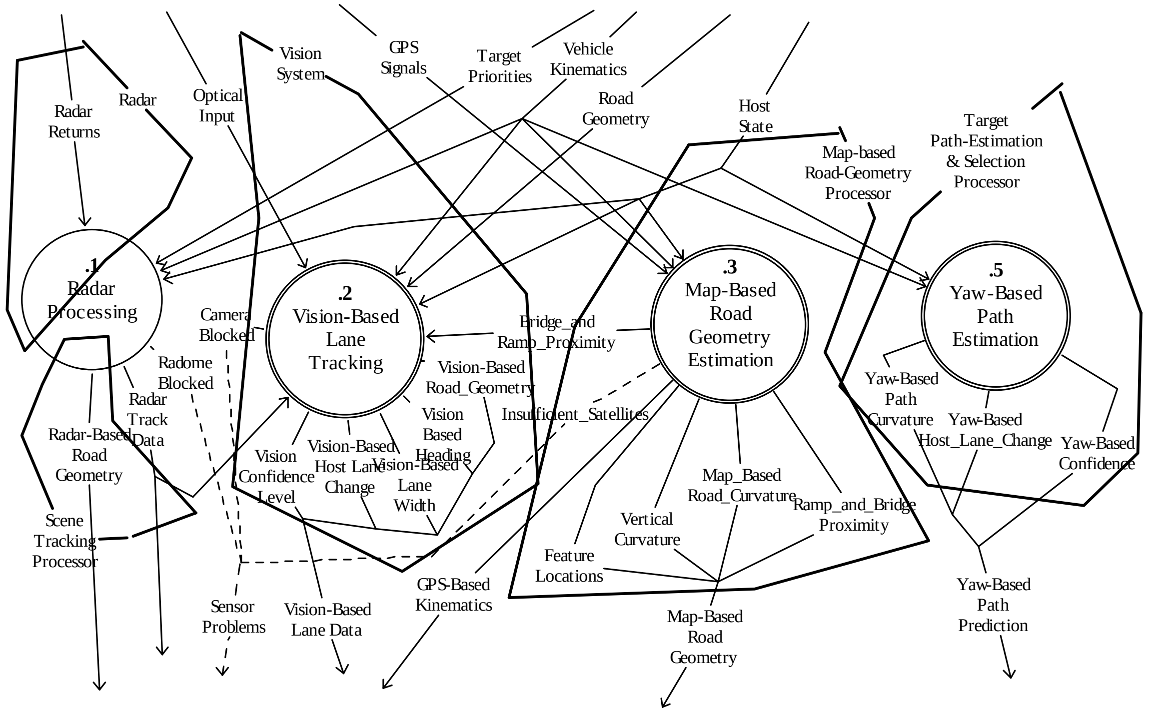


Figure A9



C/DFD 1: Sensor_Specific_Functions

Figure A10

List of Acronyms

ABS	Antilock Brake System
ACC	Adaptive Cruise Control
ACAS	Automotive Collision Avoidance System
CAMP	Crash Avoidance Metrics Partnership
CAN	Controller Area Network
CCC	Conventional Cruise Control
CW	Collision Warning
DAS	Data Acquisition System
DCS	Delphi Chassis Systems
DDE	Delphi Delco Electronics
DGPS	Differential Global Positioning System
DVI	Driver-Vehicle Interface
EDV	Engineering development Vehicle
FCW	Forward Collision Warning
FMCW	Frequency Modulated Continuous Wave
GM	General Motors Corporation
GMR1	General Motors Research 1 (Threat Assessment Algorithm)
GMR2	General Motors Research 2 (Threat Assessment Algorithm)
GPS	Global Positioning System
HEM	Hughes Electronics Microwave
HHDD	High Head Down Display
HURP	Human Use Review Panel
HW	Headway (Threat Assessment Algorithm)
ICC	Intelligent Cruise Control
IRB	Institutional Review Board
LOIS	Likelihood Of Image Shape
MOE	Measure of Effectiveness
MMIC	Microwave Monolithic Integrated Circuit
NHTSA	National Highway Traffic Safety Administration
OEM	Original Equipment Manufacturer
SGI	Silicon Graphics Inc.
SMCC	Stepper Motor Cruise Control
SWR	Standing Wave Ratio
TASIM	Threat Assessment Simulation
TRP	Technology Reinvestment Program
TTC	Time To Collision (Threat Assessment Algorithm)
UMTRI	University of Michigan Transportation Research Institute
VCO	Voltage Controlled Oscillator
VSWR	Voltage Standing Wave Ratio