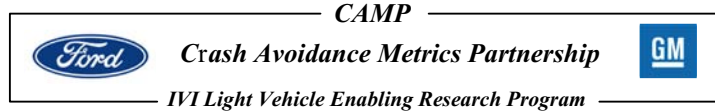


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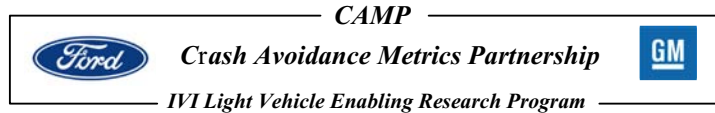
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## **PROGRAM OVERVIEW**

Ford Motor Company and General Motors Corporation formed the Crash Avoidance Metrics Partnership (CAMP) in 1995. The objective of the partnership is to accelerate the implementation of crash avoidance countermeasures to improve traffic safety by defining and developing necessary pre-competitive enabling elements of future systems. CAMP provides a flexible mechanism to facilitate interaction among additional participants as well, such as the US DOT and other OEMs, in order to execute cooperative research projects.

The CAMP Intelligent Vehicle Initiative (IVI) Light Vehicle Enabling Research Program brings together seven light-vehicle OEMs and a major automotive supplier to work cooperatively with the United States Department of Transportation (US DOT) on four separate pre-competitive projects. A single cooperative agreement covering all four projects spans 42 months beginning April 1, 2001. Each project involves a different subset of participants. CAMP's role is to manage the agreement, coordinate overall activities and provide program administration support to each of the projects.

Four CAMP Intelligent Vehicle Initiative (IVI) Light Vehicle Enabling Research Program projects were continued during this program year:



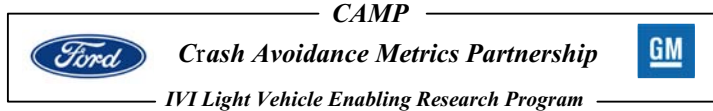
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The ***Driver Workload Metrics Project*** brings together Ford, General Motors (GM), Nissan Technical Center North America (NCTNA) and the Toyota Technical Center (TTC) to work cooperatively with the National Highway Traffic Safety Administration (NHTSA). The goal of this project is to develop metrics and test procedures that assess driver performance degradation related to driver workload from telematics systems.

The ***Enhanced Digital Maps Project*** brings together DaimlerChrysler Research and Technology North America (DCRTNA), Ford, GM, TTC and Navigation Technologies (NavTech) to work cooperatively with the Federal Highway Administration (FHWA) and the NHTSA. This effort is examining the feasibility of expanding the content and / or enhancing the resolution of present digital maps as an enabling technology for various collision avoidance systems. By the time this annual report is published, the Enhanced Digital Maps project will be completed and a final program report will have been submitted for publication. Therefore, an update on the Enhanced Digital Maps project is not included in this annual report.

The ***Forward Collision Warning Requirements Project*** is being conducted by Ford and GM in cooperation with the NHTSA. Driver performance and alert function / interface requirements associated with rear-end crash scenarios are being examined in proving grounds testing of naive subjects under a wide variety of conditions which include time



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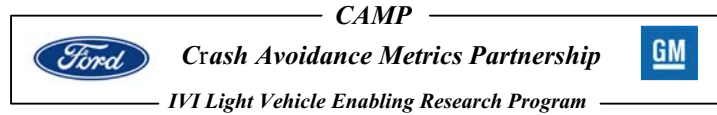
of day, lead vehicle deceleration profile, last-second lane change maneuvers and a variety of secondary distractions. In addition, testing is being conducted on the National Advanced Driving Simulator (NADS) to examine the correlation between driver's responses on a track and in the simulator, and to expand the scope of the database beyond that possible using controlled proving grounds testing.

The *Vehicle Safety Communications project* brings together BMW, DCRTNA, Ford, GM, Nissan, Toyota and VW to work cooperatively with the FHWA and the NHTSA. The Vehicle Safety Communications (VSC) Project is a two-year program to identify vehicle safety applications enhanced or enabled by external communications, determine their respective communications requirements, evaluate emerging 5.9 GHz DSRC vehicle communications technology and influence proposed DSRC communications protocols to meet the needs of vehicle safety applications.

The Annual Report for the CAMP Intelligent Vehicle Initiative (IVI) Light Vehicle Enabling Research Program for the first Program year may be found at:

<http://www-nrd.nhtsa.dot.gov/pdf/nrd-12/CAMPS.pdf>





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The Annual Report for the CAMP Intelligent Vehicle Initiative (IVI) Light Vehicle Enabling Research Program for the second Program year may be found at:

<http://www-nrd.nhtsa.dot.gov/pdf/nrd-12/CampII.pdf>



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## **PROJECT SCOPE**

The objective of this project is to develop practical, meaningful, and repeatable metrics and test procedures to assess in-vehicle task demands on drivers. These metrics and test procedures may be used by Original Equipment Manufacturers (OEMs) to estimate in-vehicle task demands during product development. This information might be used, for example, to decide which in-vehicle tasks a driver might reasonably be allowed to access and perform while driving.

The project, as originally defined, consisted of five tasks. However, during the past year the statement of work underwent a revision. The current project now consists of six tasks. Task 1 (completed) set the stage by means of a literature review on: a) criterion measures and methods with which to characterize driver workload, b) candidate models, simulations, and laboratory metrics and methods that might serve as practical, meaningful, and reliable surrogates for the criterion methods and measures obtained in driving, c) candidate in-vehicle tasks that span the range of driver demands to which metrics and methods should be responsive, and d) test scenarios. Task 2A (completed) focused on the development of workload metrics and methods through laboratory, on-road, and test track testing. Task 2B (completed) involved the assessment of available methods and procedures for reducing driver eye glance data from video recordings and lead to a process for use in the Driver Workload Metrics (DWM) Project. Task 2C (underway) focuses on the continued analysis of data collected during Task 2A, the reduction of driver eye glance data using methods defined in Task 2B, and a series workshops in which technical information will be exchanged with other organizations engaged in driver workload research (such as ADAM and HASTE). Task 4 will



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document the workload metrics and methods for use by OEMs and others. Task 5 is the project management task.

Task 3 was originally intended to validate the practicality, meaningfulness, and reliability of the proposed metrics and methods by use of a new sample of test participants, new tasks, and new evaluators without extensive prior exposure to this project. This task was removed from the statement of work by mutual agreement of the DWM Project partners. It may be reconsidered in a future study.

### **PROJECT ACTIVITIES AND ACCOMPLISHMENTS**

During the period from April 1, 2003 to March 31, 2004, the following activities were undertaken and accomplished:

- Data collection was completed with 234 persons participating in this effort. Sample size goals were realized in all testing venues (i.e., laboratory, on-road and test track).
- Data reduction programs were prepared for all three testing venues and applied to the data. The data reduction effort was completed except for eye glance data.
- A preliminary analysis of laboratory, on-road, and test track data was completed at the end of January 2004.



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- Methods for reducing driver eye glance data were reviewed, and a procedure for reducing eye glance data, collected during the on-road and test track phases of the study, was defined.
- A project briefing was held on February 25, 2004 in Washington, DC. Preliminary findings were presented.

Each of these items will be discussed in the following sections.

### **Data Collection**

The data collection effort spanned a six and one-half month period with testing conducted in three venues: a) in a laboratory, b) on public roads, and c) on a test track. Each of the 234 persons who participated in the two-day study appeared in only one of the testing venues.

The study investigated 22 in-vehicle tasks, which were performed by the test participants while driving, or operating a fixed-base simulator or other driving surrogates in the case of the laboratory work. In addition, participants also performed a two-minute “just drive” task. The tasks used in the study are listed in Table 1 along with a notation of the venue in which each task was used. The tasks were selected to span the driver’s input-output modalities, include tasks with a large body of past research available, and represent a mix of current-practice device tasks, new technology device tasks, non-device common tasks (e.g., scanning a paper map, reading text), and artificial tasks with specific demand characteristics. Training in the method of correct task performance, and practice, was provided to the participants prior to testing.



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## **Laboratory Data Collection**

The laboratory data collection was conducted in a driving buck equipped with a center stack and console containing the devices of interest in the study. The testing facility also included a low-cost, fixed-base, part-task driving simulator with the driving scene projected on to a screen mounted to the wall in front of the driver. This phase of the data collection featured the development of driving surrogates that included:

1. Static task completion (conducted alone without concurrent task demands),
2. Peripheral detection task,
3. Sternberg memory task with spatial stimuli,
4. Sternberg memory task with verbal stimuli,
5. Visual occlusion, and
6. Peripheral detection task during simulated driving with simulator.

In addition to performing the surrogates listed above, the participants also provided subjective assessments that included subjective ratings of operator workload, ratings of comfort and confidence with tasks done while driving, ratings of familiarity with in-vehicle electronic devices, and ratings of multitasking difficulty and situational awareness. In fact, all of these subjective assessments were conducted in all three testing venues.

The laboratory testing began in mid-March 2003 and concluded in early May 2003. Fifty-seven persons participated in this effort.



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**Table 1. Tasks Used in the Study by Testing Venue.**

<i>Task</i>	<i>Laboratory</i>	<i>On-Road</i>	<i>Test Track</i>
Coins	*	*	*
Cassette	*	*	*
HVAC	*	*	*
Radio Tune - Easy	*	*	*
Manual Dial Cell Phone	*	*	*
Travel Computations	*	*	*
Route Orientation	*	*	*
Voice Dial Cell Phone	*	*	*
Book On Tape - Listen	*	*	*
Just Drive	*	*	*
Biographical Q&A	*	*	*
Route Instructions	*	*	*
Sports Broadcast	*	*	*
Radio Tune - Hard	*	*	*
Insert CD, Select Track 7	*	*	*
Route Tracing	*		*
Delta Flightline	*		*
Book On Tape - Paraphrase	*	*	*
Destination Entry	*		*
Read Text – Easy	*		*
Read Text – Hard	*		*
Read Map – Easy	*		*
Read Map – Hard	*		*



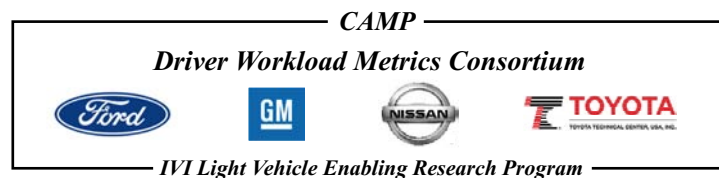
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## **On-Road Data Collection**

The on-road data collection effort featured the development of driving performance measures of driver workload. In this phase of the study, the participants drove an instrumented vehicle on a local interstate highway and performed the in-vehicle tasks while driving. See Table 1 for the list of tasks investigated in this portion of the study.

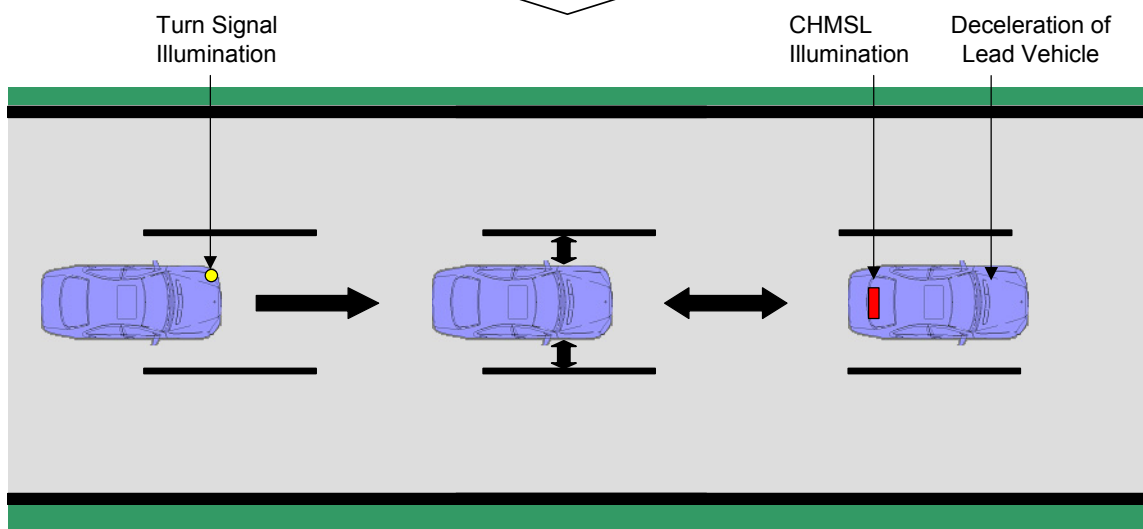
The instrumented vehicle driven by the participant was operated in the second position of a three-vehicle platoon during the testing sessions, as shown in Figure 1. The lead and following vehicles were operated by members of the project staff. During testing, the participant was directed to follow the lead vehicle at 55 mph and at a distance producing a time headway of 1.5 seconds. The participant was requested to perform the tasks while driving in this configuration.



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Three-vehicle platoon, with “multitasking” driver in middle vehicle (and lead/follow vehicles providing object and event detection stimuli)



**Figure 1. Vehicle arrangement during on-road data collection.**

In addition to driving and executing tasks, the participants were also presented stimuli to gauge the participant’s object and event detection performance. Three types of object and event detection (OED) events were used in the study. These are depicted in Figure 1 and included:

1. Lead vehicle center high-mounted stop light activation for an interval equal to the time headway between the center vehicle and the lead vehicle.
2. Lead vehicle deceleration (coast-down without brake lights) from 55 to 45 mph.
3. Following vehicle left turn signal activation for 2.5 seconds.

The performance metrics of interest during the on-road data collection included:

1. Visual allocation measures (e.g., glance location, glance counts, glance durations)





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2. Vehicle control measures (e.g., lane keeping, car following, speed control)
3. Object and event detection measures (e.g., response time and percent missed detections)

The on-road data collection was initiated on May 19, 2003 and concluded on July 28, 2003. One hundred eight participants were utilized in this portion of the study.

### **Test Track Data Collection**

The testing protocol, instrumented vehicles, OED stimuli, and performance metrics used for the test track data collection were same as that used in the on-road data collection with two exceptions. First, during the period of the test track work, the entire set of 23 tasks was investigated compared with 16 tasks for the on-road work, as shown in Table 1. Second, the roadway used at the test track was a five-mile oval with lane widths comparable to those found on the interstate highways used during on-road testing.

The test track phase of the study was conducted from August 11, 2003 through September 30, 2003 at the Ford Motor Company's Michigan Proving Ground in Romeo, Michigan. Sixty-nine individuals participated in this phase of the study.

### **Data Reduction and Preliminary Analysis**

Data reduction routines were developed in MATLAB and Excel for all three testing venues. The data reduction routines dealt with data filtering and rectification to deal with various signal-processing problems. The process developed also included steps to extract task epochs from the stream of filtered data and summarize the epochs for subsequent analysis. In this context, a task epoch refers to the time interval from the beginning to the end of the task performance. The goal of this effort was to produce a database in which



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each record in the file contained a set of performance metrics for each task performed by each of the participants in the study. The types of information contained in the summary data files for the test track and on-road data included the participant and task identification information, lateral lane keeping metrics, car following performance metrics, and OED data. Similar metrics were also obtained from the simulator outputs for the data collected in the laboratory.

Data reduction routines were applied to the data and complemented with manual verification. All start and end times for tasks were manually verified. All lane exceedences indicated in the MATLAB data reduction output were manually verified by staff members through examination of the video record.

Following the data reduction effort, a preliminary data analysis of laboratory, on-road, and test track data was conducted. The preliminary analyses emphasized exploratory data analysis methods and focused on task effects, measure repeatability, individual differences effects on results, and correlational analysis to relate surrogates to driving behavior measures. This effort was completed at the end of January 2004, and the results were presented at the project briefing on February 25, 2004. The project briefing is discussed below.

### **Assessment of Driver Eye Glance Reduction Methods**

The topic of suitable methods for reducing driver eye glance data was also major focus during the past year. All project partners judged the reduction of the eye glance data collected during the on-road and test track phases of the study to be essential to the success of the project. To address this issue, a series of meetings were held in which the currently viable methods for reducing glance information from video recordings were



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assessed. Also examined were the effects on the reliability of the reduced data of using multiple data analysts.

At the conclusion of this effort, the following points regarding the eye glance data reduction procedures were accepted by the project partners:

1. Eye glance data will be reduced manually, at the dwell level, using the following nine glance locations:
  - a. Forward (road scene)
  - b. Left (including outside mirror)
  - c. Right (including outside mirror)
  - d. Rear view mirror (center)
  - e. Instrument panel (IP), i.e., speedometer
  - f. Center stack, e.g., radio, HVAC, Navigation
  - g. Up (including visor and road scene)
  - h. Down (below IP, Center stack, interior only)
  - i. Other
2. Data will be reduced twice by two independent analysts, and then mediated by a third analyst to resolve any discrepancies between the first two analysts.
3. Data reduction discrepancies that will require mediation are circumstances where the two analysts differ in the location listed, or cases where the start of the glance differs by more than three video frames.



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4. The data will be coded in such a manner that glances to task materials will be distinguished from glances to locations within the vehicle.

In addition, it was also agreed that eye glance data from 36 test participants would be reduced. This total consists of 18 on-road and 18 test track participants, balanced across age and gender characteristics. Currently this work is underway at The University of Iowa and TNO in The Netherlands. The reduced data is expected in June 2004.

### **Briefings**

A project status briefing was held at ITS America headquarters on February 25, 2004. CAMP DWM consortium members, USDOT staff, Mitretek Systems staff, and guests from the Virginia Tech Transportation Institute attended this briefing. The major focus of this meeting was to review the preliminary finding from the initial data analysis effort.

### **ACTIVITIES PLANNED FOR THE NEXT PERIOD**

The activities planned for the next period include the following:

- Additional analyses of the driver performance data to enhance insight into the measures, methods, and phenomena of driver distraction;
- Summary analysis of the eye glance data for 72 test participants;
- Integration of the eye glance data into the engineering data stream to support selected analyses aimed at a better understanding of distraction phenomena;
- Technical workshops with the HASTE and ADAM research teams to exchange data and views on the conduct of driver distraction research;
- Preparation of the final report for this project (draft due September 30, 2004);

CAMP

*Driver Workload Metrics Consortium*



*IVI Light Vehicle Enabling Research Program*

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- Preparation of a database suitable for distribution through the USDOT to the driver distraction research community; and

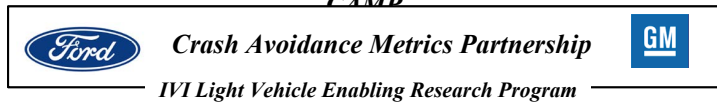
Final briefing to the USDOT on this project scheduled for September 30, 2004.



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ID	Task Name	2001				2002				2003				2004				
		Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	
1	Task 1 - Review the Literature																	
2	Task 2A - Develop Workload Metrics																	
3	Data Collection Completed																	
4	Task 2B - Assess Eye Glance Data Reduction Methods																	
5	Task 2C - Extended Data Analysis & Industry Workshops																	
6	Task 4 - Document Workload Metrics																	
7	Task 5 - Project Management																	
8	Briefing #1																	
9	Briefing #2																	
10	Briefing #3																	
11	Briefing #4																	
12	Final Briefing																	
13	Draft Final Report Submitted																	
14	Databases Submitted																	

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**PROJECT SCOPE****Task 1 - Refining the CAMP Crash Alert Timing Approach by Examining “Last-Second” Braking and Lane-Change Maneuvers Under Various Kinematic Conditions**

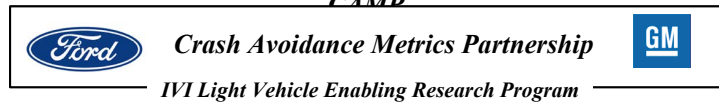
The final report for Task 1 was published during this Program year, and may be accessed at:

<http://www-nrd.nhtsa.dot.gov/pdf/nrd-12/HS809574Report.pdf>

**Task 2 & 3A - Surprise Braking Trials, Time-to-Collision Judgments, and Post-FCW Alert “First Look” Maneuvers Under Realistic Rear-End Crash Conditions**

The closed-course experimental work under Task 2 and Task 3a conducted over the past year has had two major goals. These goals are being addressed under closed-course conditions employing the surrogate target, test track methodology developed in the first CAMP FCW Project, which allows driver behavior to be observed under safe, controlled, and realistic rear-end crash scenario conditions.

*The first major goal of this research is to address the extent to which a wide range of factors impact the effectiveness of the previously developed CAMP FCW alert timing approach. This work examined the extent to which FCW alert effectiveness is impacted by driver characteristics, environmental factors, interface design, distraction activity,*

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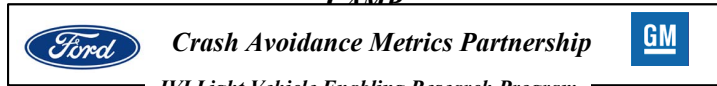
kinematic conditions, and training/false alarms. The Surprise Trial Methodology Technique employed in the first CAMP FCW Project was again used here to run 17 distinct surprise trial conditions.

*The second major goal of this work is to use visual occlusion techniques under real approach conditions to further understand driver's decision-making and avoidance maneuver behavior in rear-end crash scenarios, and to provide a calibration dataset for data gathered under simulated approach conditions.* With respect to this latter point, since simulators will likely be used as a tool for examining the effectiveness of crash alert systems, it is important to understand how driver behavior and judgments compare under real approach versus simulated approach conditions. Two different visual occlusion techniques were employed in this research. The Time-to-Collision (TTC) Judgment Occlusion Technique involved occluding the driver's vision during the last phase of an in-lane approach to a lead vehicle, after which the driver's task was to press a button at the instant they feel that they would have collided with the vehicle ahead. The second technique employed, the First Look Occlusion Technique, involved occluding the driver's forward vision (as an extreme form of driver distraction) during the initial phase of an in-lane approach to a lead vehicle, after which the driver's vision was opened and the driver's task was to avoid colliding with the lead vehicle. This technique is intended to simulate a "surprised" distracted driver, who immediately following a FCW alert presentation, must quickly decide upon and execute a crash avoidance maneuver.

**ACTIVITIES & ACCOMPLISHMENTS**

Data collection for Task 2a and 3a were completed over the past year, and both the statistical analysis and final documentation of these results will be submitted for publication approval review on 5/14/04.





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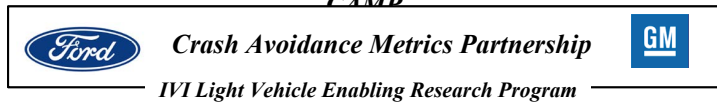
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**Task 4 - Investigating of Last-Second Braking and Steering Maneuvers on the National Advanced Driving Simulator (NADS)**

The focus of this task was to replicate a subset of the braking and steering scenarios run in both Task #1 under this project and the previous CAMP FCW project to better understand the relationship between last-second maneuver data obtained on a closed course versus with the NADS. In simple terms, this study involved replicating last-second braking and last-second lane-change maneuvers using the NADS, and comparing driver behavior and performance to the closed-course results. The selected subset of last-second maneuver conditions includes 34 braking and 22 steering trials that were completed by each driver. The braking and steering trials were equally divided amongst doing normal and last-second braking/steering.

The virtual environment for this simulated drive consisted of a flat, three-lane roadway with lanes that are 4-meters wide. Dashed white lines separated the lanes and there were shoulders on both sides of the road. The road surface had a texture that resembled concrete and the features along the roadway were rich enough to give drivers a sense of speed.

**ACTIVITIES & ACCOMPLISHMENTS**



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Task 4 testing began on February 5<sup>th</sup>, 2003 and ended March 27<sup>th</sup>, 2003. A total of 72 drivers, equally divided among age group (20-30, 40-50, 60-70) and gender, participated in this study. The reduced summary data was delivered to CAMP in August 2003. The NADS team has recently begun their efforts to provide CAMP with the raw data and other information and support that will allow the CAMP FCW team to complete their comparison of the NADS vs. CAMP on-road results. The NADS team has estimated that they will complete the proposed work by early June 2004. Based on this timing, the CAMP FCW team is estimating that they will be able to complete the Task #4 Final Report to NHTSA by September 2004.



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ID	Task Name	Start	Finish	1998		1999		2000		2001		2002		2003		2004		2005		2006	
				H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2
1	Task 1 - Study 1 ("Last-Second Manuever")	Thu 4/1/99	Mon 7/16/01																		
2	Task 2 - Study 2 ("Closed Course - Minimum Rec. Alt")	Wed 5/1/02	Fri 4/30/04																		
3	Task 3A - Study 3A (Surprise Trial Follow On to Task 4)	Wed 4/30/03	Fri 4/30/04																		
4	Task 4 - Study 4 ("Simulator Replication of Baseline")	Fri 3/1/02	Thu 9/30/04																		
5	Task 8 - Technical Project Management	Fri 1/1/99	Thu 9/30/04																		
6	Program Start	Thu 4/1/99	Thu 4/1/99																		
7	First Progress Briefing	Wed 6/13/01	Wed 6/13/01																		
8	NADS Demo	Thu 11/15/01	Thu 11/15/01																		
9	NADS Study 4 Demo	Fri 4/26/02	Fri 4/26/02																		
10	Second Progress Briefing	Thu 8/28/03	Thu 8/28/03																		
11	Third Progress Briefing	Thu 6/10/04	Thu 6/10/04																		
12	Fourth (and Final) Progress Briefing	Thu 9/30/04	Thu 9/30/04																		
13																					
14																					



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## **VSC PROJECT OVERVIEW**

The Vehicle Safety Communications (VSC) Project is a program to identify vehicle safety applications enhanced or enabled by external communications, determine their respective communications requirements, evaluate emerging 5.9 GHz DSRC vehicle communications technology and influence proposed DSRC communications protocols to meet the needs of vehicle safety applications.

Seven light-vehicle automobile manufacturers formed the VSC Consortium (VSCC) to participate with the Department of Transportation in this cooperative project: BMW, DaimlerChrysler, Ford, GM, Nissan, Toyota, and VW. The automotive team is identifying and evaluating a comprehensive list of vehicle safety applications enhanced or enabled by external communications, determining their respective communications requirements, and working with standards development organizations to ensure that proposed 5.9 GHz Dedicated Short Range Communications (DSRC) protocols support vehicle safety applications.

During this program year, the VSC project produced the following significant results:

- Used field test results to establish the potential of DSRC to support a variety of vehicle-vehicle and vehicle-infrastructure applications.
- Impacted the DSRC standards and related rules in areas which are critical to making DSRC viable for automotive vehicle safety applications by securing nine



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major accommodations through active participation in the development of DSRC standards during the past year.

- Demonstrated, through simulation testing, the capability of the planned DSRC priority mechanism to allow high priority messages to be sent with almost no delay, while non-priority messages encountered delays of up to fifty milliseconds.
- Developed a potential security approach that is likely to be able to support vehicle safety communications, both for RSU and OBU installations.
- Developed, built and tested two antenna designs that meet all the identified requirements of the vehicle safety communications testing program.



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## **PROJECT SCOPE**

The VSC project goals are to:

- Estimate the potential opportunity for safety benefits of communication-based vehicle safety applications in terms of reductions in vehicle crashes and functional productive years saved.
- Clearly define the communications requirements of selected vehicle safety applications.
- Assess the ability of proposed DSRC communications protocols to meet the needs of safety applications.
- Work with standards development organizations to influence proposed DSRC communications protocols to meet the needs of vehicle safety applications.
- Investigate specific technical issues that may affect the ability of DSRC (as defined by the standards) to support deployment of vehicle safety applications.
- Estimate the deployment feasibility of communications-based vehicle safety applications.



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## **PROJECT ACTIVITIES & ACCOMPLISHMENTS DURING THE PROGRAM**

### **YEAR**

#### **Task 1: Review of Literature and Ongoing Activities & Task 2: Analysis of the DSRC Standards Development Process**

A document containing an integrated summary from the Task 1 and Task 2 research has been prepared for public release.

#### **Task 3: Identify Intelligent Vehicle Safety Applications Enabled by DSRC**

A document summarizing the Task 3 research has been prepared by the VSCC for publication, and USDOT review and approval processes are underway.



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#### **Task 4: Refinement of Vehicle Safety Application Communication Requirements**

##### *Activities*

Field testing under Task 4 proceeded based upon test scenarios developed by the technical management team. The technical team was able to arrange for the use of GM's Milford Proving Grounds to conduct the test track portions of the identified scenarios. As well, the technical team conducted a number of test sessions on public roadways to determine the effects of variable traffic conditions.

As a result of Task 6A, the VSCC DSRC communications test kits were upgraded to run the Linux operating system. This has allowed the kits to run the Linux driver for the 802.11a radio card. This enhancement was made to provide more dependable operation of the test kits in the field test environment. The Linux driver was also modified to allow radio operation closer to DSRC operational parameters in terms of frequency, channel width and power control. The Linux operating system provided more reliable performance of the test kits in general, which facilitated the testing program. However, debugging successive versions of the software required a significant amount of time.

Priority mechanisms will be a critical part of the DSRC system, since these mechanisms must allow safety applications to access the communications channel ahead of less-critical applications. Enhanced Distributed Coordination Function (EDCF) is being introduced as part of the IEEE 802.11e Quality of Service standardization effort. The simulation testing in Task 4 was focused upon studying the potential effectiveness of EDCF to provide priority communications for vehicle safety applications. EDCF has been designed to prevent collisions between packets in the communications medium. This is accomplished by specifying the random back off time according to the message





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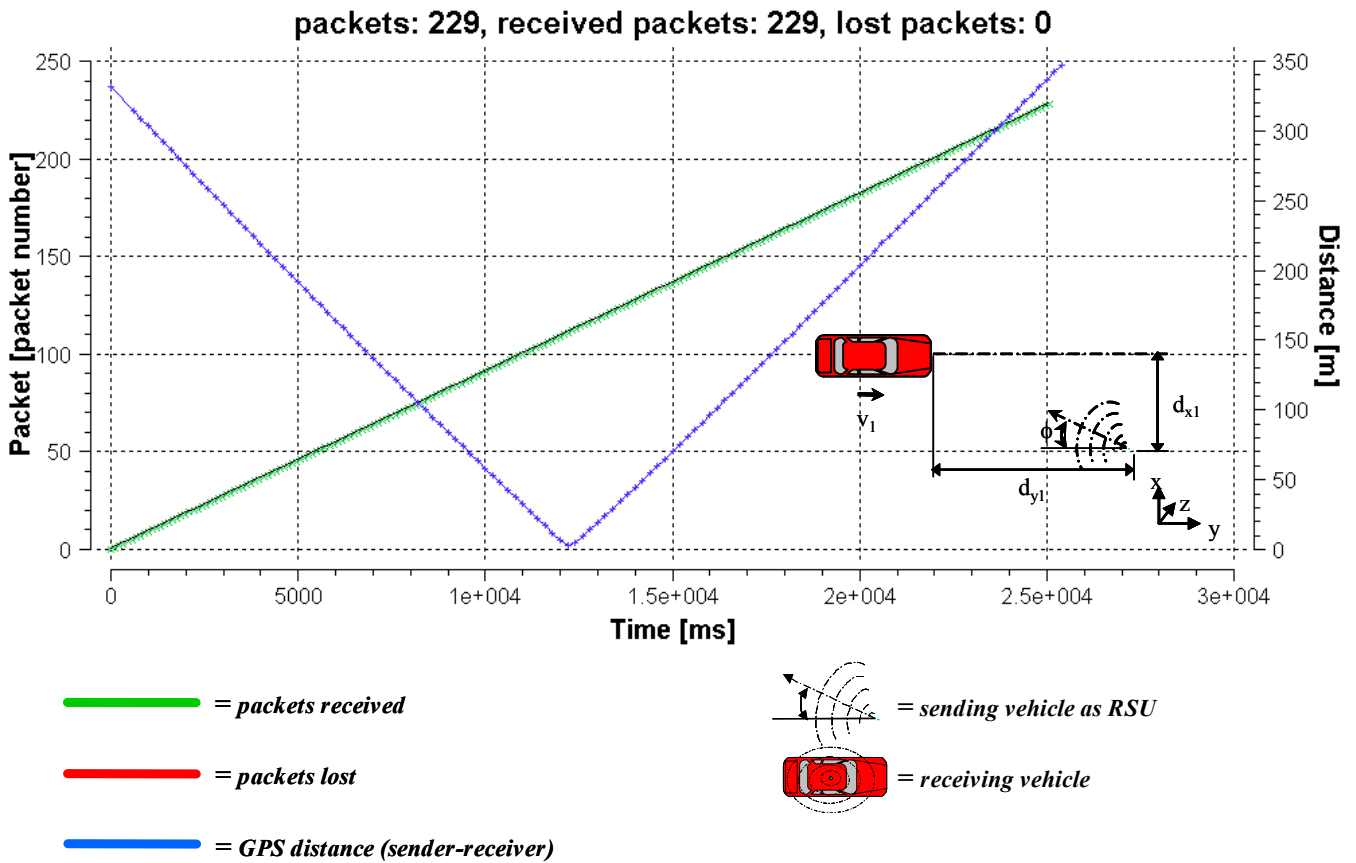
priority. Thus, lower-priority messages should have a longer back-off time. By using this process, high priority messages should have much better chances to access the channel before messages with lower priority. For the Task 4 simulation testing of EDCF, there were 530 cars in the simulation with 20 m separation distance per car per lane.

Transmission power was set for a distance of 200 m and packet size was 500 bytes. Out of the 530 cars, one car was given high priority while all others had no priority. The test results showed that virtually all of the high priority messages were sent with almost no delay. Conversely, non-priority messages encountered delays of up to approximately 50 ms. This is significant for vehicle safety applications, since 50 ms, in addition to the proposed ~100 ms transmit interval for the control channel in the DSRC standards, could potentially create latencies beyond the 100 ms latency requirements for many of the identified vehicle safety applications

With field testing completed for the majority of the test scenarios, the range reliability results were better than had been expected with 50 milliwatt or less transmission power, supporting communications beyond the Task 3 safety application maximum required range of 300 meters. Occultation and multipath results were consistent with expectations. For direct-line-of-sight tests (no obstructions) and for tests with one obstructing or interfering vehicle (sedan, SUV), many of the test track results demonstrated zero packet loss. For example, test scenario 1-2 results (summarized in Figure 1) showed all 229 packets were received out of 229 packets sent between a stationary sending vehicle (acting as an RSU), and a receiving vehicle traveling at 60 mph, at distances up to 350 meters.



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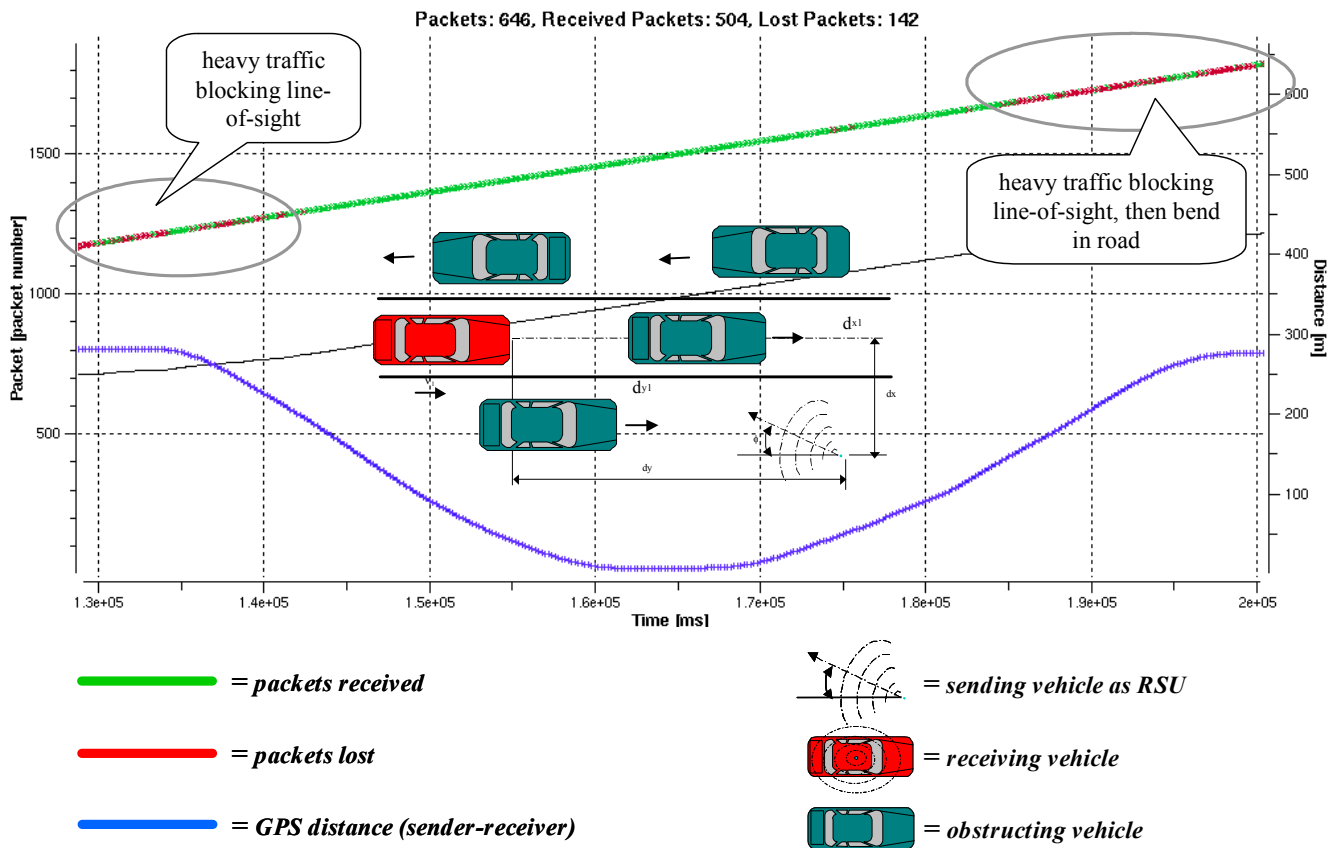
**Figure 1 – Test Scenario 1-2: Stationary RSU Sender, Receiving Vehicle at 60 mph**  
**Example of Simple Communications Link Testing (One-Way)**



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Even in dense traffic conditions (consisting only of passenger cars), the communication performance exceeded initial expectations. For example, test scenario 1-5 results (summarized in Figure 2) showed 78% of packets received (504 out of 646) for arterial road conditions with heavy traffic, and up to 300 meters between sender and receiver.



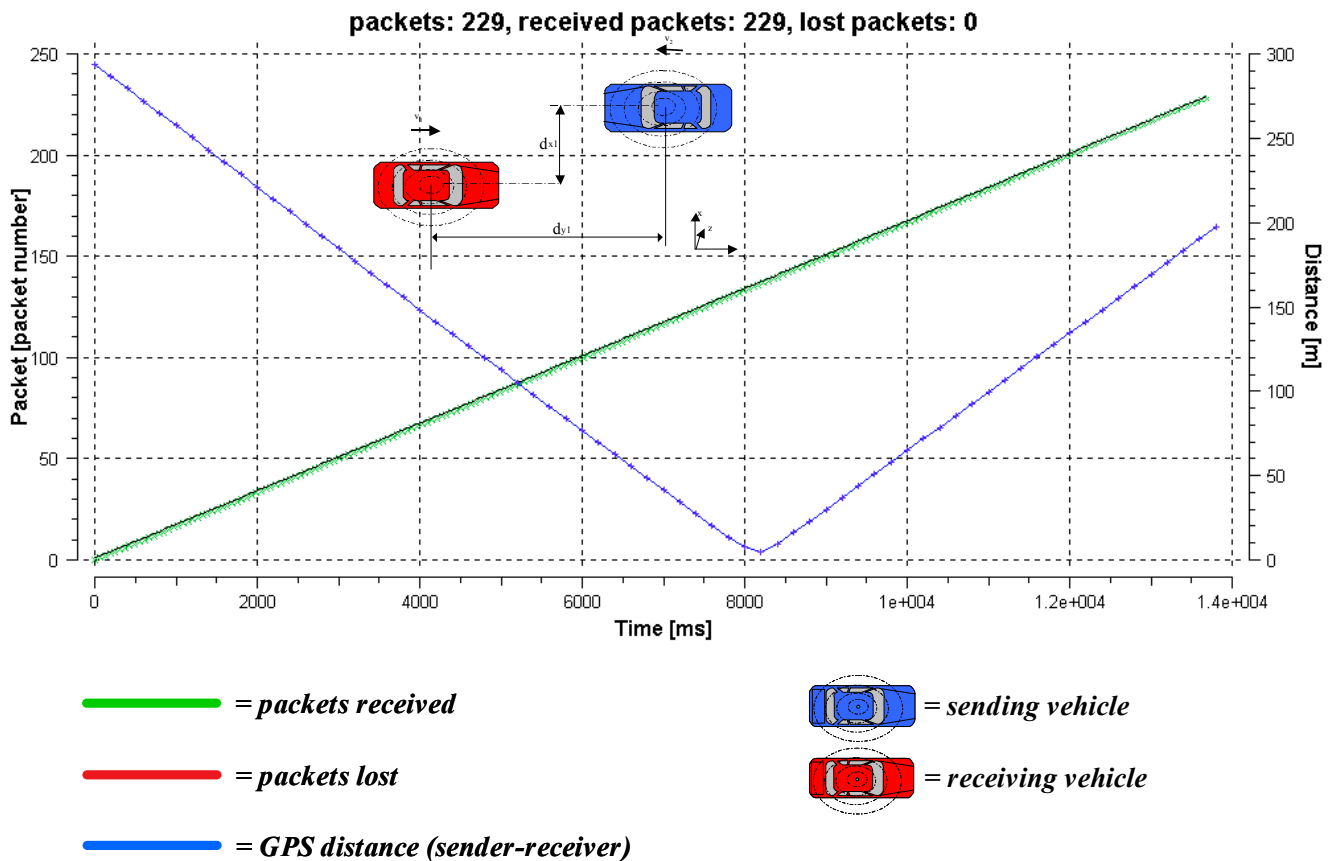
**Figure 2 – Test Scenario 1-5: Stationary RSU Sender**  
**Receiver at Various Speeds with Heavy Traffic**  
**Example of Simple Communications Link Testing (One-Way)**



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Communication at various speeds, including freeway speed limits, was successful. Test scenario 2-26, for example, demonstrated 100% packet reception for two vehicles both traveling at 50 mph, approaching each other from opposite directions, from distances of over 200 meters.



**Figure 3 – Test Scenario 2-26: Sender & Receiver Approaching Each Other  
 from Opposite Directions, Each at 50 mph  
 Example of Simple Communications Link Testing (One-Way)**



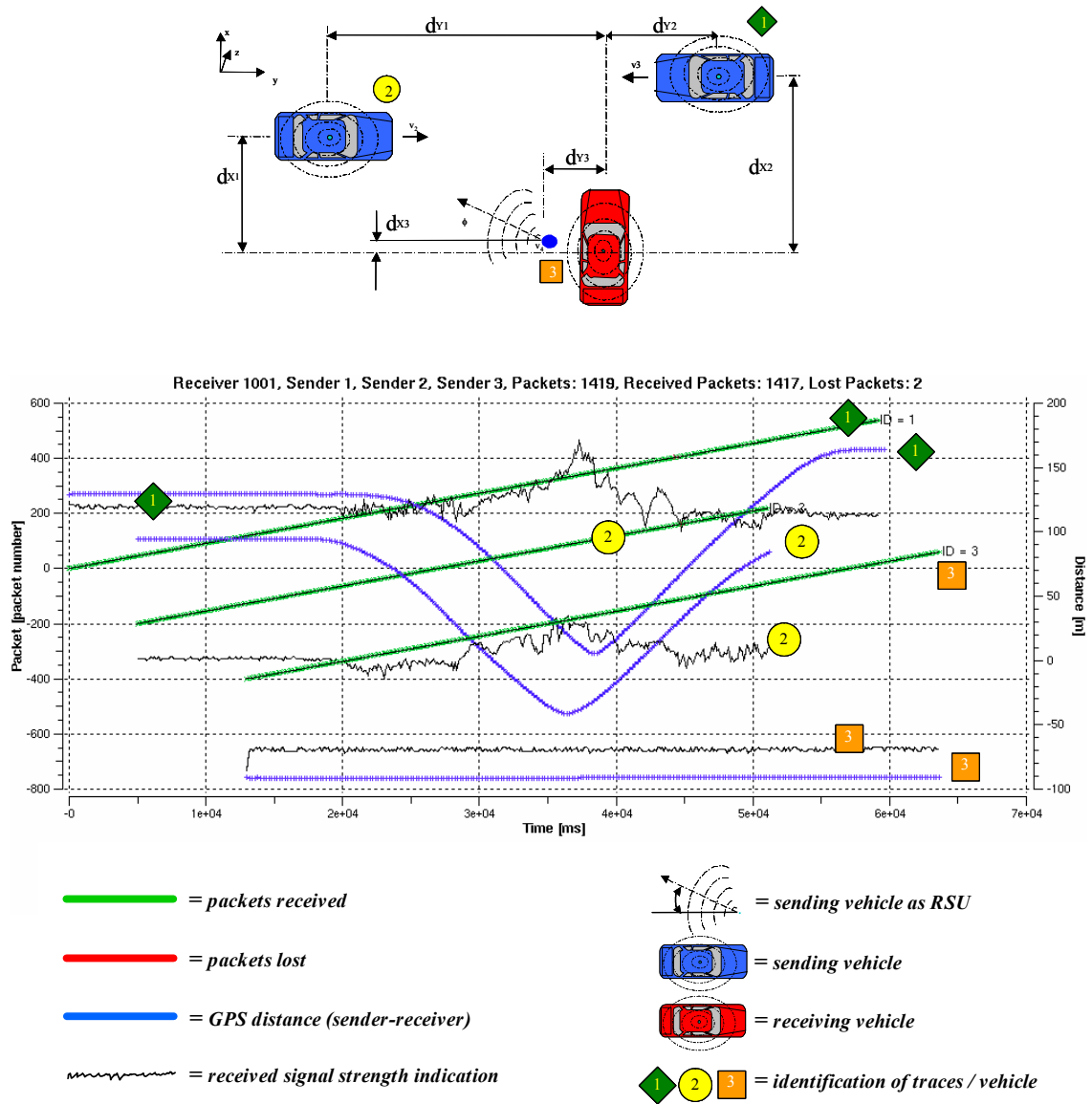
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Tests that included both three and four test kits were conducted to evaluate multi-sender capabilities in various driving configurations. This multi-sender testing showed that the presence of multiple DSRC transmitters sending data on the same channel at the same time did not create any noticeable interference. For example, test scenario 4-11 results (summarized in Figure 4) demonstrated that for simultaneous transmissions from two vehicles traveling in opposite directions at 25 mph and one stationary vehicle (representing an RSU), only two packets were lost from the 1419 total packets sent by the three transmitters. In order to differentiate the data that was received from more than one sender unit, the respective data plots for different senders were generally shifted to a lower location on the summary diagram (as in Figure 4), with negative values on the Y-axis indicating the amount of the offsets. This plotting approach allowed useful visual interpretation of the multi-sender test results.



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**Figure 4 – Test Scenario 4-11: Simultaneous Transmissions, Stationary Receiver, Stationary RSU Sender plus 2 Sending Vehicles Approaching Each Other from Opposite Directions, Each at 25 mph**  
**Example of Simple Communications Link Testing (One-Way)**



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### *Accomplishments*

Since DSRC equipment is not yet available, 802.11a has been used to approximate DSRC operations. The general conditions throughout the field-testing for scenarios 1, 2 and 3 (with the exception of several tests with power control), included: single-sender/single-receiver testing only, broadcast of repetitive small packets (100-400 bytes), update rates of 20-100 milliseconds, ranges exceeding 300 meters, 5.15-5.25 GHz and 5.725-5.825 GHz (802.11a) transmission frequencies, 20 MHz channel width, up to 50 milliwatt transmission power (at the output port of the radio card), dry weather, and 6 Mbps data rate. Basic communication works well under these present test scenario conditions, and the single sender/single receiver transmissions, as tested, indicate the capability to support a variety of vehicle-vehicle and vehicle-infrastructure applications.

Major terrain obstructions and buildings appear to prevent the reception of DSRC-like transmissions, where no alternative reflective pathway is present. For example, test results indicate that basically no communication is possible over the crest of a hill, or around a corner with no buildings present and vegetation obstructing the direct line-of-sight path. These types of situations require special attention when developing not only the communication protocol but also the safety applications themselves. In the case of a large, commercial truck (over 10,000 lbs) obstructing the line of sight, as expected, a degraded level of performance was observed that often led to a total loss of packet reception. In some test results, communication was still possible in some configurations, apparently using an alternate path other than the direct-line-of-sight (i.e., ground reflections).



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In certain instances and at repeatable ranges, null zones were observed where packet loss occurred. These were most likely caused by the expected phenomenon of reflected signals canceling out the direct signal under specific sender-receiver geometries. With careful radio, system and application design, it is likely that the effects of this phenomenon can be minimized.

In the multi-sender test scenarios, similar test results were obtained under different configurations. In general, less than 1% of the packets sent simultaneously by multiple senders were lost. The track/road conditions, and multipath considerations, appeared to offer the best explanations for the minimal observed packet losses. As expected from theoretical evaluations, with only two or three vehicles sending data simultaneously, there is only a very remote possibility that any packets would be lost due to data congestion or packet collisions.

The Task 4 simulation testing of the EDCF priority mechanism included over 500 vehicles. The simulation test results showed that EDCF could be expected to allow a high priority message to gain the radio channel access quickly, and thus provide priority treatment for vehicle safety communications in fairly congested environments.





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## **Task 5: Participation in, And Coordination with, DSRC Standards Committees and Groups**

### *Activities*

As part of Task 5 activities, the VSCC technical team developed a technical position regarding standardization proposals that was subsequently used as the basis for the Alliance of Automobile Manufacturers to provide reply comments to the FCC Notice of Proposed Rule Making (NPRM) for 5.9 GHz DSRC.

The VSCC supported the establishment of the IEEE 802.11 DSRC Study Group, which was approved by the IEEE 802.11 plenary at the July meeting. The VSCC also actively participated in the DSRC Standards Writing Group meeting in August, where IEEE P1609 (upper layer) DSRC standards were being developed. The VSCC established its requirement for an efficient header scheme to allow IPv6 compatibility at the packet level without burdening vehicle safety communications with excessive overhead. As well, the VSCC had a strong influence on the planning for the DSRC security standard being developed under IEEE P1556.

As a result of the consistent, active participation at DSRC standards meetings on a monthly basis, the VSCC identified five issues relating to the DSRC standards development process that were of concern for the deployment of vehicle safety applications:

- 1) The movement of lower layer DSRC Standards to IEEE 802.11, has major potential benefits, but significant risks as well. One potential benefit is that the



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IEEE 802.11 Working Group has high credibility with regard to its technical capabilities in the area of wireless networks. Potential risks include possible changes to the existing ASTM lower layer standard as well as the potential for delays in the completion of the IEEE 802.11 lower layer standard.

- 2) Although the FCC DSRC Report and Order has mandated the ASTM lower layer standard, this does not include upper layer protocols. For interoperability, rules for the use of the 5.9 GHz DSRC spectrum need to specify the use of upper layer standards, in addition to the lower layer standards.
- 3) The DSRC Standards Writing Group has drafted preliminary suggested priorities for identified applications. However, no process or responsible authority has yet been identified or established to set and maintain the priority levels for various applications.
- 4) There is a risk within the VSCC security developments that the solutions that provide adequate security may be too costly, or too bandwidth inefficient, to be deployed. There are also major risks involved with coordinating such a solution with the security solutions of other stakeholder groups.
- 5) According to the legal review by ITS America lawyers, vehicle-to-vehicle safety applications cannot legally be considered public safety at this time. This may become a major issue, due to its potential impact on vehicle safety application priorities.



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As described in the following accomplishments section, the fifth issue has been effectively resolved in the FCC Report and Order, published in February, through the indirect intervention of the VSCC.

### *Accomplishments*

As part of the Task 5 activities, the VSCC attended every meeting of the DSRC Standards Writing Group, and associated ASTM E2213, IEEE P1609, IEEE P1556 meetings during the past year, as well as all IEEE 802.11 Working Group meetings beginning in July, when the DSRC lower layer standards development was moved to the IEEE 802.11 Working Group from the ASTM E17.51 DSRC group. In addition, the VSCC has assumed leadership positions in the newly formed SAE DSRC Technical Committee, and has attended all the meetings of this committee. Through this active participation in the development of the DSRC standards, the VSCC has accomplished the following during the past year:

- 1) Secured support for broadcast-type messages needed by vehicle safety applications throughout the range of DSRC standards. The broadcast-type messages were identified by the VSCC technical team as the most likely transmission mechanism to support the initial range of vehicle safety applications. Through active participation in the DSRC standards developments in ASTM and IEEE, the VSCC has secured effective support for broadcast-type messages to support vehicle safety applications in the completed and planned DSRC standards.



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- 2) The concept of Random Medium Access Control (MAC) addresses for On-Board Units (OBUs) was introduced and promoted by the VSCC. This technique was accepted by the DSRC Standards Writing Group and became embedded in the DSRC standards. The use of this technique in the DSRC standards allows privacy to be protected by not being able to explicitly identify a particular vehicle by its DSRC transmissions.
- 3) In order to allow the maximum number of vehicles to simultaneously use the control channel, the VSCC insisted that full IPv6 (Internet Protocol version 6) headers not be required for vehicle safety broadcast transmissions. The full IPv6 headers contain more bytes than the entire expected vehicle safety message payload, and the mandatory use of these headers would have greatly reduced the number of vehicles that could use the control channel at the same time. Instead, several approaches were identified to allow efficient vehicle safety transmissions. One of these approaches will be embedded into the DSRC standards.
- 4) Horizontal and vertical directionalities that would be very favorable for electronic toll collection systems were specified in the initial drafts of the ASTM 2213 lower layer standard. The VSCC successfully made the case in the ASTM meetings that the majority of anticipated vehicle safety applications require omni-directional antenna coverage. This portion of the standard was subsequently revised to support the omni-directional antenna coverage necessary to support vehicle safety applications.
- 5) DSRC antennas were initially specified in the lower layer ASTM standard as “right-hand, circular polarization”. This designation would make it difficult and



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expensive to implement omni-directional antennas. The VSCC insisted that vertical polarization also be allowed for DSRC antennas, and this accommodation was written into the revised ASTM 2213 lower layer standard.

- 6) In the band plan that was initially proposed to the FCC by ITS America, channel 172 was specified as the “vehicle-to-vehicle” channel, at the prior suggestion of the DSRC Standards Writing Group. When the VSCC analyzed the communications requirements of the identified potential vehicle safety applications, it became apparent that both vehicle-to-vehicle and vehicle-to/from-infrastructure vehicle safety communications must operate on the same channel. The VSCC made this argument effectively in the DSRC Standards Writing Group, and convinced the group that vehicle-to-vehicle safety communications should be allowed to operate on the control channel along with vehicle-to/from-infrastructure safety communications.
  
- 7) Channel 172, previously defined as the “vehicle-to-vehicle” channel, was designated the “high-availability, low-latency channel” by the DSRC Standards Writing Group, at the suggestion of the VSCC. The necessity of this channel is illustrated by the pre-crash application scenario: when two vehicles determine that a crash is imminent, they need to immediately switch to a channel that is uncluttered with routine communications and effectively exchange information in the final few hundred milliseconds before the crash that can be used to help mitigate the effects of the crash on the occupants of the vehicles. Although the FCC did not designate specific uses for channels other than the control channel in the DSRC Report and Order, this “high-availability, low-latency channel” is being embedded into the DSRC operations specified in the upper layer standards.



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- 8) The legal definitions for “public safety” services do not apply for the types of vehicle-to-vehicle safety applications being considered by the VSCC. Changing the definitions for public safety would have required an Act of Congress. This issue was raised within the DSRC Standards Writing Group, and was conveyed to the FCC through the ITS America legal representatives. Based upon this intervention, the FCC Report and Order specifically describes “vehicle safety” and “public safety” services as the high priority users of the 5.9 GHz DSRC spectrum.
  
- 9) In conjunction with Task 6B, the VSCC is providing significant input into the IEEE P1556 DSRC security standard development.

### **Task 6: Test and Validation of DSRC Capabilities**

Task 6 now includes four projects:

- Task 6A: “Vehicle Safety Communication Protocol Research for DSRC”
- Task 6B: “DSRC Security for Vehicle Safety Applications”
- Task 6C: “DSRC Antenna Basic Performance Requirements”
- Task 6D: “WAVE Radio Module”



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## **Task 6A: Vehicle Safety Communication Protocol Research for DSRC**

### *Activities*

“Vehicle Safety Communication Protocol Research for DSRC” was launched in August. Upgrading the test kit software has been a continuous process since that time. The initial upgrades included the capability to operate on 10 MHz channels, software options for power control, and the option of locking the transmission frequency to 5.8 GHz. These enhancements were incorporated into version 2.7 of the test kit software. These enhanced capabilities were designed to allow the completion of Task 4 field testing for test scenarios that required power control, as well as field testing to determine if the 10 MHz channel width has an impact on packet loss rates under selected test scenarios.

Multi-sender capabilities were subsequently developed for the test kit software to enable the field testing of the final Task 4 test scenarios. The first software version to include this capability was completed in February. A significant amount of debugging was required with the multi-sender software. Often the bugs were only discovered in the course of attempting to conduct Task 4 testing. The trouble-shooting and debugging took quite a bit of time to accomplish, but the current version of the test kit software – version 3.0.4 – seems to have fixed most of the identified bugs.

The power output of the test kits remains inconsistent, however, and is not reliably related to the power indicated in the software settings. This situation was discovered during the antenna testing in Task 6C, and has not yet been able to be rectified.



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### *Accomplishments*

The upgraded test kits enabled the completion of Task 4 field testing of the multi-sender scenarios under test conditions more closely approximating DSRC operations.

### **Task 6B: DSRC Security for Vehicle Safety Applications**

#### *Activities*

“DSRC Security for Vehicle Safety Applications” was launched in August. Interaction with the standards development process, under Activity 1, was conducted through participation in conference calls of the IEEE P1556 DSRC security standards development group. The threat model development work completed under Activity 2 was coordinated with NIST in order to describe a threat model that meets the evaluation requirements of NIST, as security advisor to the USDOT. Relevant threats were identified within four classes of potential attackers. The first class - attackers with a programmable radio transmitter/receiver – was determined to be capable of launching replay/tunneling, denial of service, RF fingerprinting, remote compromise and remote management types of attacks. Attackers with access to an un-tampered VSC unit comprised the second class. These attackers would be capable of change of location, indicator mismatch, sensor spoofing and GPS spoofing types of attacks. The third class of attackers identified were those who have access to a compromised VSC unit. By using a compromised unit, these attackers would be able to perform attacks involving duplication, physical law violations and increased ability to compromise other units. The final class of attackers would be ‘inside’ attackers, having insider knowledge of the





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manufacture of the units. These attackers would be capable of performing key extraction, cryptographic attacks on privacy and RF fingerprinting with database attacks.

A number of out-of-scope threats were also identified. One of these threats was physical denial of service attacks, where units would be physically disabled, for example, by smashing the antenna. Another identified out-of-scope attack was jamming the DSRC radio frequencies so that no communications would be possible.

The constraints analysis was subsequently completed. This analysis included a collection and interpretation of information provided by VSC technical team members. This information has been used to constrain the evaluation of the various approaches considered in the development of the VSC security approach.

### *Accomplishments*

A potential security approach that is likely to be able to support vehicle safety communications, both for RSU and OBU installations, was developed.

## **Task 6C: DSRC Antenna Basic Performance Requirements**

### *Activities*

“DSRC Antenna Basic Performance Requirements” was initiated in September. The initial approach included technical clarification of the project activities, as well as preliminary assessment of the current test kit antennas and polarization recommendations for future DSRC vehicle antennas. The initial polarization recommendation from the



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contractor was for vertical polarization, due to operational characteristics, as well as economic considerations, but both vertical and circular polarization were considered in this task.

All the project milestones, except for the delivery of antennas, have been completed. The two antenna designs selected were roof-mounted with magnetic attachment, and side-mirror-mounted using a clamping device. These designs were chosen to allow flexible testing on a wide range of test vehicles. The performance simulation for these designs showed that for the roof mounted antenna design, the elevation of the peak gain shifts upward as the ground plane narrows/shrinks. The cable route and mounting location also showed a minor impact on modeling the coaxial cable feed point. For the mirror mounted design, the dipole array includes a taper that reduces the impacts of the cable feed point.

### *Accomplishments*

The anechoic chamber and bench test results were encouraging. The measured gain of the mirror mount antenna showed good agreement with the predicted performance as in the simulation. The ripples in the azimuth radiation pattern were due in part to the fixture suspending the antenna in free space and the housing. The antenna provided good gain and nearly uniform coverage over  $\pm 90^\circ$  azimuth. The elevation pattern also showed good elevation coverage to  $\pm 30^\circ$ . The measured Voltage Standing Wave Ratio (VSWR) of the mirror mount antenna was also in agreement with the simulation. The VSWR was nearly flat at approximately 1.3:1 over the entire frequency range of interest including the Wireless Local Area Network (WLAN) and ITS DSRC bands. The roof mount antenna



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was not as broad banded as the mirror mount design. The VSWR in the ITS DSRC band for the roof mount design was approximately 1.4:1 and 2.1:1 in the WLAN band.

In the vehicle level range testing, the measured vehicle level performance of the side mirror antenna showed no unexpected results and minimal vehicle influence. Each location provided good pattern coverage and gain for the respective driver and passenger sides of the vehicle. The simulated diversity combination of both patterns indicated nearly uniform azimuth coverage 360° around the vehicle.

Both the 5/8 wave and a 4 element WLAN roof mount antennas were tested on a 36” diameter ground plane, a vehicle with a sun roof, and a vehicle without a sun roof. These measurements compared the vehicle and sun roof effects on antenna performance as compared to performance on a ground plane. The 4 element WLAN antenna served as a reference antenna which was used in earlier drive testing conducted in the WLAN frequency band. The antennas compared well on both the ground plane and vehicle without a sun roof. However, the 5/8 wave was more impacted by the presence of the sun roof. Both antennas exhibited gain bias to the vehicle rear and front to back gain variations of 4dB due to the sun roof.

Two antennas have been designed, built and tested both at component level and vehicle level. The results showed that both antennas performed as designed and met all goals of the design specification. Because the performance of each antenna can be influenced by vehicle type, the results are typical for sedan type vehicles. Through extensive drive testing, the mirror mount antennas have been shown to provide consistently good vehicle communications over both WLAN and ITS DSRC bands to at least 500 meters  $\pm 90^\circ$  broadside of the vehicle. The 5/8 roof mount antenna performance can be influenced by



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vehicle roof surface features, such as a sun roof. However, for recommended roof locations, the 5/8 wave antenna also met design and performance goals.

### **Task 6D: WAVE Radio Module**

The initial work package for the “WAVE Radio Module” project was initiated in March. This work package will develop the detailed specification for the WAVE radio module, based upon the preliminary requirements, in conjunction with research into the technical capabilities achievable with currently available hardware. The purpose of the WAVE radio module is to support the testing proposed for Task 10 of the VSC project.

A contractor was selected for Task 6D through a competitive bidding process. Weekly conference calls are underway between the VSC technical team and the contractor to establish the detailed design specifications. A design review to formally approve the specifications is planned for the beginning of May.

### **Virginia Tech Test Kits**

As stated in the VSC project statement of work, with regard to VSCC DSRC communications test kits: “Spare units will also be available for possible collaboration with Virginia Tech.” As a result of another USDOT program, Virginia Tech was conducting related research, and was provided with two VSCC DSRC test kits. Researchers at Virginia Tech subsequently developed application demonstration software

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*IVI Light Vehicle Enabling Research Program*

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that could be run effectively on the test kits. This software running on the test kits was used for portions of the Virginia Tech intersection collision avoidance demonstration at Turner-Fairbanks during the IVI meetings in June.



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ID	Task Name	Start	Finish	2003												2004											
				A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D			
1	<b>VSC Project</b>	Wed 5/1/02	Thu 10/28/04	[Blue bar spanning all days from 5/1/02 to 10/28/04]																							
2																											
3	<b>Task 1</b>	Thu 5/2/02	Fri 6/28/02	[Black bar from 5/2/02 to 6/28/02]																							
15																											
16	<b>Task 2</b>	Wed 5/1/02	Fri 6/28/02	[Black bar from 5/1/02 to 6/28/02]																							
40																											
41	<b>Task 3</b>	Wed 5/15/02	Thu 1/30/03	[Black bar from 5/15/02 to 1/30/03]																							
62																											
63	<b>Task 4</b>	Wed 5/1/02	Wed 12/31/03	[Black bar from 5/1/02 to 12/31/03]																							
95																											
146	<b>Task 5</b>	Wed 5/1/02	Fri 4/23/04	[Black bar from 5/1/02 to 4/23/04]																							
234																											
235	<b>Task 6</b>	Mon 6/30/03	Mon 8/16/04	[Black bar from 6/30/03 to 8/16/04]																							
236	Task 6A	Fri 8/1/03	Wed 5/26/04	[Blue bar from 8/1/03 to 5/26/04]																							
237	Task 6B	Thu 8/28/03	Wed 5/26/04	[Blue bar from 8/28/03 to 5/26/04]																							
238	Task 6C	Mon 6/30/03	Thu 4/29/04	[Blue bar from 6/30/03 to 4/29/04]																							
239	Task 6D	Mon 3/22/04	Mon 8/16/04	[Blue bar from 3/22/04 to 8/16/04]																							
240																											
241	<b>Task 7</b>	Mon 12/1/03	Thu 6/10/04	[Black bar from 12/1/03 to 6/10/04]																							
248																											
249	<b>Task 8</b>	Wed 5/1/02	Fri 4/30/04	[Black bar from 5/1/02 to 4/30/04]																							
292																											
293	<b>Task 9</b>	Mon 5/3/04	Fri 7/30/04	[Black bar from 5/3/04 to 7/30/04]																							
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309	<b>Task 13</b>	Mon 5/3/04	Thu 10/28/04	[Black bar from 5/3/04 to 10/28/04]																							
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313	<b>Task 14</b>	Mon 5/3/04	Thu 10/28/04	[Black bar from 5/3/04 to 10/28/04]																							



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