Final Report

of the

Working Group

on

Advanced Vehicle Control Systems (AVCS)

Mobility 2000

March 1990
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVCS Working Group Members</td>
<td></td>
<td>iv</td>
</tr>
<tr>
<td>1.0 INTRODUCTION</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1.1 The Promise of Intelligent Vehicle Highway Systems (IVHS)</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1.2 Definition</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1.3 Background</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>1.4 Scope</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>1.5 Goals and Objectives</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>1.6 Report Overview</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>2.0 PROGRAM PLANNING AND DEVELOPMENT CONSIDERATIONS</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>2.1 Introduction and Overview</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>2.2 Planning Considerations</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>2.2.1 Identification of Targets of Opportunity and AVCS Requirements</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>2.2.2 Human Factors Issues</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>2.2.3 Evaluation Protocols</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>2.2.4 AVCS Development: Participants and Roles</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>3.0 PROGRAM PLAN</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>3.1 AVCS—I: Individual Vehicle Control</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>3.1.1 Scenario</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>3.1.2 Overview</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>3.1.3 Identifying the “Safety” Targets of Opportunity</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>3.1.4 Technologies and Benefits</td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>3.1.5 Proposed Milestones</td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>3.1.6 Funding Requirements</td>
<td></td>
<td>19</td>
</tr>
<tr>
<td>3.2 AVCS—I: Cooperative Driver-Vehicle-Highway Systems</td>
<td></td>
<td>23</td>
</tr>
<tr>
<td>3.2.1 Scenario</td>
<td></td>
<td>23</td>
</tr>
<tr>
<td>3.2.2 Overview</td>
<td></td>
<td>24</td>
</tr>
<tr>
<td>3.2.3 Targets of Opportunity</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>3.2.4 Technologies and Benefits</td>
<td></td>
<td>26</td>
</tr>
<tr>
<td>3.2.5 Proposed Milestones</td>
<td></td>
<td>26</td>
</tr>
<tr>
<td>3.2.6 Funding Requirements</td>
<td></td>
<td>29</td>
</tr>
<tr>
<td>3.3 AVCS—I: Automated Vehicle-Highway Systems</td>
<td></td>
<td>29</td>
</tr>
<tr>
<td>3.3.1 Scenario</td>
<td></td>
<td>29</td>
</tr>
<tr>
<td>3.3.2 Overview</td>
<td></td>
<td>34</td>
</tr>
<tr>
<td>3.3.3 Targets of Opportunity</td>
<td></td>
<td>34</td>
</tr>
<tr>
<td>3.3.4 Technologies and Benefits</td>
<td></td>
<td>35</td>
</tr>
<tr>
<td>3.3.5 Proposed Milestones</td>
<td></td>
<td>36</td>
</tr>
<tr>
<td>3.3.6 Funding Requirements</td>
<td></td>
<td>36</td>
</tr>
</tbody>
</table>
3.4 Total AVCS Funding Summary ............................................. 36

4.0 IMPLEMENTATION ISSUES .................................................. 36
  4.1 Organizational Structure ............................................. 36
    4.1.1 Institutional Arrangement .................................... 36

Table 3.4 Advanced Vehicle Control Systems Public and Private Funding ........ 45
  4.1.2 Technology Transfer Protocol .................................... 47
  4.1.3 International Collaboration ..................................... 47
  4.2 Finance ................................................................. 47
  4.3 Deployment Barriers .................................................. 48
    4.3.1 Social ............................................................ 48
    4.3.2 Safety ............................................................ 49
    4.3.3 Organizational ................................................. 49
    4.3.4 Legal .............................................................. 50
    4.3.5 Political .......................................................... 50
    4.3.6 Environmental ............................................... 50
  4.4 Infrastructure Requirements ........................................ 50
  4.5 Marketing and Public Relations ..................................... 51

5.0 CONCLUSIONS AND RECOMMENDATIONS ................................. 52
<table>
<thead>
<tr>
<th>Figure/Table Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1-1 Freeway Construction in California</td>
<td>2</td>
</tr>
<tr>
<td>Figure 2.1 Conceptual Phases in AVCS Development</td>
<td>5</td>
</tr>
<tr>
<td>Table 3.1.4 Overview of AVCS–I Technologies</td>
<td>13</td>
</tr>
<tr>
<td>Figure 3.1.5 AVCS–I Development Plan</td>
<td>17</td>
</tr>
<tr>
<td>Figure 3.1.6 AVCS–I Funding Alternatives</td>
<td>21</td>
</tr>
<tr>
<td>Figure 3.2.5 AVCS–II Development Plan</td>
<td>27</td>
</tr>
<tr>
<td>Figure 3.2.6 AVCS–II Funding Alternatives</td>
<td>31</td>
</tr>
<tr>
<td>Figure 3.3.5 AVCS–III Development Plan</td>
<td>37</td>
</tr>
<tr>
<td>Figure 3.3.6 AVCS–III Funding Alternatives</td>
<td>39</td>
</tr>
<tr>
<td>Figure 3.4.1 Total Program Summary</td>
<td>41</td>
</tr>
<tr>
<td>Figure 3.4.2 Advanced Vehicle Control Systems: 1990 — 2010</td>
<td>43</td>
</tr>
</tbody>
</table>
AVCS Working Group Members

Alexandra H. Argyropoulos, The Mitre Corporation

Milt Baker, Motorola, Inc.

Steven A. Barsony, Urban Mass Transportation Administration Engineering Evaluations

G. Sadler Bridges, Texas Transportation Institute

Larry W. Darnes, FHWA

Peter Davies, Castle Rock Consultants

Neil Emmott, Castle Rock Consultants

Paul Fancher, University of Michigan

Robert E. Fenton, Ohio State University

Tom Griest, LABTEK Corporation

Jim Haugen, Haugen Associates

Tommie Howell, Texas Department of Highways & Public Transportation

Ronald Knipling, Allen Division

Thomas P. Kozlowski, Federal Highway Administration

Michael E. Krueger, Hughes

Richard C. Lavigne, Traffic Systems Division Turner-Fairbank Highway Research Center

William A. Leasure, Jr., National Highway Traffic Safety Administration, Co-Chairman

Mark Lill, Motorola, Inc.

Bill McCall, Department of Transportation

Larry Minor, Federal Highway Administration

Mark Readinger, TRW, Inc.
AVCS Working Group Members (Con't)

Charlie Robards, Lockheed Missiles and Space Division

Don Savitt, Hughes Aircraft Company

David Schmidt, Arizona State University

Steven E. Shladover, Institute of Transportation Studies

John Vostrez, California Department of Transportation, Co-Chairman
Advanced Vehicle Control Systems

1.0 INTRODUCTION

1.1 THE PROMISE OF INTELLIGENT VEHICLE HIGHWAY SYSTEMS (IVHS)

The level of service on the principal road systems within most major U.S. cities has dropped to the lowest level on the scale for much of the day. With reserve capacity quickly being used up, additional demand will increase congestion dramatically even from current levels — a fivefold increase in delay is projected over the next two decades. Over this same time period, the number of crashes, fatalities, and injuries can be expected to increase 60 percent assuming that the current fatality risk per vehicle mile is expanded proportionate with the Federal Highway Administration (FHWA) medium estimate of VMT growth. Similar conditions existed after World War II when demand on the system took a quantum jump, and the highways simply did not have the capacity. What was needed then, and what is needed again, is a way to substantially increase the capacity and safety (since much of the delay is due to accidents) of the system. Doubling of the lane capacity and reducing the accident rate by 60 percent was accomplished in the 1950's and 60's by grade separating the intersections and by controlling access. The freeway was a marvelous improvement in level of service and safety. It greatly increased the competitive position of the U.S. private sector. It dramatically improved people's mobility and quality of life.

However, as the freeway system matured, problems began to appear with over demand, congestion, accidents, air quality deterioration, and foreign energy dependency. Freeway development followed the classic industrial decay curve cycle. Every new system must be augmented by, or replaced by, new systems to keep up with changing demands. As an example, the freeway development process in California peaked in the early 1960's (see Figure 1-1). This would have been the logical time to start the development of automated vehicle features, thus continuing the improvement in system efficiency to match the increase in demand. Instead, we have waited until the early 1990's, resulting in two decades of worsening conditions on our systems.

Development of the next generation system holds the same or even more promise as its predecessor, the freeway. A doubling or tripling of lane capacity and a dramatic increase in safety is well within reach of the technology.

IVHS technologies - Advanced Driver Information Systems (ADIS), Advanced Traffic Management Systems (ATMS), and Advanced Vehicle Control Systems (AVCS) - can be deployed, in combination, within the same time frames and at no greater cost than the freeway. The 10-year development phase and 20-year deployment phase indicated for IVHS matches the 30-year freeway development phase (1955-1985).

IVHS can realize dramatic improvement in the productivity of private and public transportation and goods movement. It will improve efficiency on freeways, city streets, and in parking structures. The technology is robust and flexible, allowing capacity to match varying demand characteristics and land use patterns.

IVHS offers the only hope of really solving transportation problems instead of merely managing worsening conditions over time. What is called for is no more than what transportation professionals have already done twice in this century with paved roads and freeways — a major technological advance.

1.2 DEFINITION

Advanced vehicle control systems include individual vehicle controls, cooperative driver-vehicle-highway systems, and eventually full automation on certain roadways. Such systems are possible today because of the tremendous advancements that have been made in vehicle and roadway sensors, servo systems, image processors, computers, and communication systems. While the other components of IVHS make driving more efficient by providing the driver with better information about the macro-level conditions that affect his decision-making, the AVCS can provide information about highly localized and rapidly changing conditions in his or her immediate vicinity and can initiate actions based on those conditions. AVCS, therefore, can have more significant impacts on the productivity (capacity,
Figure 1-1 Freeway Construction in California

speed) and safety of road travel. AVC systems can enable drivers to operate their vehicles closer together while maintaining a higher level of safety than at present, by enhancing drivers' ability to detect and avoid hazards and eventually by assuming responsibility for controlling the speed, steering, and braking of the vehicles. By compensating for the limitations of the human driver, AVCS makes it possible to achieve step function increases in road capacity and safety rather than just offering incremental percentage improvements.

1.3 BACKGROUND

Research on the technologies associated with automating highway operations started more than 30 years ago. These were mostly small private sector efforts. The support from the government for these efforts was late in coming and contained only token funds. Despite the great promise shown by these efforts, the transportation community was busy building highways and did not take the initiative to establish the well-funded, focused effort needed to advance the technologies to the stage where they could begin the long deployment process. The addition of new highway lanes has now become less practical. This, coupled with the availability of new electronic and communications technologies, has made high technology solutions more feasible and politically, economically, and environmentally attractive. Highway transportation research and development efforts are being refocused toward AVCS and other IVHS approaches to relieve congestion and improve safety.

1.4 SCOPE

Advanced vehicle control systems are one of the four major components of the IVHS program that were described by the Mobility 2000 group in San Antonio, February 1989. The other components are Advanced Traffic Management Systems, Advanced Driver Information Systems, and Commercial Vehicle Operations. The last category is not independent of the other components, but rather was created to signify that the needs of commercial vehicles are different in many cases from those of personal vehicles. AVCS will build upon the technologies developed and deployed during the other facets of the overall IVHS program to solve the nation's safety and congestion problems.

The technologies involved in advanced vehicle control systems are very extensive, but for the purposes of this report are generally limited to:

- Driver warning, vision enhancement, and assistance systems
- Automatic steering control or automatic headway control — platooning
- Obstacle avoidance or automatic braking
- Automatic trip routing and scheduling
- Control merging of streams of traffic
- Transitioning to and from automatic control

AVCS technology is broad-based, requires a multimodal approach, extends to both rural and urban needs, and involves the movement of both people and goods. The architecture of AVCS must also be flexible enough to accept higher levels of technology as they are produced.
1.5 GOALS AND OBJECTIVES

AVCS enhances the control of vehicles by facilitating and augmenting driver performance and, ultimately, relieving the driver of most tasks.

The major goals of programs to develop and deploy advanced vehicle control systems are the same as for the IVHS Program as a whole: congestion relief, improved safety, increased speed and trip-time reliability, travel convenience, and industrial competitiveness. AVCS differs from other IVHS work in that it goes beyond the efficient management of the existing limited system and has the potential to provide quantum improvements in throughput and safety.

More specifically, the AVCS program has set the following goals:

- **Long-term Goals:**
  - Solve the urban congestion problem
  - Develop an accident free ground transportation system
  - Reduce the negative environmental impacts of the transportation system levels.
  - Regain energy independence in the United States.

- **10-year Goals:**
  - Deploy AVCS arterial systems and vehicle products which demonstrate the capability for 50 percent reduction in accident rates when used nation-wide.
  - Deploy freeway-based AVCS system which at least doubles lane capacity.
  - Design and demonstrate features of an AVCS-based, higher speed or higher productivity Post-Interstate Freeway Network.
  - Deploy freeway-based AVCS system with new features of modal and technology integration — e.g., roadway electrification; new transit operations; remote or automated parking; and goods movement.

1.6 REPORT OVERVIEW

This report is divided into five sections including this introductory section. Section 2 reviews critical AVCS program planning and system development considerations. The third section presents the program plan for the development and implementation of AVCS and brief scenarios illustrating the use of AVCS in the near, mid and long term highlighting in a qualitative sense the benefits to be expected from the implementation of such systems. It includes a schedule for the research, demonstration, and deployment of each of the components of advanced vehicle control systems. The fourth section describes the implementation issues associated with organization and funding of the program. Also addressed in Section 4 are institutional issues associated with the development of advanced vehicle control systems. Section 5 presents conclusions and recommendations resulting from the overall study of the AVCS technology.

2.0 PROGRAM PLANNING AND DEVELOPMENT CONSIDERATIONS

2.1 INTRODUCTION AND OVERVIEW

An intensive, systematic, multi-year program of research, development, demonstration, and evaluation is required to reach the goal of improving highway safety and reducing congestion through the application of AVCS concepts. It is envisioned that a large number of individual AVCS technologies will undergo system development in the coming years and decades. Although there will be many different specific initiatives proceeding somewhat independently, an overall program plan and common system development protocols are needed to ensure that the AVCS concept progresses systematically. This chapter overviews major AVCS development initiatives and discusses critical AVCS planning considerations. It addresses targets of opportunity and risks to be avoided in AVCS development. Three levels of AVCS technology are anticipated and planned:

- **AVCS—I:** Individual Vehicle Control (Autonomous Driver-Vehicle Systems)
- **AVCS—II:** Cooperative Driver-Vehicle-Highway Systems
- **AVCS—III:** Automated Vehicle-Highway Systems
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This program plan outlines activities and milestones necessary for systematic research, development, demonstration, and evaluation of systems and concepts pertaining to AVCS-I, II, and III. A conceptual development model for AVCS applications, regardless of technological complexity, is shown in Figure 2-1. This model identifies nine conceptual phases in AVCS development from initial problem assessment through summative evaluation of system effectiveness. The system development model serves as a structure for addressing AVCS planning requirements and concerns.

2.2 PLANNING CONSIDERATIONS

The development of an AVC system involves transforming a target of opportunity into a set of requirements and then into an actual functioning system. Since AVC systems involve important human-machine interactions, the development of system requirements and specifications includes an analysis of human behavioral implications. AVC systems are to be viewed not merely as vehicle and/or highway systems, but rather as interventions that will have important influences on the dynamic performance of the total driver-vehicle-highway system.

There are a number of important considerations to be addressed to ensure that the development of an AVC system will result in a successful application of technology. Four critical requirements of AVC system development are:

- Early identification and analysis of targets of opportunity to enable the establishment of system functional goals.
- A full accounting of the role of humans in the system; specifically of the "human operating characteristics" that are likely to impact system effectiveness.
- Rigorous evaluation at several key stages of system development to assess AVCS performance, reliability, benefits, and disbenefits.
- Coordinated government-industry effort with clearly established organizational roles within each system development effort (although the roles may vary across different AVCS developments).

These critical considerations in system development, and recommended approaches to addressing them, are discussed below.

2.2.1 Identification of Targets of Opportunity and AVCS Requirements Definition

The initial phases of AVCS development (i.e., blocks 1 & 2 in Figure 2-1) assess the problem at hand and define the most important elements of the desired solution. Targets of opportunity are identified and system functional goals are set. This involves a process of prioritizing, whereby safety, congestion, and/or other problems to be solved (or opportunities to be exploited) are compared to determine where the needs, opportunities, and probabilities of success are likely to be greatest.

Identification of targets of opportunity relating to AVCS accident countermeasures involves the use of accident data to characterize relevant accident types in terms of patterns of occurrence, prevalence, and severity. Causal and contributory factors associated with relevant accident types are analyzed and used to define ways AVCS can reduce crashes and fatalities. The most important causal or contributory factor in most crashes is a failure of information processing by the driver in the seconds preceding the crash. An understanding of driver information processing in the context of the interactions of driver, vehicle, and highway environment permits the setting of functional goals for the AVCS.

Identification of targets of opportunities relating to congestion-related AVC systems follows a similar line of thought and research. Traffic congestion is analyzed in terms of the types of traffic tie ups that occur, their relative severity, and their causes and contributory factors. Problem assessment analyzes the causal relationships to identify specific targets of opportunity. For example, studies of platooning as a congestion countermeasure first assess the problem size and characteristics of highway...
AVCS DEVELOPMENT

1. Identify Targets of Opportunity:
   - Accident Analysis
   - Congestion Analysis

2. Set Functional Goals/Requirements

3. Feasibility/Trade-off Studies of Alternative Solutions/Designs

4. Develop Technology

5. Design and Build Prototype Device/System

6. Test/Evaluation
   - Engineering Performance
   - Driver-Vehicle-Highway Interface

7. Limited Production and Operational Testing

8. Full Scale Production and Deployment

9. Summative Evaluation

Figure 2-1. Conceptual Phases in AVCS Development
Advanced Vehicle Control Systems

congestion due to vehicle spacing, and then analyze related driver, vehicle, and highway factors. An understanding of vehicle spacing parameters and their relation to highway congestion permits the derivation of desired vehicle spacing under a platooning system. The specification of acceptable or desired spacing distances becomes a platooning system functional requirement.

2.2.2 Human Factors Issues

By definition, AVC systems will change the way that drivers perform the driving task. AVC systems will enhance perception, aid working memory, support driver decision-making, augment responses, or otherwise change ways that drivers perceive, make decisions, and respond. If the human factors impacts of a prospective AVCS are not fully understood and controlled, the benefits may be nullified or, even worse, unacceptable hazards or other negative side-effects may be created. For this reason, human factors considerations permeate the AVCS development process.

Driving is a dynamic information processing activity. In-depth studies of accident causation have found that driver information processing errors are predominant as accident causes or contributory factors. Similarly, urban roadway congestion problems are related to driver information processing capabilities; for example, the capability of drivers to react quickly and appropriately to potential hazards. Human information processing models encompass mental or behavior activities such as sensation or perception, working memory, decision-making, response execution, and attention. Each of these subsystems of information processing has limitations in terms of speed, quantity of information, and types of information that can be handled reliably. And, there are limits on the total “mental energy” or mental resources available to support the information processing. Stressing any one subsystem of human information processing or the total system beyond its capacity may result in unreliable human performance.

Successful AVC systems will generally act by enhancing one or more element of human information processing. For example, lateral object detection devices (as might be employed to facilitate lane changing by heavy trucks) have the potential to enhance perception and decrease the workload on the driver, thus improving driver performance in general. However, an undesirable effect may be that the driver relies too heavily on the AVCS and thus fails to use side mirrors or other existing visual cues. Occasional system false positives or false negatives alter the driver’s decision process in a detrimental way.

Apart from human information processing, there are a number of human factors issues to be addressed for each AVCS. These include:

- Driver education or training requirements. What specific knowledge, skills, and attitudes are required to operate the device, and do they need to be trained?
- Public acceptance. Individuals may react negatively to AVCS concepts due to perceived inconvenience, sense of loss of personal freedom, difficulty of device use, decrease in the enjoyment of driving, incorrect assessment of risks (e.g., platooning may be judged by the public as being unsafe when it may actually be more safe). Each AVCS development should address how to maximize public acceptance through public education, system design, driver training, or other means.
- Impact of the AVCS on important subgroups of drivers; e.g., Alcohol or drug-impaired
  - Elderly drivers
  - Physically impaired or handicapped
  - Illiterate or low mental ability
  - Anthropometric extremes
  - High-risk groups (e.g., young males, long-haul commercial drivers)
- Failure mode human factors — how the human reacts to system failure (e.g., in the event of temporary failure of a platooning system, will drivers revert safely to normal highway spacing).

2.2.3 Evaluation Protocols

Several phases of AVCS development will involve the application of sophisticated evaluation protocols.
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Each AVCS development is likely to involve several different evaluation methods, with the selection of methodologies dependent on the phase of system development, specific evaluation questions to be answered, and information attainable from different approaches. Some of the more important of the evaluation protocols and methods to be employed in AVCS development include:

- Engineering test and evaluation to determine device reliability and performance parameters.
- Human engineering studies on the design of AVCS human-machine interfaces; includes evaluation of AVC systems in terms of existing human factors guidelines and/or new human factors research specific to AVCS concepts and individual AVCS devices.
- Driving simulation studies to permit safe and controlled experimentation, targeted toward a specific traffic or accident scenario, to determine the impact of AVC systems on driver behavior and on crashes and congestion.
- Instrumented vehicle tests to determine how AVC systems affect vehicle handling and control characteristics.
- Field operational tests before full-scale device deployment to demonstrate AVCS effectiveness.
- Post-deployment summative evaluations on a broad scale (e.g., national level) to document AVCS benefits and/or disbenefits.

The development of each AVCS concept will be subjected to rigorous evaluation using the above and other appropriate methodologies. More systematic research and evaluation protocols will be developed to apply to AVC systems. The driving simulator is particularly important as a research and evaluation tool for AVCS especially with regard to the human factors and safety aspects. The application of simulation technology to AVCS R&D will provide several distinct capabilities that cannot be achieved by other means:

- Highly controlled experimentation on specific traffic or accident scenarios.
- Economical testing of many different variations and modifications of AVCS configurations and characteristics.
- Testing of AVC concepts before the actual hardware exists.
- Safe laboratory testing of experimental devices when other evaluation methods would expose drivers to hazardous conditions.
- Collection of detailed, dynamic data on driver performance under both baseline and AVCS conditions.

2.2.4 AVCS Development: Participants and Roles

Joint government-industry effort is needed to optimize the success of each AVCS development and the overall AVCS initiative. There are several distinct groups of individuals, institutions, and organizations that will be involved in the AVCS program and specific system developments. Possible participant roles may include:

- The Federal Government will define functional requirements and set priorities for safety-related issues.
- Federal, state, and local governments will define functional requirements and set priorities for congestion-related issues.
- State and local governments will provide highway facilities for operational test projects.
- Research organizations and educational institutions with expertise in human factors, highway transportation systems, highway safety, computer systems, artificial intelligence, etc., will provide technical resources and facilities.
- Major U.S. automotive companies and their suppliers will provide expertise, concepts, and technical capabilities and facilities for the development and testing of devices, systems integration, and demonstration of advanced vehicle control capabilities.
Advanced Vehicle Control Systems

- Individual inventors and small entrepreneurs will provide concepts and develop and perform preliminary tests of new technology.

Organizational roles will vary depending on the size and nature of the AVCS development effort. For example, AVCS—I developments will require little involvement of state and local governments since these devices will be vehicle-based and will require no infrastructure changes. At the other extreme, AVCS—III will involve large operational tests on highly instrumented highway facilities. Extensive state and local participation in system development is anticipated, particularly in relation to system demonstrations. Since organizational roles and responsibilities will vary across different AVCS developments, they will need to be clearly defined and communicated for each major development in order to facilitate and enhance the system development process.

3.0 PROGRAM PLAN

3.1 AVCS—I: INDIVIDUAL VEHICLE CONTROL

3.1.1 Scenario

It's 6:30 a.m. John is leaving his suburban home to drive the 40 miles to his office just inside the city limits. The sun won't be up for 10 more minutes, it's dark and a morning fog reduces visibility even further. While backing out of his driveway, John hears the signal of his Near Field Proximity or Backup Warning System. He immediately applies the brakes. He leaves the car and finds that his son's bicycle was carelessly left behind the car. While moving the bike, John speculates on how much money the backup warning system has saved him this past year alone. As he cautiously proceeds towards the main arterial road, he switches on the Infrared Roadway Enhancer and is able to see the outline of a pedestrian crossing the street 100 feet ahead. He silently gives thanks to the engineers who came up with that handy gadget.

Before he leaves his neighborhood, John checks his Vehicle Diagnostic Status Panel and notices that he has enough gas for two more trips to work, but that his left rear tire is dangerously low on air. John stops at the next service station, fills the tire with air, the tank with gas, and then continues on to work.

John feels relaxed while driving to work knowing that his on-board computers are monitoring all vehicle systems and helping him drive safely under all conditions. As he leaves the local streets, John increases his speed towards 55 mph. Noting some heavy traffic in his lane ahead, he depresses his left turn signal. Immediately the Lane Occupancy Warning System informs him a vehicle is accelerating and moving to close a gap in the left lane. John decides to wait for a safer gap. Finding one a few minutes later, John effortlessly moves to the next lane, thinking the Enhanced High-speed Steering Assist option he purchased was worth the extra money.

Since the traffic is moving smoothly, John switches on his Adaptive Cruise Control and Lane Keeping Systems. These allow him to maintain a set speed in lane center while keeping a safe distance behind the car ahead. His Automatic Braking System and Anti-lock Brakes will also give John added protection in the event of sudden stops by the cars ahead. John relaxes, and begins to think about his first meeting of the morning. An alerting signal from the Driver Vigilance Monitor brings John's attention back to his driving task, and he silently reminds himself he is still in control, and must be alert to unforeseen dangers and watch for his exit.

A short time later, John exits the freeway, drives to the industrial park, and maneuvers over the patched-up roads in poor condition from the hard winter. John's car, equipped with an Active Suspension System, provides a comfortable ride and stable platform for his coffee mug. He turns into the company parking lot, finds and moves into an empty slot, where the car automatically slows, and stops inches from the car in front of him. The Automatic Braking System not only protects John on the highway but doubles as a parking aid. He can still remember the old days when parking involved kissing bumpers in parking lots in order to accommodate all the employee cars. Insurance rates are now lower because of the new safety devices and help offset their costs in his new car.
3.1.2 Overview

AVCS-I includes only those advanced vehicle control systems that are vehicle-based, i.e., they are totally self-contained within the vehicle and do not require the existence of any roadway and/or roadside equipment to satisfactorily perform their desired function(s). The principal benefits provided by the majority of the devices or systems envisioned to be included in this category will be significant reductions in the yearly toll of crashes, fatalities, injuries, and economic costs that result. The technology of the AVCS-I devices or systems will, in addition, serve as the basis for control systems envisioned to be included in AVCS-II and AVCS-III. AVCS-II and AVCS-III systems will further improve safety and significantly increase the throughput of our nation's highways (and thereby reduce congestion, especially in urban areas).

There exists significant potential for improvement in traffic safety through application of AVCS technology, initially by means of warning and collision avoidance systems and eventually through various stages of automatic control. In recent years, there have been dramatic advances in the development and application of high technology to motor vehicles and highways, including various vehicle and roadway sensors and servo systems, image processors, computers, and communication systems. Development of these technologies has focused on increasing vehicle performance, driving comfort, and convenience and more recently increasing safety and reducing traffic congestion. The possibility of greatly increased highway safety is clearly evident as one considers technology development trends and the potential for crash avoidance measures provided by these technologies through: (a) reduction of driver exposure to high risk environments, (b) reduction of the incidence of high risk driver behavior, (c) facilitation of earlier driver response to an imminent crash by providing additional seconds of warning and stopping time, and (d) improvement of the overall quickness and quality of driver-vehicle response in a likely crash scenario.

Studies have shown that 50 percent of all rear end and intersection-related collisions and 30 percent of collisions with oncoming traffic could have been avoided had the driver recognized the danger 1/2 second earlier and reacted correctly. Over 90 percent of these crashes could have been avoided had the drivers taken appropriate countermeasures 1 second earlier. The continuing development of innovative electronic, computer, information and communications technology by the engineering and scientific communities has the potential to provide these fractions of seconds to expand the driver's margins for safety in high-risk environments. AVCS-I systems can help drivers better sense impending danger, sense lapses in their judgement or skills, and eventually even compensate for some of their errors.

This is not a novel concept; indeed, it has been commonplace in aircraft design for years. Modern air transports are equipped with a wide array of devices that monitor the condition of the aircraft (e.g., fire detection or hatch closure monitoring systems), the environment in which it is being operated (e.g., weather radar), as well as the way it is being operated (e.g., stall warning indicators). Collectively these devices are intended to either warn pilots of potential dangers, aid them in performing the flying task, or, in some cases, compensate for errors. The program that is outlined herein would lay the groundwork for the introduction of that design philosophy and its associated technologies into the automotive arena.

A sober appraisal of the IVHS issue, however, reveals that significant safety risks may be imposed by systems that are ill-suited to the human operator. In particular, care must be taken to match in-vehicle displays and control systems to human capabilities so that drivers are not overloaded, distracted, or disoriented. Accordingly, while large safety benefits are possible, any national program in IVHS must be configured to also guard against the introduction of new safety hazards.

3.1.3 Identifying the “Safety” Targets of Opportunity

Highway traffic safety problem assessment typically involves the use of accident data systems to characterize relevant accident types in terms of patterns of occurrence, prevalence, and severity. To set priorities and obtain the highest potential payoff, it is necessary to define workable crash problems and
Advanced Vehicle Control Systems

the functional requirements for countermeasures to address them, i.e., maximize potential safety improvement by appropriately applying those advanced technology developments which have the highest probability of payoff. To do this, analyses are needed to develop an understanding of the distributions of crashes, fatalities, and injury levels and the distributions of human, vehicle, and roadway or environmental factors resulting in the crashes.

A systematic approach to the identification of safety countermeasures is to proceed through an iterative three-step program to:

- Assess the prevalence and severity of classes of crashes,
- Identify the characteristics and relative contribution of causal and contributory factors, and
- Identify the functional requirements of countermeasure systems aimed at eliminating or reducing these contributions.

3.1.4 Technologies and Benefits

AVCS–I systems aid the driver through "perceptual enhancements," "warnings," or "control" actions. In performing their safety and mobility functions, all AVCS–I systems depend upon on-board sensors. These sensors provide signals containing information pertinent to the status of important aspects of the driver-vehicle-roadway system.

AVCS–I systems are distinguished herein (see Table 3.1.4) by the manner in which they aid the driver. For example, "perceptual enhancement" refers to systems that aid drivers by providing an enhanced "image" of the driving scene. The driver is expected to interpret the enhanced images and to control the vehicle in a manner that improves both safety and mobility under adverse environmental conditions. "Warnings" differ from "perceptual enhancements" in that warnings provide an interpretation of sensor signals. Warning systems send messages concerning hazards to the driver. Messages such as "no brake lights" or "erratic driver behavior" are examples of warnings to aid drivers in making prudent decisions. "Control enhancement" pertains to AVCS–I systems that alter control actions to supplement those provided by the driver. Control enhancements include antilock and/or automatic braking systems, cruise control, and lane-keeping technologies. These types of systems perform control functions that are difficult or tedious for the driver to do well.

The technologies associated with AVCS–I are in various stages of product development or definition. In Table 3.1.4, an attempt has been made to provide an indication of the development status of each of the technologies identified. The range represents a continuum: (1) no technology applied to a given problem (NA), (2) technology available to support demonstration of a concept (Demo Concept), (3) commercial products available on the aftermarket (Aftermarket), and (4) products integrated into production vehicles as either optional or standard equipment (Optional or Standard).

In those cases where technology is sufficiently developed to allow AVCS–I systems to be implemented in vehicles, the current applications of this technology might be regarded as "technology driven" in the sense that proof of concept studies have demonstrated feasible devices. Nevertheless, means for evaluating the performance of these systems need to be developed in terms of quantifiable performance signatures and measures. The anticipated benefits listed in Table 3.1.4 provide an indication of the types of safety-related performance that would be assessed in analyses and simulations, laboratory research, vehicle experiments, and vehicle-in-use field operational tests conducted to investigate the safety of deploying vehicles equipped with these systems.

3.1.5 Proposed Milestones

Figure 3.1.5 outlines the projected schedule for carrying out the R&D, operational testing, and deployment efforts required to bring AVCS–I products into widespread use by the motor vehicle fleet in the United States.
Advanced Vehicle Control Systems
Table 3.1.4 Overview of AVCS-1 Technologies

<table>
<thead>
<tr>
<th>Function</th>
<th>Technology</th>
<th>Benefit</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. WARNING SYSTEMS</td>
<td></td>
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</tr>
<tr>
<td>Provide Driver with a warning indicating that braking or steering action should be taken to avoid hitting an obstacle</td>
<td>Obstacle Detector (for objects in front of vehicle)</td>
<td>Reduce frequency and/or severity of front-end crashes</td>
<td>Demo Concept - Cars</td>
</tr>
<tr>
<td>Provide driver with a warning if an intended vehicle action (e.g., lane change) will place the vehicle in the path of an adjacent object or vehicle or if an object is in the immediate path of a vehicle while backing up</td>
<td>Near Field Proximity (blind spot) Monitoring System/Backup Warning Indicator</td>
<td>Reduce frequency and/or severity of lane change, and blind spot related crashes, and crashes involving backing into pedestrians and fixed objects</td>
<td>Aftermarket - Heavy Vehicles</td>
</tr>
<tr>
<td>Provide driver with a warning if lapses in driver attention/vigilance are detected</td>
<td>Driver Vigilance Behavior and Status Monitoring System</td>
<td>Reduce frequency and/or severity of crashes involving falling asleep at the wheel, fatigue, drugs, alcohol, etc.</td>
<td>Demo Concept/NA</td>
</tr>
<tr>
<td>Provide driver with a warning if any of his vehicle components/systems are malfunctioning, operating with decreased performance or failed</td>
<td>Vehicle Status/diagnostic System</td>
<td>Reduce frequency and/or severity of crashes and/or breakdowns resulting from vehicle component/system failure</td>
<td>Standard/Optional</td>
</tr>
<tr>
<td>Provide driver with a warning that the vehicle is approaching its rollover threshold so that appropriate action can be taken to prevent rollover</td>
<td>Rollover Threshold Warning</td>
<td>Reduce frequency and/or severity of rollover crashes, particularly for trucks</td>
<td>Demo Concept</td>
</tr>
</tbody>
</table>
Table 3.1.4 Overview of AVCS-I Technologies (con't)

<table>
<thead>
<tr>
<th>Function</th>
<th>Technology</th>
<th>Benefit</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. PERCEPTUAL ENHANCEMENT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Provide driver with an enhanced image of the roadway ahead under adverse visibility conditions at night</td>
<td>Infrared Imaging</td>
<td>Reduce frequency and/or severity of crashes involving a lack of ability to see/detect objects ahead</td>
<td>Demo Concept</td>
</tr>
<tr>
<td>Provide a projection of vehicle information (e.g., speed) on the windshield with a virtual image located in front of vehicle</td>
<td>Head-Up Display</td>
<td>Reduce frequency and/or severity of crashes involving dashboard distraction and driver accommodation</td>
<td>Standard/Optional</td>
</tr>
<tr>
<td>Provide driver with the ability to vary the tint of the windshield and/or mirrors</td>
<td>Variable Window/Mirror Transmittance</td>
<td>Reduce frequency and/or severity of crashes involving reduced visibility and glare</td>
<td>Mirror – Standard/Optional Window – Demo Concept</td>
</tr>
<tr>
<td>Improve visibility without increase in glare</td>
<td>Advanced Technology Headlighting (e.g., polarized, ultra-violet)</td>
<td>Reduce frequency and/or severity of crashes involving reduced visibility and glare</td>
<td>Demo Concept</td>
</tr>
</tbody>
</table>
### Table 3.1.4 Overview of AVCS-I Technologies (con't)

<table>
<thead>
<tr>
<th>Function</th>
<th>Technology</th>
<th>Benefit</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. CONTROL ENHANCEMENT</td>
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<tr>
<td>Provide driver with improved steering control at all speeds</td>
<td>4-Wheel Steering</td>
<td>Reduce frequency and/or severity of crashes involving crash avoidance maneuvers</td>
<td>Semi-Active - Standard</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Active - Optional</td>
</tr>
<tr>
<td>Provide driver with improved vehicle handling/control under harsh and non-level road conditions</td>
<td>Active/Semi-Active Suspensions</td>
<td>Reduce frequency and/or severity of crashes involving loss of vehicle control under poor road conditions</td>
<td>Standard/Optional</td>
</tr>
<tr>
<td>Provide driver with improved steering control at high speeds</td>
<td>Variable Assist Steering</td>
<td>Reduce frequency and/or severity of crashes involving excessive steering response by driver</td>
<td>Optional</td>
</tr>
<tr>
<td>Provide driver with improved vehicle control/stability while braking</td>
<td>Antilock Braking</td>
<td>Reduce frequency and/or severity of crashes involving braking on slippery surfaces or emergency braking</td>
<td>Standard/Optional</td>
</tr>
<tr>
<td>Supplement driver control with capability of automatically maintaining minimum headway while cruise control is operational</td>
<td>Adaptive Cruise Control</td>
<td>Reduce frequency and/or severity of crashes involving failure to disengage cruise control</td>
<td>Demo Concept</td>
</tr>
<tr>
<td>Supplement driver control with capability to automatically apply brakes if there is a potential for collision</td>
<td>Automatic Braking</td>
<td>Reduce frequency and/or severity of crashes involving failure to brake in time</td>
<td>Demo Concept</td>
</tr>
<tr>
<td>Supplement driver control with capability to automatically maintain lane position</td>
<td>Lane Keeping Control System</td>
<td>Reduce frequency and/or severity of crashes involving failure to maintain position in lane</td>
<td>Demo Concept</td>
</tr>
<tr>
<td>------------------------------------------------------</td>
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<td>------</td>
</tr>
<tr>
<td>Development of Safety Evaluation Protocols</td>
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<tr>
<td>Safety Assessment of AVCS-I Systems</td>
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<tr>
<td>Warning Systems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obstacle Detection (Front)</td>
<td>******</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Near Field Proximity/Backup</td>
<td>******</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Driver Status</td>
<td>******</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle Status</td>
<td>******</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perceptual Enhancements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infrared Imaging</td>
<td>******</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head-up Display</td>
<td>******</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable Transmittance (Windows/Mirrors)</td>
<td>******</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polorized/Ultra Violet Headlights</td>
<td>******</td>
<td></td>
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</tr>
</tbody>
</table>

**LEGEND**

- R&D
- OPER. TESTS
- DEPLOY

3-9
Figure 3.1.5: AVCS-I DEVELOPMENT PLAN (Cont.)


Control Systems

4-Wheel Steering

Active/Semi-Active Suspensions

Variable Assist Steering

Antilock Brakes

Adaptive Cruise (Autonomous)

Automatic Braking

Lane Keeping (Autonomous)

LEGEND

R&D

OPER. TESTS

DEPLOY
Advanced Vehicle Control Systems

AVCS-I system development will be characterized by a number of distinct, but interrelated initiatives. The following points further explain the anticipated process and the assumptions on which the milestones or schedule are based:

- The term "operational test," as used here, means that the device or system has reached a stage of development that it can be incorporated into vehicles which can be operated in normal traffic conditions by typical drivers. Deployment implies that the product is being marketed with widespread use of the device or systems as the goal.

- All programs such as these are iterative in nature, at least until the final design is fixed for deployment. Thus, there is considerable overlap between R&D and operational testing.

- The deployment, validation, and utilization of evaluation protocols overlays the entire AVCS-I system development effort. This is why R&D is shown as still being necessary even when commercially available devices or systems have already been incorporated into motor vehicles.

- A prioritization process that includes systematic identification of targets of opportunity and feasibility studies of alternative solutions will determine the pace of development of AVCS-I technologies. Based on this prioritization process, specific AVCS-I initiatives may be accelerated, delayed, or even discontinued if they are shown not to be feasible or cost-beneficial.

- The milestone or schedule assumes that IVHS and AVCS are significant national goals, and, thus, that substantial funding will be available to accelerate the normal R&D process.

- The milestone or schedule assumes the existence of a research driver simulator by early 1995 to support R&D on driver performance under baseline and AVCS-I conditions.

- Because the ultimate success of AVCS-I technologies depends on the matching of devices or systems to the capabilities and limitations of the populations of drivers that will use the devices, human factors must be a significant focus of the R&D effort. In addition, ensuring highly reliable designs which fail "soft" is crucial, especially for those systems providing some level of vehicle control.

In addition to the above, a few words of explanation are needed regarding two specific technologies shown in Figure 3.1.5:

- **Autonomous lane keeping.** It would be difficult to develop a practical, vehicle-based lane keeping control system. For this reason, the time frames shown in the milestone chart are quite long. On the other hand, the development of such a system would be greatly simplified by the existence of a supporting roadway-based infrastructure. Thus, the AVCS-I lane-keeping control system should not be viewed as a technology that needs to be developed before analogous AVCS-II and III lateral control systems can be developed.

- **Vehicle status.** Vehicle status systems have been available on motor vehicles for many years. In general, such systems alert the driver to the existence of a malfunction, but do not specifically diagnose the malfunction. Additional diagnostic information is also now available to mechanics who have the equipment needed to interrogate the onboard computer and could easily be provided to drivers. The question is what information do drivers need with regard to the status of their vehicle and how should this information be presented. It is anticipated that future systems will provide vehicle status information which will be specific, fault-diagnostic and prescriptive.

3.1.6 Funding Requirements

Figure 3.1.6 shows that $270 million will be needed to fund the research and development and field operational test programs that will ensure the deployment of AVCS-I technologies. This figure shows the expenditures for the years 1991-1995,
ADVANCED VEHICLE CONTROL SYSTEMS

Figure 3.1.6

AVCS I

<table>
<thead>
<tr>
<th>Timeframe</th>
<th>R &amp; D</th>
<th>Operational Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY 1991-1995</td>
<td>$80</td>
<td>$45</td>
</tr>
<tr>
<td>FY 1996-2000</td>
<td>$60</td>
<td>$50</td>
</tr>
<tr>
<td>FY 2001-2010</td>
<td>$20</td>
<td>$15</td>
</tr>
</tbody>
</table>

Totals: $125 $110 $35

Millions of Dollars

$100
$80
$60
$40
$20
$0

R & D
Operational Tests

1996-2000
2001-2010

Operational Tests

$45 $50 $15

3-12
Advanced Vehicle Control Systems

1996-2000, and 2001-2010. Yearly breakdowns of the expenditures are provided in Section 3.4.

3.2 AVCS—II: COOPERATIVE DRIVER-VEHICLE-HIGHWAY SYSTEMS

3.2.1 Scenario

The information and warning systems first introduced during the 1990's have become standard features on all new automobiles and trucks. Coupled with retrofits to older vehicles, over 75 percent of drivers can now benefit from the use of driver vigilance, behavior, and status monitoring systems. Sophisticated vehicle diagnostic units and journey data recorders have become the rule rather than the exception, and the widespread use of speed and distance sensing units has had a dramatic effect in reducing accidents.

The deployment of these systems since their initial introduction in the 1990's has undoubtedly had a major impact on traffic safety and driving comfort. More recently, however, further advanced technologies have been added which have begun to revolutionize society's whole perception of automobile travel. In particular, newly implemented systems have brought about significant and much-appreciated reductions in traffic congestion.

As Claire Parker departs from her home to make her way to the office, she remembers back to the time before these new systems had been introduced. Only a year ago, her 20-mile trip to work could take up to 2 hours at the height of the rush hour. The stresses of stop-and-go traffic, uncertainties over delays, and fears of an accident used to make Claire dread her trip to and from work every day. Since the new automated lanes opened on her route to work, however, she looks forward to an easy, predictable trip.

The recently implemented automated lanes are an outgrowth of High Occupancy Vehicle (HOV) lanes which were widely used throughout the 1980's and 1990's. They combine this exclusive right-of-way concept with the use of cooperative vehicle or roadway electronics for a new standard of transportation service.

More precisely, what the new system does is facilitate the grouping of cars into small linear strings, called platoons, which travel at a controlled speed of up to 65 mph. The system automatically takes into account adverse weather conditions and adjusts platoon speed accordingly. Each platoon can consist of up to 12 cars and each car in the platoon is electronically and precisely controlled to travel at a close distance from the car ahead of it. The result is a greatly increased highway capacity, with an automatically controlled travel speed and greatly reduced driving stress.

Claire approaches the facility as she would a normal freeway entrance. However, at the entrance ramp she pauses long enough to push an authorization button in her car. This button transmits information necessary to allow her to enter this restricted access roadway. The information transmitted includes the fact that she has a functioning in-vehicle unit installed on her car. It also includes basic status information on her car such as whether there is a sufficient level of fuel onboard and how long it's been since the car was last inspected. The response to her transmittal is almost immediate and Claire accelerates onto the right hand lane.

Once Claire's car reaches a speed of 55 mph, the new system assumes speed control and holds it at that speed. Claire immediately notices that platoons of cars in the left-hand lane are passing her. With their speed controlled to 65 mph, their passing speed is a comfortable 10 mph. The next passing platoon contains only six cars, meaning it has room for her car to join the string. As the last car in the platoon passes her, a signal light on her dashboard turns green, indicating that it is safe for her to merge into the left-hand lane and join the platoon. Claire turns into that lane and experiences the headway sensitive speed control system automatically accelerating her car to catch up to the remainder of the platoon. This is achieved in seconds. She then pushes a second button which activates her automatic steering system and Claire is able to take her hands off the steering wheel completely.

With Claire, and other drivers in the surrounding vehicles, now relaxed after the removal of the driving task, the platoon continues to make rapid, uninterrupted progress. Claire can relax because
fault tolerance built into the system assures her that even if her system malfunctions, she will be safely exited from the platoon.

Since the roadway will soon be electrified so that electric cars can pick up power as they travel, Claire and her fiance, Bob, have already been thinking about having one of their cars be an electric one after they are married. This will give their electric car as much range as they need to go anywhere in their metropolitan area. And the tax incentives to encourage clean air make it less costly to own than her gasoline-powered car.

To Claire, and others like her, the most obvious and important benefits of the AVCS-II technology are reduced congestion and improved convenience. These considerable benefits have already drawn in substantial numbers of private users. Many new vehicles are being fitted with the required onboard equipment as standard equipment and highway agencies are expanding the very low cost infrastructure to interurban routes.

3.2.2 Overview

AVCS-II requires both vehicle and highway-based equipment and utilizes the vehicle-to-vehicle and roadway-to-vehicle communications systems developed in ATMS and/or ADIS. AVCS-II begins implementation of a driver-vehicle-highway "system" whereby vehicle lateral and longitudinal position is controlled when the suitably-equipped vehicles are operated on dedicated instrumented lanes. Vehicles would enter and exit such lanes voluntarily and under manual control, but be under full or partial system control while in the lanes. It offers enhanced trip speed on designated instrumented lanes in congested corridors for specially-equipped vehicles. Conventional vehicles would not be permitted on the designated AVCS-II lanes. AVCS benefits will include increased travel speed and enhanced safety through bottleneck locations at a modest cost compared to gaining the same benefits by increasing the number of parallel lanes. AVCS-II is the logical stepping stone from the in-vehicle control systems of AVCS-I to the expanded control anticipated in AVCS-III.

Platooning is the principal focus of current AVCS-II system development. In platooning, vehicles are electronically linked into "platoons" on one lane of a freeway. A car-to-car headway control system that can accurately and reliably maintain car spacing is the key element necessary for successful platooning. In addition, accurate vehicle speed control, platoon-to-platoon control, and automatic entrance diagnostics (at the interface between regular highways and designated instrumented lanes) are also needed. Each platoon would consist of a cadre of closely spaced vehicles. Optimal platoon parameters (e.g., travel speed, platoon size, headway distance, distance between platoons, types of vehicles permitted, degree of segregation of vehicle types) will be determined as part of platooning research and development.

This R&D will consider both technological and human factors relating to safety, efficiency, and economy. Platooning technology development choices are vitally dependent upon improved understanding of driver capabilities when in an "electronic assistance" mode. The role of the driver will be fundamentally changed. Extensive studies will be required to ascertain how drivers, with their wide variations in capability and performance, will adapt to an "electronic assistance" mode. For example, can drivers with some additional sensor input, reliably merge into platoons, or must this function be fully automated? Can drivers learn to accept automated headway control at less than a car length spacing? Can they adapt to partial control situations (e.g., a merge or demerge situation where longitudinal control is automated but lateral control is manual)?

As noted in Section 2.2.2, failure mode human factors is an important AVCS-II research concern. A critical AVCS-II R&D question is how drivers will respond to full or partial failure of the AVCS-II system. Other AVCS-II human factors issues include driver education or training requirements and public acceptance of the relinquishing of manual driver control of vehicles while operating on AVCS-II facilities. Work underway will allow the basic principles of platooning to be demonstrated in the next 2 years.

An additional need, particularly in large urban areas, is to significantly reduce pollution from today's levels in the face of dire forecasts of increas-
Advanced Vehicle Control Systems

ing traffic and much heavier congestion. Roadway electrification and the use of roadway powered electric vehicles is a promising approach which is closely tied to AVCS developments. Roadway electrification technology offers the advantages of electric propulsion while eliminating the range disadvantage. In a roadway powered electric vehicle system, power cables are buried beneath the roadway surface and passing vehicles are able to draw off power via an inductive pickup. This permits vehicles to recharge batteries while standing or moving on such a roadway.

Other AVCS—II system development initiatives include safety enhancing AVCS lanes (that vehicles can be "locked" into but with driver override), high-speed roadways or lanes, intelligent cruise control (involving instrumented highways), and improved safety equipment as a result of vehicle-to-vehicle and vehicle-roadside communications.

AVCS will require a greater R&D investment than AVCS—I. This is due to the communications and control functions (e.g., longitudinal and lateral control) that are required. These functions have stringent requirements in terms of reliability, safety, and related product liability concerns. The development, testing, and final selection of sensor and reference systems will be critical technology issues.

3.2.3 Targets of Opportunity

The first operating platooning facility will most likely consist of 20-25 miles of a two-lane freeway with a barrier separation from the remainder of the freeway lanes. The initial system could possibly be integrated into an existing High Occupancy Vehicle (HOV) facility to minimize costs. A realistic operation would involve 5,000 – 10,000 vehicles and drivers. Assuming adequate funding, detail design could be initiated in the mid-1990’s with system operations beginning in the last few years of the century.

A short demonstration segment of electrified roadway has begun operations. This segment is being used to test a single bus operating at low speeds. Future demonstration work will include the addition of a variety of new vehicles, higher speeds, related off-roadway operations, and different fleet duty cycles over the next several years.

An initial deployment of a limited fleet of possibly 500 personal vehicles, some fleet van services and small van transit service, should be possible by 1995. This deployment will cover a restricted area, including some 10 or 20 miles of powered roadway. Such a system could easily be expanded to gradually cover a wider range, accommodating an ever growing fleet of private owners and both public and private services. A major breakthrough in range capability, and, therefore, attractiveness to the consumer, will occur with the first freeway deployment. This deployment step will be especially attractive when combined with the dedicated instrumented platoon lanes. Within the first decade of the next century, it is possible to foresee this combination becoming a major force in attacking congestion or pollution simultaneously.

Therefore, the principal beneficiaries will be users of these dedicated lanes located in high-volume major commuter corridors. There will be associated environmental, economic, and land use benefits through the alleviation of corridor capacity pressure. Since the benefits will be greatest for multi-passenger vehicles (i.e., in person-hours saved), AVCS—II will provide significant incentives for transit operators, their passengers, commuters in vanpools, and other potential HOV facility users. Heavy commercial vehicles represent another potential user group, although safety concerns related to heavy truck use of AVCS—II facilities, together with smaller vehicles, will need to be addressed. Specific AVCS—II targets of opportunity include:

- States and localities planning new HOV facilities on new multi-lane freeways.
- States and localities considering adding HOV lanes to existing facilities.
- New state toll road authorities or private toll road developers.
- Developers of major new bridges or tunnels, where reduction in cross sectional areas could produce major cost savings.
Advanced Vehicle Control Systems

3.2.4 Technologies and Benefits

Specific AVCS-II technological elements include the following:

- Automatic lateral control
- Automatic longitudinal control
- Vehicle-to-vehicle communications (e.g., for merge or demerge)
- System integration of AVCS-II technologies (e.g., platooning systems)
- Intersection hazard warning
- Electric propulsion

The first three of the preceding elements are component technologies that, when combined, enable the development of a true driver-vehicle-highway platoon system. Platooning offers the primary benefit of a several-fold increase in lane capacity and the secondary benefit of enhanced safety.

AVCS-II intersection hazard warning systems will entail vehicle-to-vehicle communication of intended travel path. Such devices would extend beyond the obstacle detectors developed under AVCS-I to detection or warning of a potential collision based on each vehicle’s intended travel path. Intersection safety will be the primary benefit.

Electric propulsion enhances longitudinal control performance, which will probably enable shorter headways and, therefore, higher capacity. Electric propulsion has environmental benefits over gasoline propulsion that will make it easier to get approval for deployment in sensitive areas.

The following principal technological AVCS-II research and development issues will be addressed:

- Low-cost high-performance sensing of distance, velocity, acceleration, torque, rotation, etc.
- Low-cost high-performance computation
- Image processing and pattern recognition
- Reliability, safety, or fault tolerance
- Low-cost high-performance communication (vehicle-to-vehicle and highway-vehicle)
- Nonlinear and adaptive control
- Electric propulsion

One specific R&D need associated with AVCS-II is for AVCS roadway test facilities. Test facilities representing a range of conditions (speeds, curves, grades, weather) are needed. The eventual allocation of funds between R&D and operational tests will depend upon the extent to which test and evaluation work is carried out on such a facility (R&D) versus in the real world on actual highways (operational test). Following test and evaluation utilizing test facilities and other evaluation protocols, AVCS-II systems will be subjected to operational test applications on specially designated and instrumented freeway lanes.

Most AVCS-II technologies are in the early phases of system development, although the first demonstrations of roadway electrification and platooning will occur in the early 1990's. For example, experiments with longitudinal control are being conducted in the San Diego area on I-15 reversible HOV lanes (when these lanes are closed to the public) during 1990.

3.2.5 Proposed Milestones

Figure 3.2.5 outlines the projected schedule for carrying out the research, development, and operational test efforts required to bring the AVCS-II systems into widespread applications on urban and intercity freeways.

This milestone or schedule chart assumes that IVHS and AVCS are significant national goals and, thus, substantial funding will be available to accelerate the normal R&D process. In addition, it assumes that a roadway test facility is available by 1993-1994 to permit test and evaluation of AVCS-II applications before initiation of field operational tests.
Figure 3.2.5: AVCS-II Development Plan

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LEGEND

- ----- R&D
- ***** OPER. TESTS
- ------ DEPLOY
Advanced Vehicle Control Systems
3.2.6 Funding Requirements

Figure 3.2.6 shows that $815 million will be needed to fund the research, development, and operational test programs that will ensure the deployment of AVCS-II technologies. This figure shows the expenditures for the years 1991-1995, 1996-2000, and 2001-2010. Yearly breakdowns of the expenditures are provided in Section 3.4.

3.3 AVCS-III: AUTOMATED VEHICLE-HIGHWAY SYSTEMS

3.3.1 Scenario

For commuters living in the suburbs, the morning drive is now a realization of the many benefits of a state-of-the-art transportation system, not a mind numbing lesson in confusion and frustration. From the moment Norm turns the ignition key, he is aware of the advances in the transportation system. He pushes the "office" button on his destination selection console to indicate that he wants to head towards his office and the computer starts working out the fastest route to get there in this morning's traffic. The car completes its systems maintenance check and the journey begins with Norm driving towards the nearest freeway on-ramp. Norm controls the steering, but receives assistance from the "situation awareness" electronics equipment in the car which warns him of hazards ahead and to the side. Having avoided the neighborhood fender bender, he leaves his subdivision and pulls onto a major street.

The dramatic improvements in freeway capacity and efficiency have eased the bottleneck that used to occur just a few blocks away from his home in the suburbs. Cars from the residential subdivision can move along the surrounding streets and toward the freeway on-ramps with greater ease now that freeway congestion has been drastically reduced. The driver information and warning systems do not indicate any problems this morning, so Norm knows he can proceed directly to the nearest freeway ramp.

At the freeway entrance ramp, Norm responds to the electronic signal and pushes the button on his dashboard that initiates automatic control of his vehicle and directs his car to the off-ramp closest to his office. He can now take his hands off the wheel and his feet away from the pedals, since these no longer affect the movement of his car. He notices a brief slowdown of the car as the roadside diagnosis unit interrogates his car's diagnostics to ensure that the necessary on-board equipment is operational and that the vehicle condition is satisfactory to complete the trip. It was a good thing he had remembered to refill his tank last night so that he didn't have to repeat his experience of last week, when his car was directed into the reject lane and back to the local street because it didn't have enough fuel to complete the trip.

Once past the brief diagnosis period, the car accelerates smoothly and merges directly into a platoon of fast-moving cars. It's such a relief, not having to worry through the tricky merge maneuver the way he used to in the old days, when he never knew where he would be able to find a space in the heavy traffic stream and was always worried about getting rear-ended or sideswiped.

Norm pulls out his newspaper and catches up with the latest developments in the world, until he remembers the memo he forgot to write last night in preparation for his morning meeting. He calmly retrieves his laptop computer from the back seat and types out the memo. When he finishes, he notices that he is not on Highway 580, where he normally travels, but is on 880 instead. His curiosity aroused, he turns on his map display unit and discovers that there is a resurfacing project underway on 580, which has taken a lane out of service, reducing its capacity. The central routing computer enabled him to avoid this by rerouting his trip onto the alternate route. Even though this would be a couple of miles longer, it would save some time this morning.

With the integration of electronic signposts, highway signs, and road markers, the cars in the platoon stay together for much of the journey to the city, with the faster moving platoons in the left lane and the slower platoons in the right lane. As Norm's car approaches its exit, the trip computer beeps to warn him that it is preparing to exit the freeway. Although Norm's car will remain in the fully automated mode until he has safely reached the exit.
**ADVANCED VEHICLE CONTROL SYSTEMS**

**Figure 3.2.6**

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<th>Operational Tests</th>
<th>Totals</th>
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<tr>
<td>FY 2001-2010</td>
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<td>$70</td>
<td>$80</td>
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</tbody>
</table>

**Operational Test**

- FY 1991-1995: $30
- FY 2001-2010: $70

**Totals**

- FY 1996-2000: $480
- FY 2001-2010: $80
ramp, he is alerted prior to the exit so that he is prepared to resume control of the car. The detection of the road markers and the electronic signs prevent the car from running the signal at the bottom of the off-ramp. Norm punches in the right numerical code to assure the computer that he is awake and alert and ready to resume control of the car (just like one of those old sobriety check devices his boss had once told him about).

The traffic signals at the intersections near the freeway exits are integrated into the new transportation system to manage the flow of cars that have exited the freeways. The traffic signal integration system allows Norm and his fellow commuters to move away from the freeway and into the commercial and business district of the city with much greater ease and much less of the stop-and-go traffic patterns that were present before the new traffic signal system.

Although more commuters like Norm have chosen to drive to work, the traffic management capabilities of the advanced traffic network integrated with AVCS have kept the morning and afternoon commuting times to a minimum. Rush-hour commuters are not the only ones that have benefitted from the changes that have taken place. Sports and concert fans, along with theater patrons, and shopping center customers cherish the simplicity with which they drive to the stadium, theater, and mall. The horrendous traffic jams that used to occur with regularity have given way to a much more orderly exit from these places.

As cars leave the parking areas in the semiautomatic mode, they enter automatic merging lanes leading to the adjacent freeways. In the merging lanes, small groups of cars form platoons and accelerate and merge into the traffic flow as space permits. The newly formed platoons travel down major inner-city expressways, allowing the traffic to exit the parking areas with greater efficiency and speed than many had imagined. The parking lot that used to take a half hour to empty after the basketball game is now deserted within 10 minutes.

Elsewhere on the West side of town, the roadway electrification program has proven its usefulness with the postal service and the public transit authorities. For vehicles such as buses and trucks running along fairly consistent routes, the electricity available through the supplemental power supply in the streets has allowed the use of electric vehicles to be integrated into the city's transportation network. Electric vehicles, operating primarily on batteries, extend their range using these recharging facilities in the downtown area. The electric roadway program has helped the city keep its commercial vehicle pollution under control while providing a major reduction in the noise level in many downtown areas.

Commuters to and from nearby cities continue to enjoy the benefits brought about by the modernization of existing highways. With the complete integration of the automated vehicles and the advanced highways, businessmen and workers travel between cities in much less time than required just 20 years ago. Instead of travelling at average speeds of 30 - 40 mph, cars operating in the fully automatic mode now travel at the 75 mph speed limit for the entire trip. Tourists visiting Washington, D.C., can now routinely visit nearby cities like Baltimore and Annapolis as the difficulty of traveling on unfamiliar roads has been eliminated and the speed of automobile travel between these urban areas has increased.

This year, John's parents took their annual vacation to Florida as an overnight drive in their camper. After filling up their reserve tank with gasoline, they drove onto I-95 after dinner, punched in the exit number closest to their motel in Daytona Beach, then retired to the back of the camper, watched the evening news, and went to bed (just as the long distance truck drivers do it these days!). When they got up in the morning and saw how beautiful the sunrise was in Jacksonville, they decided to stop for a walk along the beach. They punched the "next exit" button on the trip computer and in the space of 2 minutes were out on the local streets, driving themselves to the beach. It was so nice to have the camper, with all of its comforts, and the freedom to go where they wanted to go, when they wanted to go. Just a few years before, they had despaired of being able to make a trip like this because neither one of them had the stamina or driving skill to drive such a long-distance, high-speed trip. Modern technology has its advantages after all!
Advanced Vehicle Control Systems

3.3.2 Overview

AVCS-III includes complete automation of the driving function for vehicles operating on specially equipped freeway facilities. It builds on the developments in AVCS-I and II, incorporating elements in both the vehicles and the roadway, to provide “automatic chauffeuring” of vehicles from arrival at the freeway on-ramp to departure from the freeway off-ramp. It does not, however, go so far as to automate the trip all the way from the driver’s origin to destination, because that introduces significantly greater complications.

Implementation of AVCS-III will require significant additions to the technologies developed for AVCS-I and II. In addition to the basic lateral and longitudinal control functions, it will also require automation of lane changing and merging into and out of the traffic stream, as well as safe means for effecting the transitions between manual and automatic control, including checking the condition of both the driver and the vehicle. More significantly, it will require the development of the communications and data processing networks and algorithms to effect automatic routing and scheduling of vehicle trips from first freeway entrance to last freeway exit and the integration of the automated system with the pre-existing manual system of traffic management and control on local streets and arterials.

AVCS-III significantly expands the safety and productivity benefits gained from AVCS-I and II, and adds further benefits of convenience for drivers (enabling them to read or write, for example, while on the automated portion of a trip so that this time can be used productively). AVCS-III eliminates driver error as an accident cause for all trips on the automated facility, offering the potential for a significant safety benefit, and it also greatly reduces the delay-producing potential for any accidents or breakdowns that do occur by avoiding the “rubber-necking” of drivers slowing down to take a closer look. The vehicle condition checking that will be necessary upon entering the facility should also significantly reduce the incidence of mechanical breakdowns of poorly maintained vehicles on the freeways. The greatest benefit is likely to come from the dramatic increase in freeway capacity that AVCS-III makes possible, and from the resulting elimination of freeway congestion. AVCS-III should enable the vehicle to travel at full speed for virtually the entire freeway trip, regardless of the time of day, at the price of a small delay upon entrance to the system to enable the trip to be scheduled through the network. This should help reduce some of the pollution and energy waste that are presently attributable to urban traffic congestion. The routing and scheduling function of AVCS-III helps to ensure the most efficient distribution of vehicles throughout the network so that network capacity is fully utilized and incidents can be accommodated with minimum disruption to traffic. The coordination of the automated freeway operation with the local traffic management system ensures that the increased volume of freeway traffic remains compatible with the local streets and arterials, avoiding bottlenecks at the system entrances and exits.

3.3.3 Targets of Opportunity

The incremental benefits of AVCS-III technology over the two earlier stages of AVCS will be significant to all users of the road transportation system, in both urban and rural areas. Productivity, safety, and convenience enhancements are widely applicable, extending to both urban and rural highway users, including private, commercial, and transit vehicle operators. Commercial and transit vehicle operators, for whom high hourly operating costs make reductions in trip times particularly valuable, should see very high benefits from AVCS-III in congested urban areas. Similarly, private automobile drivers who waste much potential leisure time in traffic jams, would welcome the recapture of that time for more pleasurable uses. For intercity (rural) travel, the convenience of “driverless” operation could produce great economies for trucking operations and could make vacation travel more pleasant for private individuals and families. It could even ultimately enable the vacation traveler or long-distance trucker to sleep through an overnight journey of hundreds of miles, arriving refreshed the next day ready for a full day of activity.

These beneficiaries of AVCS-III help to categorize the targets of opportunity for development of the earliest systems. It seems that these would clearly be aimed at the most congested urban areas and at
the intercity corridors with the heaviest commercial trucking traffic. It would also be easiest to phase in implementation of AVCS—III technologies in locations that are already planning new road construction and/or that have the space to construct new roads, because it is likely to be politically difficult to remove an existing facility from public use to equip it with the new technologies and then reserve it only for use by the suitably-equipped vehicles.

3.3.4 Technologies and Benefits

In AVCS—III, the benefits are generally enjoyed when all the technologies are applied together, to create a complete system. It is not really meaningful to assign separate benefits to the different constituent technologies, because all of the technologies are needed in order to create an automated freeway and the benefits are derived from the complete “package” of technologies in the system. The elements that must be included in an AVCS—III system include:

- Drive by wire
- Steer by wire
- Automatic on-board diagnostics (which must be interrogated and found to be acceptable before entry to AVCS—III facilities would be allowed)
- Automatic obstacle detection
- Automatic lateral control
- Automatic longitudinal control
- Vehicle-vehicle and vehicle-wayside communication for control
- Human interfaces for transitions to and from control
- Integration of automated roadway with arterials and local streets
- Automatic traffic merging control
- Automatic lane-changing control
- Automatic trip routing and scheduling
- Automatic obstacle detection and avoidance
- Reliability and safety enhancement features for all functions (real-time condition monitoring, fault detection, separate degraded performance and emergency operating modes, etc.).

It would also be very beneficial to have vehicles equipped with electric powertrains in order to provide AVCS—III functions, both for technical and environmental reasons.

In order to provide the above AVCS—III functions, it will be necessary to proceed through an orderly sequence leading from basic research to design, prototype development and testing, refinements, field operational testing, and deployment. The basic research foundation upon which the rest of the program must be built, should incorporate the following elements:

- Low-cost, high-performance sensing of: distance, velocity, acceleration, torque, rotations etc.
- Low-cost, high-performance computation
- Image processing and pattern recognition
- Reliability, safety, or fault tolerance
- Low-cost, high-performance communication (vehicle-vehicle and vehicle-ground)
- Traffic engineering (traffic flow and control)
- Network modeling
- Optimal network routing and scheduling (algorithms)
- Nonlinear and adaptive control
- Electric propulsion (especially batteries)
- Man and machine interfaces.

The design and development stage will include component, subsystem, and system level design work to meet the requirements of each of the driving functions, based on the research outlined immediately above. This stage will also require extensive system engineering activity, both at the level of the individual driving functions and at the higher level of the complete integrated transportation system. Substantial test facilities will need to be developed so that all of the technologies can be tested thoroughly before they are first exposed to public scrutiny in field operational tests.

The only element of the AVCS—III technology that is commercially available today is drive by wire, which is available only on the top-of-the-line BMW model. Many of the technologies are in the basic research stage, with some progressing into the design and development stage as well. This means that some years of research and development activity will be needed on AVCS—III before operational tests would be considered.
Advanced Vehicle Control Systems

3.3.5 Proposed Milestones

Figure 3.3.5 outlines the projected schedule for carrying out the research, development, and operational test efforts required to bring the AVCS-III systems into widespread application on urban and intercity freeways.

This milestone or schedule assumes that IVHS and AVCS are significant national goals and, thus, substantial funding will be available to accelerate the normal R&D process. In addition, it assumes that a roadway test facility is available by 1993-1994 to permit test and evaluation of AVCS-III applications before initiation of field operational tests.

3.3.6 Funding Requirements

Figure 3.3.6 shows that $1,390 million will be needed to fund the research, development, and operational test programs that will ensure the deployment of AVCS-III technologies. This figure shows the expenditures for the years 1991-1995, 1996-2000, and 2001-2010. Yearly breakdowns of the expenditures are provided in Section 3.4.

3.4 TOTAL AVCS FUNDING SUMMARY

AVCS is the most complicated and longest-range of the IVHS technologies. As such, it needs the largest investment over the longest period of time to reach fruition. The attached figures (Figure 3.4.1 and 3.4.2) and table (Table 3.4.1) show basic estimates of the type of funding needed for the research and development and field operational testing of the three stages of AVCS over the next 20 years. The estimates do not include deployment costs, which are expected to be considerable, but which are indeterminate at this time. The funding estimate for R&D and operational tests includes both public and private investments, with the division between the two being left undefined at this time pending future policy decisions. Note that the funding for operational testing exceeds the R&D funding for AVCS-II and AVCS-III, simply because of the scale of the operational tests needed to show what the technologies can do. The funding for operational testing lags R&D by several years in each case because it is unwise to advance into operational testing before the technology has been thoroughly shaken out in the laboratory and on the test track.

The resources for AVCS-I total $270 million, for AVCS-II $815 million, and for AVCS-III $1,390 million, reflecting the increasing complexity of the higher levels of functionality. In addition, it is estimated that an additional $250 to $500 million will be required to construct and operate the needed specialized facilities (e.g., research driving simulator and roadway test facility) to support AVCS development and evaluation. The annual funding peaks at $270 million in the year 2000 in this plan. Although this may seem like a great deal of funding, it is negligible compared to military weapons development programs and is even low compared to what DOT spent on the supersonic transport project 2 decades ago (where expenditures topped $300 million in the peak year, a figure which has not been escalated to current-year dollars).

4.0 IMPLEMENTATION ISSUES

4.1 ORGANIZATIONAL STRUCTURE

4.1.1 Institutional Arrangement

It is of utmost importance that an organization be designated and put in place to steer the development and implementation of Advanced Vehicle Control Systems (AVCS). Ideally, such an organization would be composed of representatives from industry; universities; and state, local, and Federal Government.

A need for an organization overseeing the development of an Intelligent Vehicle Highway System (IVHS) was recognized by Mobility 2000 in April 1989. A special task force was established to determine the optimum organization model that would fulfill this need. The task force recommended that the U.S. Department of Transportation, Office of the Secretary of Transportation (OST), provide the leadership in organizing a national IVHS effort. The organization would be implemented as follows:
### Figure 3.3.5: AVCS-III Development Plan

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#### LEGEND
- R&D
- OPER. TESTS
- DEPLOY

3-28
ADVANCED VEHICLE CONTROL SYSTEMS

**AVCS III**

Figure 3.3.6

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Totals: $80 $500 $810

Millions of Dollars
ADVANCED VEHICLE CONTROL SYSTEMS

Figure 3.4.1

TOTAL PROGRAM SUMMARY

- R & D
- Operational Tests

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Millions of Dollars
Figure 3.4.2
ADVANCED VEHICLE CONTROL SYSTEMS: 1990-2010
($MILLIONS - Public and Private)
Table 3.4
ADVANCED VEHICLE CONTROL SYSTEMS
($Millions - Public and Private)

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Advanced Vehicle Control Systems

• The Secretary would form a joint high level IVHS Council to include major interests of government, industry, and academia, in charge of establishing:
  - Basic program goals
  - Priorities and program categorical allocations
  - Accelerated implementation and applications projects
  - Standards and protocols
  - Increased public information
  - Recommendations for incremental stages of development
  - Legislative initiatives
  - Policy
  - International cooperation
  - Industry cooperation and support
  - Identity of legal concerns
  - Involvement of major vehicular fleets
  - Professional staff development

• The Secretary would direct the modal Administrators (FHWA, NHTSA, UMTA), with FHWA as chair, to be an IVHS advisory committee to the Secretary and to:
  - Carry out programs specific to their modal responsibilities
  - Review and advise the Secretary on the IVHS Council recommendations
  - Provide budget oversight
  - Advise on needed legislation and interagency cooperation
  - Define IVHS administrative and technical elements within their respective organizations
  - Appoint a secretary to the IVHS Council

• The modal Administrators would carry on program administration using existing contract authority and through special arrangements for large scale demonstration projects.

• Also, the Administrators may elect to appoint project level technical committees.

4.1.2 Technology Transfer Protocol

Work on AVCS research will be going on in numerous public and private sector laboratories. The technology transfer protocol must be worked out and agreed to in advance of the start of any national effort. The protocol must protect private sector proprietary technology, but at the same time allow all participants to learn from the work of the participants and reduce the tendency for each research group "to reinvent the wheel." Patent rights will have to be worked out for these technology development partnerships. The technology transfer arrangements should also include sharing of monitored foreign work on IVHS.

4.1.3 International Collaboration

The deployment of the best technology within the shortest time frames is a goal that makes sense against the backdrop of the pressing safety, congestion, and environmental issues facing many of the world's urban areas. International collaboration on transportation technology development is essential. However, can international competitiveness be preserved for each of the competitors? The answer is yes, if the collaboration is properly structured. Negotiations between the European, Japanese, and American groups could produce mutually beneficial results. Areas of joint effort could be:

- Development of control models
- Human factors research
- Computer simulation of alternative control schemes
- Compatible communications systems
- Electronic based system certification
- Development of test facilities
- Field experiments and test protocols
- International standards

4.2 Finance

The United States has fallen behind in the development of advanced technology for streets and highways. One of the reasons for this is that traffic safety and congestion problems occurred earlier and are more severe in other areas of the world than in the United States. However, an equally important barrier to progress is the division of interests between the private sector which develops the equipment and the public sector which is responsible for designing and constructing the roads and other elements of the transportation infrastructure. Industry finds it difficult to participate in these
Advanced Vehicle Control Systems

fields, largely because it can not see the opportunity for significant earnings.

U.S. industry has been accused of having too short a time horizon to commit to long range research, or to engage in the development of advanced products which do not have near-term payoffs. There are many reasons for this. Some, such as the relationship between the price of the company's stock and the last quarterly report, are well publicized. Other reasons are more subtle and less well understood by the public and most transportation professionals. The time value of money, for example, would deter prudent investors from committing to product programs with time horizons of more than 10 years, unless the survival of a company or major investment depends on it.

There are few, if any, financial incentives for the private sector to invest in new research on technology and product developments which have long time horizons. The investors would have to be confident of annual sales many times as large as would be justified for more traditional near-term markets. The risks to the investment include the development of new and superior technology, the ending of patent protection and the leakage of knowledge as key staff members change jobs, publish technical papers, or retire.

A related problem may occur when a new company or product has received support (from the government, a corporate sponsor, venture capitalists, or families) through the proof of principle stage and then needs capital to create the production capacity to meet projected market needs. At this point in the development, many start-up companies go to the public market for capital (so called initial public offerings). These stock issues limit their future options (and willingness to take risks) by placing emphasis on the need for quarterly earnings. In the recent environment, this may be complicated by concern over being acquired by unfriendly investors.

As a result, many potentially beneficial products and services are being neglected or lost. Some foreign countries, in particular, Japan, have different financial incentives and as a result it is not uncommon for Japanese investors to purchase start-up U.S. companies at this critical stage in their development. This will lead to a loss of social benefits, reduction in the quality of life and/or the loss of the market to a foreign producer.

The strategies which governments could employ to encourage investments in these developments do not appear to have been thoroughly explored. There is no consensus on what could be done. There has not been any significant recent public or private initiative on these problems.

The study of this important issue should examine candidate strategies in depth. These could include:

- Federal (or State) grants, how they would be awarded, size, recovery philosophies for the government, etc.
- Joint private-public companies, how they would be chartered, source of funds, earning requirements, etc.
- Trust funds, what would be taxed, how the money will be allocated etc.
- Changes in tax regulations to encourage long range investments.
- Modification of antitrust and liability laws and precedents to provide protection for new industries through the time at which initial research and development investments are recovered.

4.3 DEPLOYMENT BARRIERS

No major technological breakthroughs will be needed to achieve the goals of advanced vehicle control. However, major cultural and institutional barriers to the deployment of the technologies need to be removed. These include social, safety, organizational, legal, political, and environmental considerations. They are addressed in the following sections.

4.3.1 Social

Public acceptance of AVCS will be a principal concern. Who will benefit from the technology and how will costs be allocated? Will costs be borne by the general public, or only by direct users of the technology? Will AVCS technology be perceived as a threat to contemporary lifestyles, privacy, or individual autonomy? What will be the education or training requirements for AVCS drivers, and will...
drivers be able and willing to attain the needed new skills? These social issues and concerns must be addressed in the planning and development of the AVCS concept.

4.3.2 Safety

AVCS technology introduces more significant safety issues than the other IVHS technologies because of the addition of control functions to the information exchange functions that predominate in the rest of IVHS. These safety issues represent both increased opportunities for improvement over present conditions and increased risks if systems do not work as intended.

Substantial research and engineering development efforts will need to be devoted to minimizing the probability of failures and then again to minimizing the consequences of those failures that do occur. The trade-offs between system cost and reliability will have to be confronted directly, in a process of dialogue between the technical and political communities. The general public and their elected and appointed officials will have to be satisfied that sufficient attention has been paid to safety before any AVCS technology can be implemented, even for demonstration purposes. This will require convincing experimental results and the publicizing of their significance in ways that can be comprehended by the public.

It is difficult to anticipate human responses to the sensations of utilizing an advanced vehicle highway system, particularly for the more advanced versions in which vehicles may be operating much closer together than they do today and in which the driver has less responsibility for control of the vehicle. Much attention will have to be paid to the public's emotional responses to this form of travel and their perceptions of its safety. Perhaps the experience will first have to be offered to the public in amusement parks, in the form of rides that can be experienced in complete safety, but do not necessarily appear to be as safe as people demand for their daily modes of transportation.

Education of the public about the relative safety of existing transportation systems will be a key element. If the causes of present-day accidents are understood better, it should become possible to appreciate the potential for improvements that AVCS technology offers, while at the same time recognizing that AVCS will not be perfect. Enhanced public awareness about transportation safety is vital so that appropriate public policy measures are taken. The public perception of the relative safety of different modes of travel must be brought as close to reality as possible.

4.3.3 Organizational

Financial and organizational interests which have developed over the years to build highways or provide services may feel threatened by advanced vehicle control concepts. For example, highway builders and their suppliers may, at first, oppose the automation concept since there would be a de-emphasis on new heavy construction. Studies to define the rehabilitation and reconfiguration requirements of AVCS contractors and suppliers will be required. Public transportation providers may oppose AVCS development if it were perceived to provide greater benefits to private automobiles than to public transit. Truckers may oppose such systems aimed at automating traffic flow if they are excluded. The above organizational interests and concerns will need to be addressed pro-actively to ensure that AVCS implementation is not unfairly damaging to any group, but that the development of AVCS concepts is not defeated by special interests to the detriment of the general public.

Internally, transportation agencies that plan, design, and implement highway features will need to change their organizational structures and procedures to accommodate IVHS and AVCS approaches. Automated highway systems will require much higher levels of reliability and predictability than do current highway systems. Vehicle interaction, condition monitoring, diagnostics, failure analysis, and similar analytical approaches will need to be integrated into highway management procedures and strategies. Some highway engineers may initially feel threatened by advanced technology approaches since these will involve mechanical, electrical, and electronic control engineers along with traditional civil, structural, and traffic engineers.
Advanced Vehicle Control Systems

to develop AVC systems. A more diverse mix of professional disciplines will be required to design, implement, and maintain the future vehicle highway systems.

4.3.4 Legal

A serious institutional barrier to development and deployment of IVHS and AVCS technology in the United States is its legal system. Court liability awards are reaching astronomical proportions, and the assessment of damage often bears little relation to responsibility. AVCS will greatly decrease accidents overall, but it is inevitable that some accidents will be caused by the system, whether these accidents are due to device malfunction, faulty system design, or human factors design deficiencies. Ways are needed to limit the liability risk of AVCS developers, both public and private. Possible approaches might involve stronger consideration of overall system benefits, narrower definitions of negligence, limitation of compensatory awards, limitations of punitive damage awards, limitations of joint liability, better training of juries, and elimination of contingent fee systems. Federally-subsidized liability insurance and/or Federal standards systems (where liability shifts to the government if products meet Federal standards) are other potential approaches to reducing liability risk.

Another legal issue of concern is antitrust. Collaboration among AVCS innovators, suppliers, and users will be particularly important. However, certain provisions of current antitrust laws restrain innovation by inhibiting collaboration among competitors. These provisions need to be reexamined in light of the need for collaboration among AVCS developers and between government and the private sector.

4.3.5 Political

Automated systems will require a much higher level of coordination across jurisdictions than do current highway transportation approaches. Regional transportation authorities or other transportation planning or management bodies that transcend jurisdictional boundaries will be needed. Internationally, ways will be needed to facilitate transportation technology trade agreements, international risk-sharing, and technology transfer. However, these arrangements must protect proprietary technology and international competitiveness.

4.3.6 Environmental

The environmental benefits from AVCS technology will result from reduced traffic congestion and the consequent decrease in air pollution. AVCS will also improve vehicle efficiency by automating functions to make driving smoother and more fuel efficient and will limit the "new concrete" approach to accommodating growth. However, the great increases in highway throughput resulting through AVCS technology will require concurrent dramatic advances in clean vehicle propulsion systems. The "more vehicles equal more pollution" obstacle must be overcome.

4.4 INFRASTRUCTURE REQUIREMENTS

The existing network of highways that support and guide the transportation system is often referred to as the infrastructure. AVCS—II and AVCS—III will equip this infrastructure with technology that can permit communication with and physically guide the vehicles on it. The vehicles using the highway must also be fully equipped or "smart." By linking the smart highways to smart vehicles, the infrastructure will evolve and conform to accommodate the latest technology and efficiently provide the best transportation facility possible.

The fully controlled highway may be 20 years into the future, but its deployment will be associated with the following attributes:

• Considerable increase in traffic throughput
• Significant reduction in travel times
• Significant reduction in accident frequency and severity
• Improvement in air quality due to reduced congestion, improved vehicle efficiency, and cleaner propulsion systems
• Improved comfort and convenience of travel

While the cost to adapt the existing infrastructure to AVCS will be significant, it will be less than the cost of accomplishing similar enhancements in throughput by construction of additional capacity. Transition from the present infrastructure system to a fully
Advanced Vehicle Control Systems

An automated system will require several years. It is important to plan and implement those AVCS improvements to the highway facility in concert with the longer-term evolution of the overall advanced transportation technologies. For example, existing freeways can be improved by implementing traffic management systems technologies that include advanced traffic signalization systems, driver information and warning systems, and special control applications such as ramp control systems. Infrastructure requirements for such technology may include the following:

- Maintenance and operation of the system,
- Lane widths and clearances,
- Grade and geometry, and
- Freeway location and traffic volumes.

Equipping the infrastructure for a higher level of automation, means that the following additional requirements be addressed:

- Start-up and diagnostic procedures,
- Communications link between the highway and the vehicle,
- Types of vehicle accepted on the highway,
- Mixture of controlled and non-controlled vehicles,
- Emergency breakdown procedures and facilities,
- Incident management, and
- Information on non-controlled sections.

Future implementation of advanced vehicle highway systems will heavily impact the existing infrastructure. Requirements for proper planning, design, and safety must be incorporated into the project scope for these projects. Critical requirements must be developed for merging automated and conventional systems. Proper and effective handling of the infrastructure is essential to the success of AVCS.

4.5 MARKETING AND PUBLIC RELATIONS

The success of the IVHS program, particularly AVCS, is highly dependent on public understanding and acceptance. Carefully designed strategies are needed to ensure high-quality system development, to gain support from decision makers, and to receive acceptance by users. Critical elements in developing and marketing IVHS and AVCS include:

- Identify key decision makers. This includes upper management at the U.S. Department of Transportation, Office of Management and Budget, members of Congress, user groups, and key state and local transportation officials. Provide comprehensive information describing IVHS and AVCS and its potential.

- Identify key users and user requirements. Identify users likely to attain the greatest benefits from AVCS and quantify those benefits. Analyze cost-benefits. Determine user willingness to pay for AVCS benefits.

- Define system requirements. Analyze current safety and congestion problems to determine the key elements of the needed solution. Specify AVCS functional requirements based on this analysis.

- Assess the available technology. Analyze key applications, underlying technologies, and key R&D issues relating to each.

- Develop an overall system architecture. Implement the AVCS phases and specific initiatives so that all are upwardly compatible with planned future systems.

- Assess organizational and political barriers to AVCS, e.g., special interests in opposition to elements of AVCS, public misgivings regarding “loss of control,” or other AVCS aspects.

- Prioritize efforts. AVCS-I, AVCS-II, and AVCS-III represent three distinct phases of R&D and deployment. Within and between phases, prioritize R&D efforts based on needs and available technology.

- Define roles and responsibilities. Determine the appropriate nature and degree of involvement for various levels of government and private organizations.

- Develop a marketing strategy to promote the benefits to be gained from AVCS. The plan
Advanced Vehicle Control Systems

fosters positive public relations and education regarding AVCS concepts and benefits. Detailed milestones, schedules, and costs are outlined.

- Maintain rigorous controls and evaluation protocols. Establish facilities, procedures, roles, and milestones for evaluating AVCS development throughout the system development cycle.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The specific goals and objectives of AVCS technology deployment are identical to those of the overall IVHS effort — enhanced safety, increased throughput (increased travel speed and improved trip time reliability), reduced environmental impacts and enhanced international competitiveness for U.S. industries. AVCS goes beyond the efficient management of the existing limited system and has the potential to provide quantum improvements in both throughput and safety.

The AVCS program has as its ultimate goal the virtual elimination of traffic crashes and traffic congestion. As a major IVHS element, it has far-reaching long-term potential, although it will take a concerted commitment to research, development, and demonstration to achieve the ultimate benefits. The autonomous in-vehicle systems (AVCS—I) will provide substantial safety enhancements for suitably equipped vehicles as soon as the technologies are commercially available. Beginning with AVCS—I, traffic throughput will increase significantly on those facilities where the infrastructure has been installed. AVCS—II will largely eliminate crashes and congestion where it is utilized. Universal elimination of crashes and congestion will require improved generations of AVCS to be applied to all vehicles, roads and streets.

Additional conclusions:

- Within the next two decades, AVCS technology will not be on every car. The purchase of the onboard equipment will be voluntary and only the most heavily travelled urban and intercity freeways will have the necessary infrastructure to allow "hands-off" driving.

- A significant investment is needed to modify the infrastructure to accommodate the AVC systems envisioned. However, this investment will be small relative to the cost of new lane construction. Moreover, AVCS benefits will justify the needed investment.

- AVCS is initially a driver-vehicle system which evolves into a vehicle-highway system as more control is added. The ultimate success of this evolution hinges upon such major factors as social acceptance, national commitment, and successful system integration and standardization.

- Careful attention to human factors is critical to the success of AVCS technologies. The issues to be addressed are very different in nature during the various stages of system evolution.

- Legal obstacles (e.g., liability risk) are a significant concern for AVCS technologies primarily because of the level of automatic control.

- A major part of the research and development funds must be dedicated to achieving a fault tolerant, reliable system at reasonable costs.

- Efforts need to be devoted to cleaner propulsion systems; otherwise, AVCS technology may never be implemented. The "more vehicles equals more pollution" obstacle must be overcome.

In order to fully realize the potential of AVCS deployment, we recommend the following:

- Create a national organizational structure to oversee and coordinate public-private partnerships for accomplishing research, development, field operational testing, and deployment of AVCS technologies. An integral part of this partnership would include the ability to pool funds.

- Provide sustained funding at levels sufficient to support a comprehensive, multi-faceted AVCS program. AVCS promises dramatic benefits, but research, development, field operational testing, and deployment costs will be significant.
Advanced Vehicle Control Systems

- Obtain legislation to limit the liability risk of those who participate in the development and deployment of AVCS technologies.

- Define the long-term requirements of the ultimate AVCS architecture to the extent possible early so that these requirements can be considered in establishing the standards for the near-term systems.

- Allocate sufficient research and development funding earmarked specifically to address the critical "reliability" and "fault tolerant" requirements that such systems must embrace to be acceptable.

- On a priority basis, develop and validate measurement and analysis tools (such as a driving simulator and a dedicated automatic control test facility) and evaluation protocols for assessing the performance and/or efficacy of AVCS technologies.

- On a priority basis, stimulate the growth of available manpower and expertise in human factors as applied to highway transportation problems.