Koopman

National Automated Highway System Consortium

Workshop # 3

September 18 - 20, 1996
Minneapolis, Minnesota

COMPARISONS OF AUTOMATED HIGHWAY SYSTEMS CONCEPTS

UNIVERSITY OF MINNESOTA
PROFESSIONAL DEVELOPMENT & CONFERENCE SERVICES
CONTINUING EDUCATION AND EXTENSION
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AHS SAFETY ANALYSIS BREAKOUT RESULTS

Session 1-B

19 September 1996

OPEN ISSUES

- Conclusions need to be considered in terms of technology *and* perceptions
  - "closer is safer" is a goal rather than a conclusion
  - public (subjective) perception of AHS rare catastrophic events vs. frequent non-severe events
  - desire for evolutionary gap reduction versus unsafe middle range gap distance
  - carryover of automated driving to non-automated driving behavior

ISSUES TO BE ADDRESSED

- broaden coverage of collision types and incidents
  - e.g., a roadway departure involving one vehicle
  - should use "crash" instead of "collision"
  - complexity versus failure rates
- assess impact of crashes on property damage
- define safety requirements early in the development process to direct AHS concept and design analyses
- lateral dynamics (expand simulations)

ISSUES TO BE ADDRESSED

(continued)

- perception: hard braking at 0.75g too high?
- non-ideal driving conditions, false alarms and missed detections, and explicit modeling of multiple collisions within a platoon
- for the obstacle-avoidance scenario, study platoon lane change behavior and mixing of vehicles with different performance characteristics
- complexities (e.g., simultaneously failures, multiple lanes)

SPECIFIC ACTION ITEMS

- stakeholders provide
  - suggestions regarding expansion of studies
  - possible ways to describe or demonstrate safety benefits during the 1997 Demonstration
  - planning of upcoming safety analyses
  - leads to empirical data regarding braking rates, secondary collisions, etc.

Workshop #3
September 19-20, 1996

Develop The AHS Architecture

Walt Faulconer

Objectives/Approach

- Develop a single architecture that can be adapted to provide various levels of functionality depending on various applications.
- Provide substantial interim deliverables
- Involve core, associates, stakeholders and contractors
- Blend/balance analytical work with consensus building

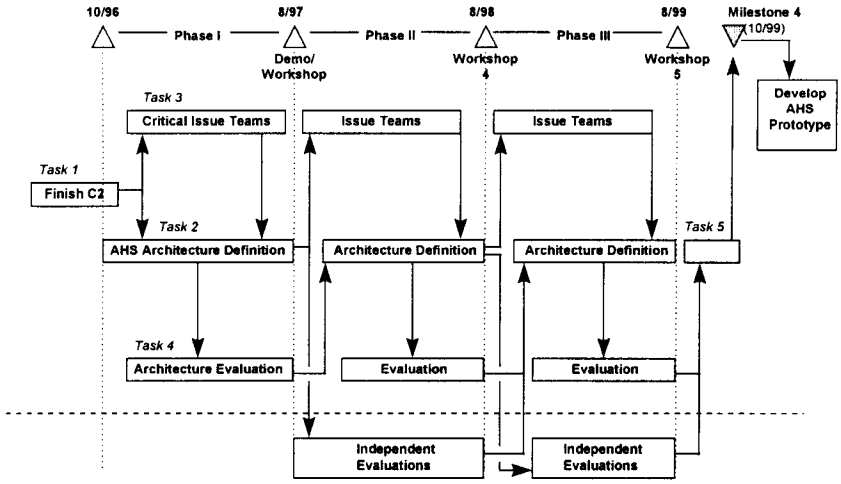
Products

- Real stakeholder needs and requirements
- Single AHS architecture
  - Operations Concept
  - Functional Architecture
  - Physical Architecture
- Requirements document used to guide AHS prototyping
- Incremental Deployment Strategy and Plan
- Viable AHS applications
- Stakeholder consensus on interim and final products

Our Toolbox Grows To Answer Key AHS Questions

	Develop Initial Suite of Concepts	Down-Select System Configurations	Develop AHS Architecture	Develop AHS Prototype
Analysis/Trade Studies	✓	✓	✓	✓
Case Studies		✓	✓	✓
Simulations			✓	✓
Subsystem Build/Test			✓	✓
System Build/Test				✓

Plan



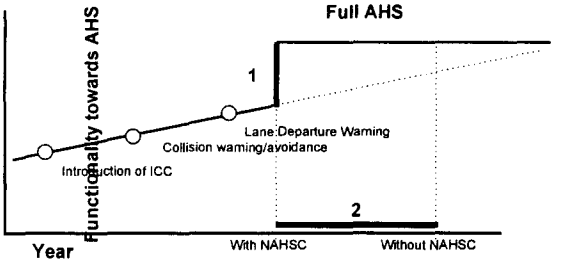
Phase I - AHS Definition Teams

AHS ARCHITECTURE DEFINITION TEAMS
- User Needs Assessment
- Architecture
- Deployment Plan

CRITICAL ISSUES TEAMS
- Driver Role & Acceptance
- Assessment of Dedicated Lanes
- Mixed Traffic Performance
- Obstacle Detection, Avoidance, Exclusion
- Vehicle Separation Policy

ARCHITECTURE EVALUATION TEAMS
- Case Studies
- Cost Evaluation
- System Performance
- Risk Analysis/Feasibility
- Safety
- Stakeholder Consensus

Evolutionary Deployment Objectives



1. What is the nature (investment, overcoming institutional barriers, etc.) that are required to make the jump to 'Full AHS' from the normal evolution of AVCS components?
2. What actions now (with limited resources) have the most ROI/benefit to bring about AHS earlier?

Summary

- Task Starts October 1st
- Major focus of AHS concept development for the Consortium for the next 3 years
- Need participation from everyone to decide what is the best AHS architecture
- Need participation from everyone to help answer/resolve the critical AHS questions, issues, and risks

Phil Koopman

National Automated Highway System Consortium

NAHSC Workshop #3

AGENDA

Thursday, September 19

8:30 **Welcoming Remarks** – Jim Rillings (Tab 1)

8:40 **Introduction** – Steven Shladover (Tab 2)
- workshop purposes and overview
- AHS vision and user services
- roles of stakeholders in concept development process
- summary of stakeholder issues raised in previous meetings

9:05 **Review of Concept Development and Evaluation Work Since Workshop #2** – Carol Jacoby (Tab 3)
- how we got to five concept families at the end of Task C1
- brief descriptions of the five concept families
- explanation of why and how we have moved from five concept families to concentration on key attributes (including Boston forum feedback)
- descriptions of concept-distinguishing attributes
- definitions of measures of effectiveness and relationship to AHS requirements

9:50 **Summary of Current Knowledge from AHS Concept Studies** – Steven Shladover (Tab 4)
- key things we have learned (known or resolved issues)
- key things we still need to learn (unknowns, open issues, problem areas)

10:10 **Break**

10:25 **Summary briefings on concept evaluation results:**

10:25 **Throughput/Travel Time Analyses** – Datta Godbole (Tab 5)

10:50 **AHS Safety Analyses** – Raja Sengupta (Tab 6)

11:10 **AHS Civil InfrastructureCost Assessments** – Ron Hearne (Tab 7)

11:30 **Societal/institutional and Environmental/Energy Evaluations** – Alan Lubliner (Tab 8)

11:50 **Instructions for first round of breakouts** – Steven Shladover (Tab 9)

12:05 **Lunch**

1:15 **First round of breakouts**:

1 - A: Throughput/Travel Time Analyses (Tab 5a)
1 - B: AHS Safety Analyses (Tab 6a)
1 - C: AHS Civil Infrastructure Cost Assessment (Tab 7a)
1 - D: Societal, Institutional, Environmental and Energy Evaluation Results (Tab 8a)

Each will have a comprehensive briefing (45 minutes) plus discussion, with questions defined in advance to stimulate discussion.

3:30 **Break**

3:50 **Plenary – Instructions for second round of breakouts – Concept-Distinguishing Issues** – Steven Shladover (Tab 10)

4:05 **Plenary report on outputs from first round of breakouts** – 4 reports at 15 minutes each

5:05 **General discussion/questions**

5:20 **Adjourn for the day**

6:00 **Reception and Buffet Dinner**

National Automated Highway System Consortium

NAHSC Workshop #3

AGENDA

Friday, September 20

7:30 **Continental breakfast**

8:00 **Convene second round of breakout sessions on concept-distinguishing issues**
2 - A: Operations and Technology Issues for Mixed Traffic Operations (Tab 11)
2 - B: AHS Infrastructure Configuration and Implementation Issues (Tab 12)
2 - C: Human Factors Issues for Partially and Fully Automated Systems (Tab 13)
2 - D: AHS Standardization and Options - what AHS features must be standardized nationally, and what can be variable to suit local preferences and needs? (Tab 14)
Each session will have a 20-minute introductory briefing to identify what we have learned about these issues, then a set of questions to address with participants.

10:00 **Break**

10:15 **Plenary – Instructions for third round of breakouts (AHS Development and Deployment Staging)** – Steven Shladover (Tab 15)

10:35 **Plenary Review of findings from second round of breakouts** – 4 reports at 15 minutes each, plus discussion.

11:50 **Lunch**

1:00 **Convene third round of breakouts on time-staging of AHS development and deployment**
Four parallel sessions, all addressing:
What sequences of deployment are reasonable and practical, within what time frames, and what needs to be done to motivate favorable deployment decisions

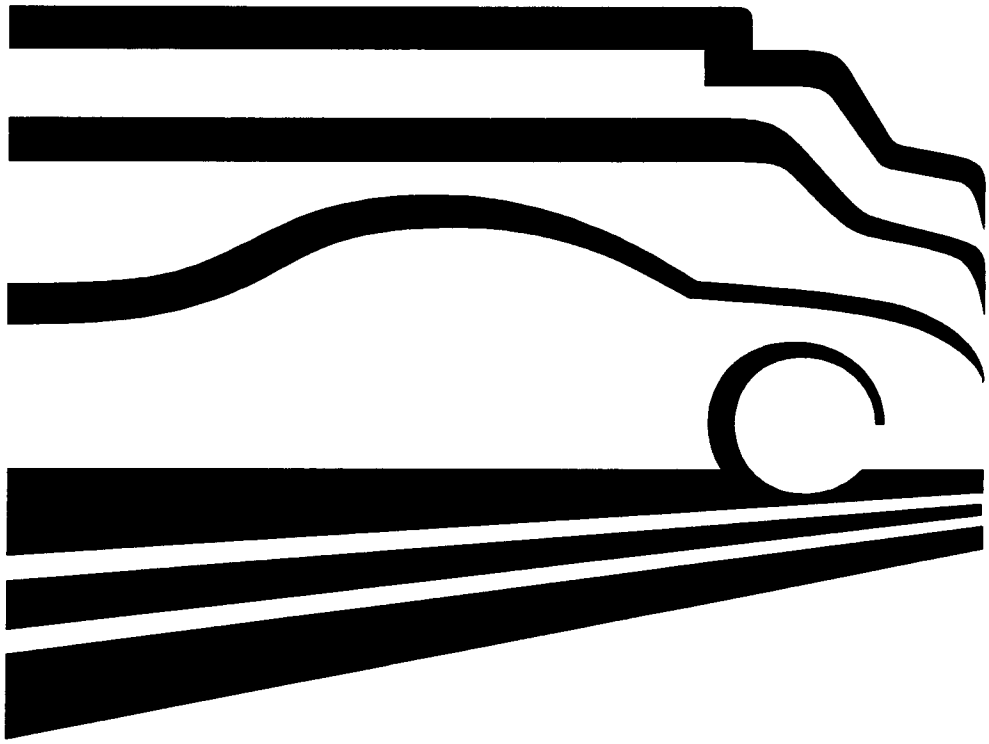
2:30 **Break**

2:45 **Plenary briefing on plans for AHS architecture development** – Walt Faulconer (Tab 16)

3:00 **Plenary review of findings from third round of breakouts** – 4 reports at 15 minutes each, plus discussion

4:10 **Closing remarks** – Dick Bishop
What happens next, and how we incorporate what we've heard here into the next stages of our work.

4:20 **Adjourn**



National Automated Highway System Consortium

WELCOME TO WORKSHOP # 3

Minneapolis, Minnestoa

Jim Rillings

NAHSC Workshop #3

Introduction

Steven E. Shladover

Workshop Purposes

1. From NAHSC to Stakeholders
   - Update on progress in AHS concept definition
   - Disseminate new knowledge gained about AHS issues

2. From Stakeholders to NAHSC
   - Participation in concept definition process
   - What you want from AHS
   - Priorities for system design trade-offs
   - Assessments of validity of assumptions
   - Assistance in thinking through difficult issues
   - Identification of issues needing more work
   - Peer review of quality of work

Workshop Outline

Thursday AM

- Plenary Briefings
  - Background
  - Concept Development Status
  - Results of Analyses (4)

Thursday PM

- Breakouts (4) to discuss results of analyses

Friday AM

- Breakouts on Key Concept Issues (4)

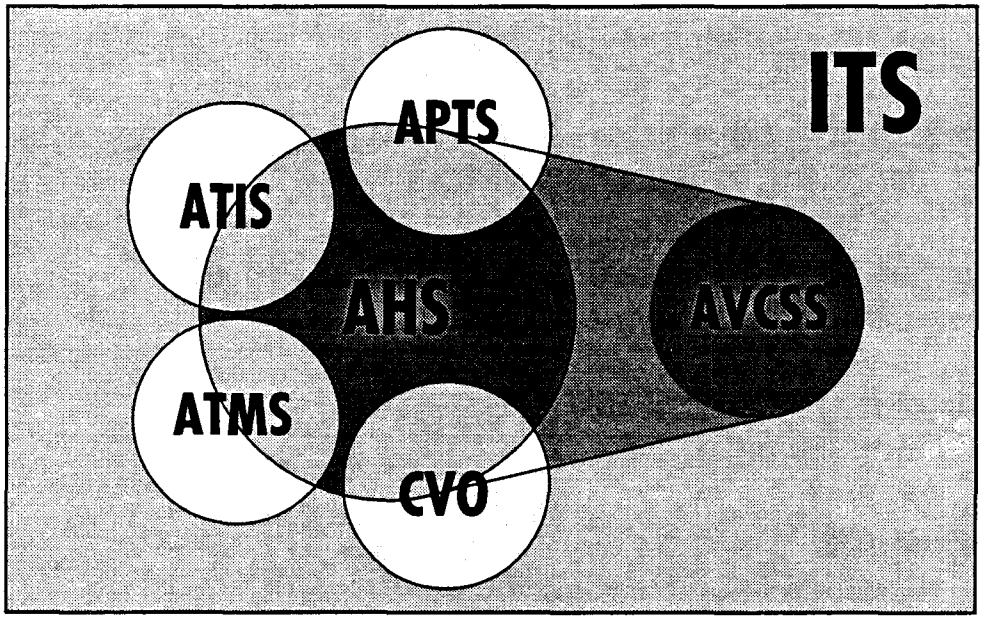
Friday PM

- Breakouts on AHS Deployment Sequences

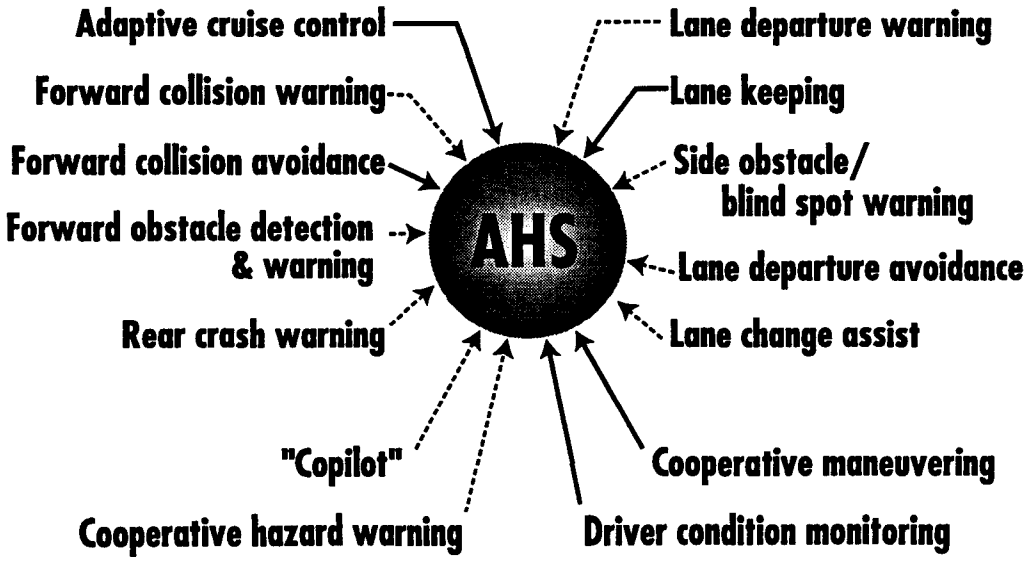
AHS Definition/Vision

- AHS is the application of vehicle/highway automation technology to provide *significant* improvements in
  - traffic safety,
  - throughput,
  - travel times,
  - comfort,
  - convenience,
  - energy and
  - environment
- AHS builds on developments in the rest of ITS, and especially in the other elements of Advanced Vehicle Control and Safety Systems (AVCSS).

AHS in the Context of ITS



AVCSS User Services



Stakeholder Inputs to AHS Concept Definition

- Participation in Workshop #2 (San Diego - Oct. 1995)
  - guiding redefinition of concepts
- Participation in Stakeholder Forum (Boston - May 1996)
  - identifying issues and priorities
- Consumer focus groups (S.F. Bay Area, May 1996)
  - willingness to pay
- Stakeholder focus group (San Diego, Sept. 1996)
  - priorities on MOEs
- Workshop #3
  - reactions to concept attributes

Stakeholder Issues from Boston Forum

- Relationship of AHS to the rest of ITS
- Need for more precise definitions of AHS user service and technology requirements
- Who will pay/own/operate/maintain/regulate AHS?
- Definition of deployment sequence(s)
- How to provide new infrastructure for AHS?
- What would driver's role be in AHS?
- Confusion about specific aspects of five concept families presented there
- Identification of benefits and user willingness to pay

Stakeholder Issues from Boston Forum (cont'd)

- Influences on urban form and travel demand
- Driver perceptions of differences among concepts
- Diverse perceived risks -
  - liability
  - investment needs
  - labor relations
  - human factors
  - driver training
  - privacy
  - regulations

Stakeholder Issues from San Diego Focus Group

- Needs-driven concept development
- Incremental deployment
- Institutional and legal concept attributes
- Stakeholder involvement in concept development
- Need evaluatory designs in case studies
- AHS definition in transportation planning terms
- Liability and customer needs (vehicle industry)

Current Status

- Very early in system development process
- General concepts, not yet designs
- Comparisons <u>across</u> concepts
- No absolute ratings of AHS relative to other alternatives

Review of Concept Development and Evaluation Work Since Workshop #2

Carol Jacoby

Hughes

3-1

Agenda

- **History – The Five Concepts**
- **Concept-Distinguishing Attributes**
- **Evaluations**

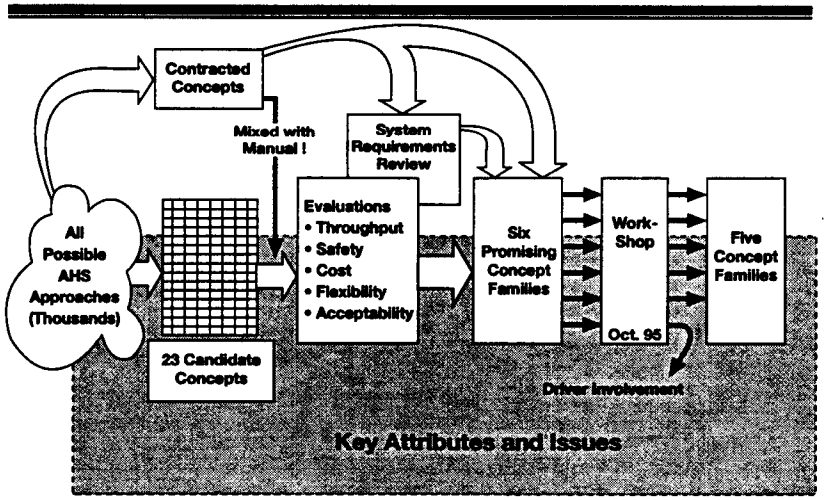
3-2

Agenda

- **History -- The Five Concepts**
- **Concept-Distinguishing Attributes**
- **Evaluations**

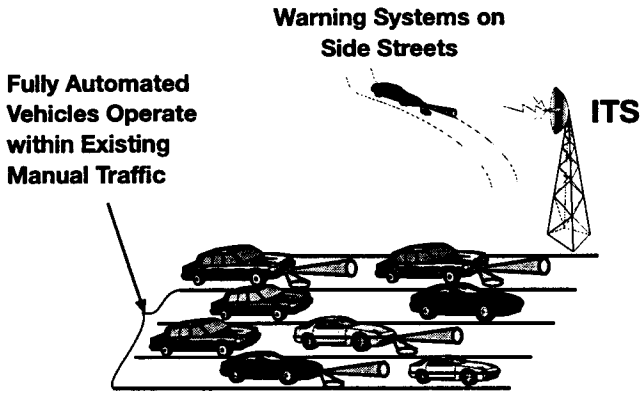
3-3

First Stage of Concept Development from Thousands to Five Concepts



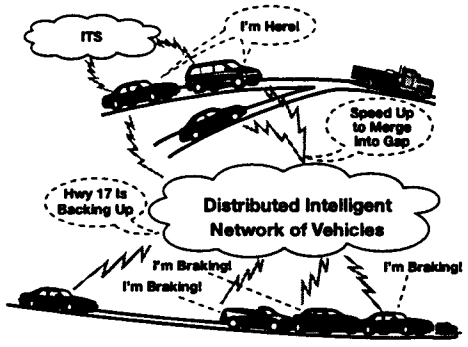
3-4

Independent Vehicle



3-5

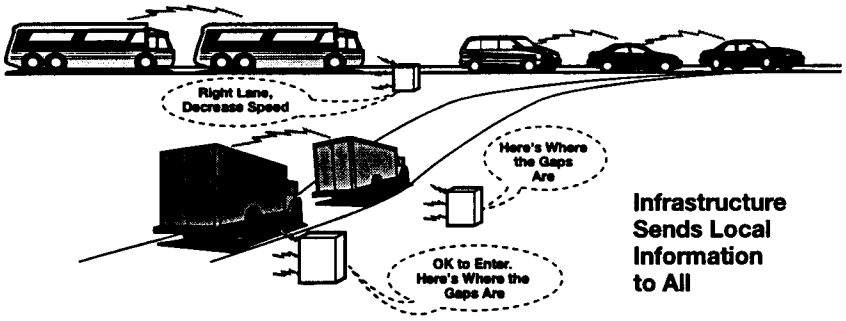
Cooperative Vehicle



- Coordination Among Vehicles
- Vehicles Collect and Share Information Without any Electronic Infrastructure

3-6

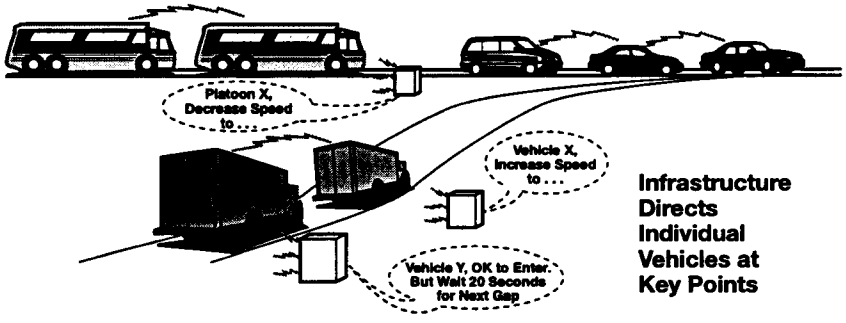
Infrastructure Supported



Infrastructure Sends Local Information to All

3-7

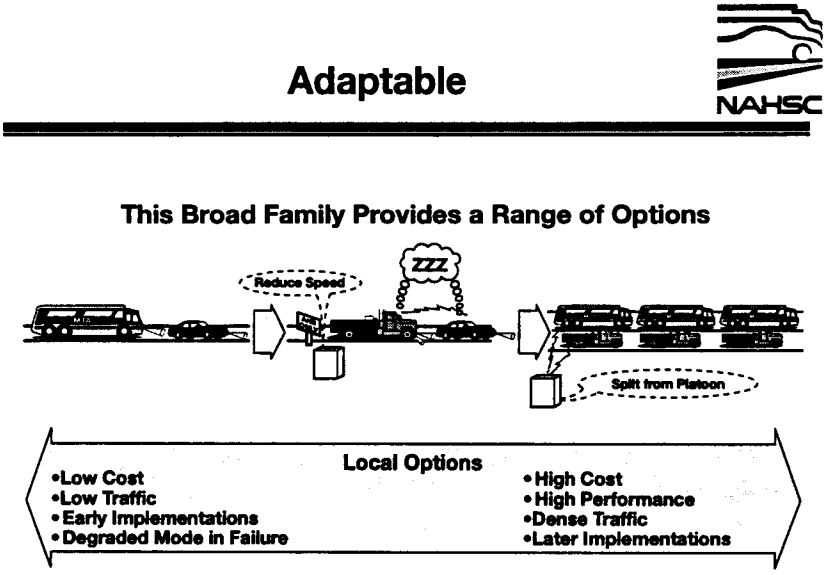
Infrastructure Assisted



Infrastructure Directs Individual Vehicles at Key Points

3-8

Adaptable



3-9

How the Concepts were Used

- **Examples for stakeholders and public of the breadth of the AHS**
- **Concrete, alternative visions**
- **Examination of evolutionary deployment strategies**
- **Exploration of full implications of design choices**
- **Context for evaluation**
- **Test cases for requirements in the Specification**

3-10

The Concepts Were Not Easy to Communicate

- The concepts did not convey the distinctions to the stakeholders
- Built-in flexibility made description difficult
- Issues were lost in concept complexity
- Boston forum government agency group requested more focus on general AHS issues
- Concepts were not sufficiently clear to support meaningful feedback or evaluation

3-11

The Concepts Had Limitations in Evaluations

- Attributes that are best examined separately were associated in the five concepts (e.g. free agent and mixed traffic)
- Promising alternatives were ignored (e.g., free agent with limited vehicle-vehicle communications)
- Flexibility of each concept made them hard to evaluate

3-12

Agenda

- History -- The Five Concepts
- Concept-Distinguishing Attributes
- Evaluations

3-13

The Consortium is Moving Toward a Flexible Concept

- There is no single right answer for AHS
- The best concept depends on timeframe, budget, congestion levels, legacy systems...
- The contracted concepts and case study all defined multiphase AHS
- Stakeholders demand incrementalism
- The solution must support local options
- The solution must support freight, transit, private vehicles
- The best solution is a combination of all of the concepts
- The questions now become
  - What should the options be?
  - How do you decide which option to choose?

3-14

The New Approach Focuses on Issues, Options and Alternatives

- **Options-oriented analysis gives more useful, meaningful results than concepts analysis**
  - **Which options make sense?**
- **Sensitivity analysis of effects of options**
  - **Which options should you choose?**
  - **What are the implications of choosing one option or another?**
  - **What are the best options for various situations?**

3-15

Six Key Attributes

- **Dedicated lanes only or mixed traffic operations**
- **Deployment sequences and timing**
- **Distribution of intelligence and communication links**
- **Platoons or individual vehicles only**
- **Obstacle detection or exclusion**
- **Driver role(s) - override or intervention opportunities**

3-16

Stakeholder Preferences Focus Group Stressed Non-Technical Attributes

- September 10-11, 1996 at Hughes, San Diego
- Facilitated by John Lathrop & Kan Chen
- Stakeholder groups represented:
  - vehicle industry
  - government agencies
  - private users
  - transit operators
  - insurance industry
  - environmental protection

3-17

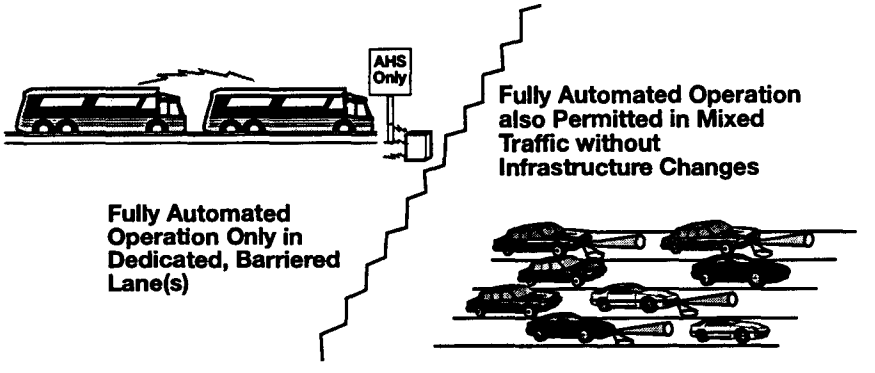
Insights from Focus Group Meeting

- Concept development should be needs-driven and market-driven.
- Incremental deployment should be emphasized.
- Institutional and legal options should be included as concept attributes.
- Therefore, selected stakeholders and non-technical experts should be involved in concept generation.

We encourage discussion of societal and institutional issues in all breakout sessions, especially Deployment

3-18

Dedicated Lanes or Mixed with Manual ?



Major Impacts: Safety, Throughput, Cost, Environment, S&I Issues

3-19

What is the Deployment Sequence?

Start with adaptive cruise control and warning systems, then ...

Dedicate a barriered lane for full automation?

or

Add capabilities toward full automation in mixed traffic?

or

Dedicate a barriered lane for use by partially automated vehicles?

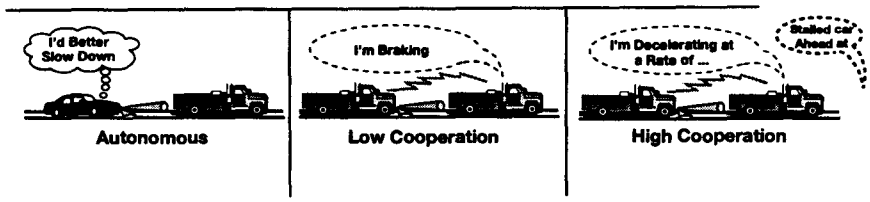
Major Impacts/ Issues:

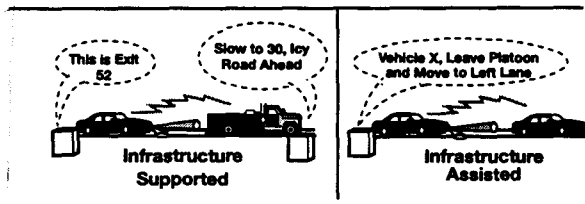
- **Role of the Federal Government**
- **Role of the public sector**
- **Role of the market**
- **Cost**
- **Technology development**
- **Other societal and institutional issues**

3-20

Distribution of Intelligence -- Where are Decisions Made ? Who Communicates ?

NAHSC





Major Impacts:
- **Safety**
- **Throughput**
- **Cost**

3-21

Should Vehicles be Grouped or Separated ?

NAHSC

Vehicles Operate Only as Individual Vehicles (free agents)

Note: Need not be autonomous

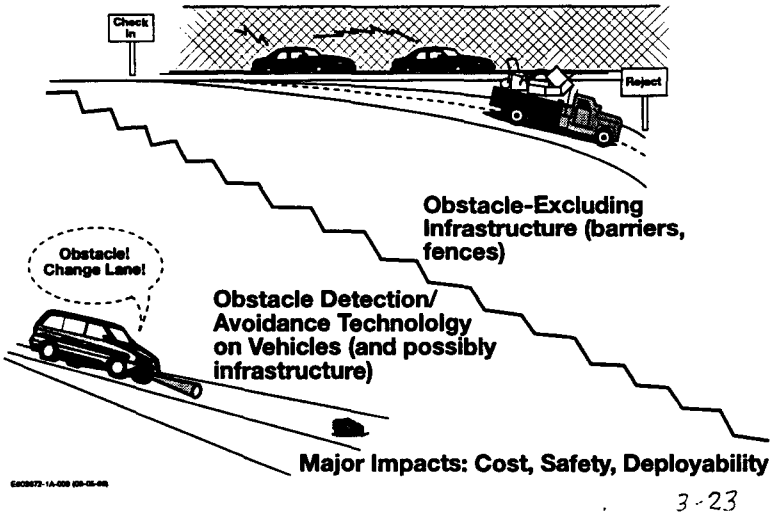
Vehicles Operate as Individual Vehicles and/or in Platoons (tightly coordinated groups with leader)

OR

Major Impacts: Safety, Throughput, Environment, Human Factors

3-22

Obstacle Avoidance or Exclusion ?



Major Impacts: Cost, Safety, Deployability

3-23

What is the Role of the Driver in Automated Mode ?

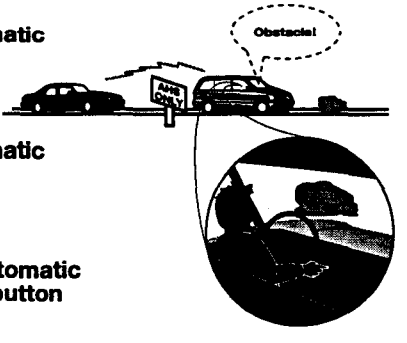
Driver can Override Automatic Control at Anytime

or

Driver can Override Automatic Control Sometimes

or

Driver cannot Override Automatic Control (except for panic button with controlled stop)



Major Impacts: Safety, Acceptability

3-24

The Consortium is Working toward Decisions for each Attribute...

Should there be one choice?

- Which one should it be?
- Should it be something in between or some variation?

Should it be a local option?

- Which choices?
- What impact does the choice have?
- Under what conditions should each option be chosen?

3-25

Agenda

- History -- The Five Concepts
- Concept-Distinguishing Attributes
- Evaluations of Effectiveness

3-26

Case Studies

- **Goal: Demonstrate applicability of AHS in an actual operational setting**
- **Several locales are being considered, covering the range of local characteristics**
  - **Houston Metro currently underway**
  - **Southern California (Los Angeles and San Diego)**
  - **Yellowstone corridor**
  - **I-35 truck route**
  - **others**
- **The agency defines the AHS application based on the concept and option "tool kit"**
- **The Consortium simulates it and performs a "shadow MIS"**

3-27

Evaluation Factors (1 of 2)

1. **Modularity and flexibility (urban/rural/interurban, private/fleet vehicles, etc.)**
2. **Evolvability**
3. **Development cost and risk (technical feasibility)**
4. **Acceptability**
5. **Market penetrability and deployability**
6. **Robustness (Response to failure or flaw)**
7. **System dependability (including failure containment)**

3-28

Some Evaluations Produce Cost-Benefit Metrics

Safety

Throughput

Cost

Environment/Energy

The Specification defines the minimum requirements on these metrics

3-29

Safety

Evaluation factors

- **Number of collisions**
- **Severity of collisions**
- **Maximum number of vehicles involved**

The evaluations are based on Failure/hazard Scenarios:

- **Hard braking**
- **Obstacle**

3-30

Throughput Evaluation Factors

- **Maximum achievable throughput**
- **Throughput degradation due to entries, exits and lane changes**
- **Corridor throughput (impact on manual lanes)**
- **Travel time**
- **Travel time variance**

3-31

Cost

Evaluation Factors

- **Vehicle life cycle cost**
- **Infrastructure life cycle cost**

Concept Characteristics that Impact Cost

- **Infrastructure**
  - **Ramps, barriers, entry/exit facilities**
  - **Sensors, Communications, Processing**
- **Vehicles**
  - **Sensors, Communications, Processing**

3-32

Fuel Consumption and Emissions

Evaluation factors

- **Fuel consumption savings**
- **Emissions reduction**

Concept Characteristics that Impact Fuel Consumption and Emissions

- **Close spacing**
- **Fraction of traffic in close spacing**
- **Smoothness of flow**

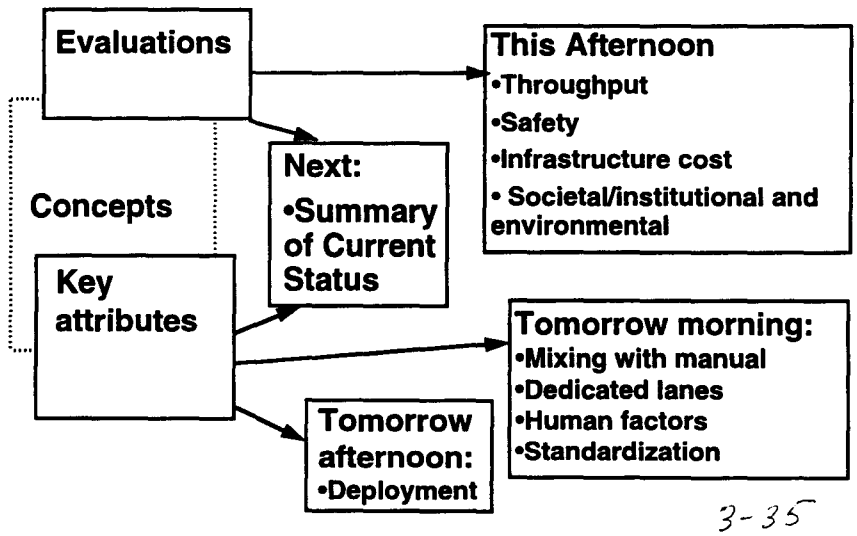
3-33

Conclusion

The Consortium's goal in concept development has shifted from selecting the one best concept to describing the tool kit and how the pieces are best used

3-34

Attributes and evaluations will be discussed in following sessions



3-35