5. CONCLUSIONS AND ISSUES

The results of the evaluation teams were approached from both a quantitative and a qualitative view. The contracted concepts provided important insights that greatly influenced the selection of the six concept families. The quantitative analysis is discussed in Section 4.6.

5.1. OBSERVATIONS ON CONCEPTS AND THEIR CHARACTERISTICS

5.1.1 Allocation of Intelligence

The Infrastructure Controlled approach, in which the infrastructure controls the vehicle at a micro level (brakes, steering and throttle) should not be continued in its present form. The ratings across all criteria were poor. The reasons for this are that this approach lacks robustness in that it risks single point failure in either the infrastructure or the communications links. In such a failure, the essentially dumb vehicles have no backup, and so the entire system is prone to catastrophic failure. There are also concerns about technical feasibility. The communication requirements are probably excessive, and the reliability requirements may not be achievable. On the other hand, alternative forms that do not have these drawbacks will be considered. In particular, contracted concepts will be carefully considered for means to achieve high infrastructure control while limiting these risks. Also, as concept designs are further refined, an infrastructure controlled module may find use in specific situations, such as backup for a failed vehicle.

The functional descriptions of the concepts indicate that some sort of centralized control is necessary for flow control and merge management in very dense traffic. Merging is a major issue area, especially as traffic density increases. The individual vehicle may not have a broad enough picture of the situation in the local area to coordinate a merge, even with communication with neighbors. For example, an entering vehicle cannot necessarily sense and track the approaching gaps as it comes up to an on-ramp. This indicates the need for some way of maintaining a broader picture of flow, gaps and obstacles. This may be done in the infrastructure via sensors or communication with the vehicles, or a sophisticated system of data fusion that would allow it to be distributed among the vehicles. Thus, the purely Autonomous approach is not viable as a mature option; however, it may provide an early stepping stone to multiple concepts, especially one that emphasizes the individual vehicle. Similarly, a purely Cooperative approach is only reasonable where there are long merge areas or low traffic rates, unless the vehicles have distributed intelligence to form a "virtual TOC."

The descriptions for those concepts based on Infrastructure Supported and Infrastructure Managed indicated that the right answer is somewhere between the two. The Infrastructure Managed descriptions did not use the continuous tracking of the vehicles, whereas the Infrastructure Supported descriptions were forced to add some vehicle-specific communications under some circumstances. This suggests a new dimensional choice, which we call Infrastructure Assisted or Coordinated. It does global general system monitoring and flow control, and coordinates individual vehicles within a local area, such as at a merge point or an incident. These points may be defined dynamically, for example, when and where an obstacle is detected. Individual vehicles are not tracked over long distances or handed off zone-to-zone. This type of concept characteristic development is consistent with the "re-concepting" approach, in which improvements to the concepts based on lessons learned are more important than selecting the best of the given options.

This also suggests a continuum of infrastructure control. There is probably no single optimum level of centralized involvement, and in fact it may vary from region to region. However, these variations are compatible within a conceptual framework, so a vehicle will be able to travel seamlessly through communities with different policies. The various levels of control will overlay on top of the vehicle-centered capabilities.

The best concepts are layered; each includes the ones below. This conclusion was especially strong from the Safety team. Multiple layers of control allow safe operation during failure. Figure 5.1.1-1 below shows the layers from Autonomous to Infrastructure Managed. The basic vehicle self-control of Autonomous underlies all of these options. Cooperative adds vehicle-to-vehicle communications and coordination. Infrastructure Supported adds infrastructure broadcasts to the vehicles and control by location. Infrastructure Assisted adds selective control by the infrastructure of individual vehicles and Infrastructure Managed extends it to control of all vehicles at a macro level. The Safety team concluded that all of these layers are necessary, so that in a failure, the AHS will degrade gracefully to a less capable, but still safe, system. Note that these layers are all active at all times, performing different tasks, so there is no need for a risky mode change in a failure.

Figure 5.1.1-1 shows other advantages of this approach. One is a smooth evolutionary path from the initial systems, which will be less complex, less capable and less expensive, to the later, full-functioned systems. Finally, this affords a range of local options, tailored to each community's budget and transportation needs, while allowing seamless travel among regions.

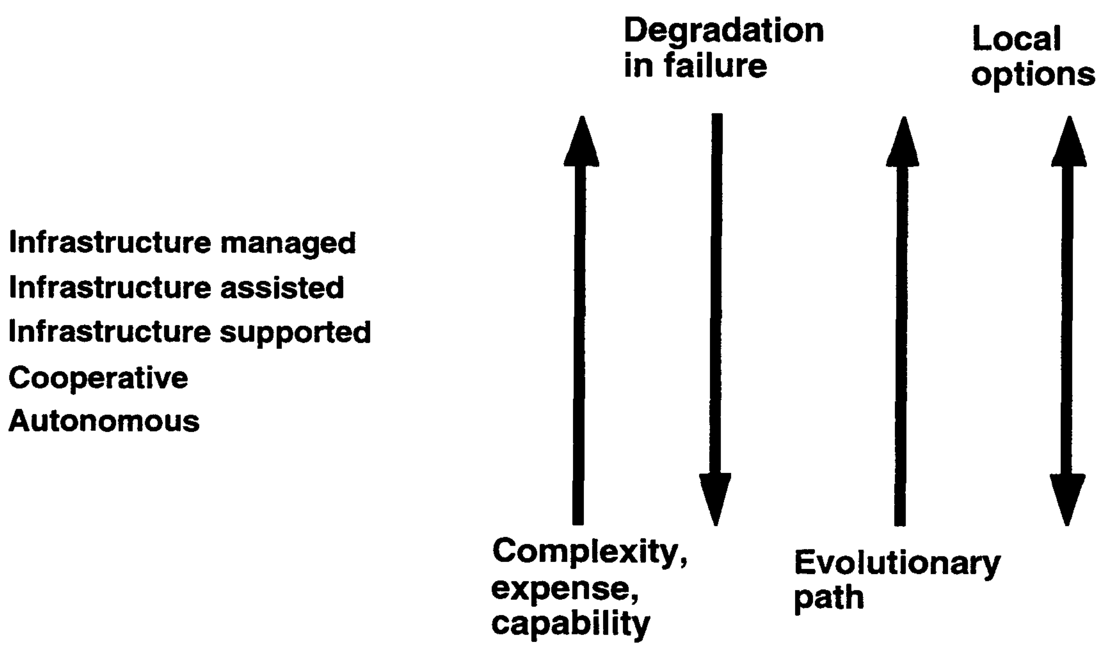

Figure 5.1.1-1. A Concept with multiple layers of functionality supports graceful degradation, a smooth evolutionary path and a range of local options

This conclusion indicates that there should be at least one concept family built around this approach. This will allow the team to compare the costs of providing the greatest amounts of layering with other more structured approaches.

5.1.2 Separation Policy

The Concept team cannot yet decide on the question of platooning vs. free agent. There is analysis to support either approach, and the results are very dependent on assumptions, such as braking speeds. This is especially true in the mixed classes of vehicles situation that the AHS must handle, in which heavy trucks and small sports cars coexist. The relative acceleration and, especially, braking capabilities greatly impact the achievable spacings. Central to all of this is the safety policy. Can minor accidents be tolerated? What constitutes "minor"? Must the number of vehicles involved in an incident be limited? To what? With what certainty? The team recommends that this issue be a significant area of study in Task C2.

It is possible that the Automated Highway needs to be able to support both platooning and free agent approaches. The above analysis will determine in what regions and under what circumstances one approach or the other will be used.

The slotting approach scored poorly relative to the other alternatives, so it will not be included in the six concept families. On the other hand, if results emerge from the contracted concept or other analysis that indicate approaches to slotting that alleviate the drawbacks, the approach will be reconsidered. In fact, as the design gets refined, slotting may be used in particular situations, such as at a merge point.

5.1.3 Mixing of AHS and non-AHS Vehicles in the Same Lane

The fully functioned AHS uses dedicated lanes. This is actually a much simpler problem than designing an AHS to allow manually-driven vehicles on the same lanes, since those vehicles are neither predictable nor controllable. There are safety risks due to this mix, and requisite conservative spacings would likely negate any throughput advantage of the AHS.

Surprisingly, one of the concepts that allowed mixing scored well on the evaluations. Although not all vehicles were instrumented, they were all tracked, so there was a complete centralized status picture.

Feedback from the Workshops has indicated that many areas cannot dedicate a lane to AHS, since they have neither lanes to spare nor funding for the construction of new lanes. An example is rural areas with long stretches of two-lane roads. The second lane is needed for passing, and so cannot be dedicated to AHS, yet the length of the road makes it unacceptably expensive to build a third lane, and in some mountainous areas, it may be next to impossible. This indicates that many roadways may never support a dedicated AHS lane.

The contracted concepts in many cases started their evolutionary schemes with mixed traffic. This gives further validation to the need to consider mixing with manual traffic at least as an early or regional option.

Of course, to get the real throughput and disengagement benefits of AHS requires dedicated lanes. All of the most highly ranked concepts used dedicated lanes.

The other aspect of this dimension is the means for separating the automated and the manual traffic when dedicated lanes are used. The evaluation of this aspect involved many questions of topography, building costs and traffic patterns, all local considerations. The team concluded that such concrete configuration should be a local decision. But virtual barriers such as yellow lines may not be safe, especially in tight platooning. Hence, the team recommended that the concept families not use virtual barriers in high-end concepts.

5.1.4 Mixing of Vehicle Classes in a Lane

The highest rated of the concepts segregates vehicle classes, such as heavy trucks and cars. This allows tighter spacing, more control and increased safety. The drawback is the expense of building separate ramps, lanes and interchanges for the various classes. This will make class separation unacceptable for most localities. AHS must serve all users, so the only other option is to mix the classes in each lane. The AHS must accept mixed classes in general, though some localities may find dedicated lanes worth the expense. Concurrent class mixing has major safety and throughput implications that need to be well understood. A local option that needs to be accommodated is to accept all classes, but avoid concurrent mixing, such as by restricting the AHS to passenger cars and small buses during rush hour, and to large trucks and buses at other times. This assumes a parallel manual highway or lane is available.

5.1.5 Entry/Exit

The comparison of dedicated and transition lanes revolved around the same kinds of local considerations--topography, building costs, traffic patterns--that drove the closely related barrier comparisons. As in that case, the team decided that this is a local decision, and that the AHS should allow localities to choose either approach.

5.1.6 Obstacle Detection and Avoidance

The Acceptability Team rejected those concepts that did not perform fully automated obstacle detection and avoidance as not being full AHS, nor providing fully disengaged driving under all conditions that the public expects from an AHS. But there is a major technical question here, as to whether or not it is possible to detect and avoid all dangerous obstacles. The Concepts Team recommended a study of this issue by the Technology Team, and this is ongoing.

The role of the human is a major issue. The Safety Team was fiercely divided on this issue. One group thought that allowing the human to take over under any circumstances introduced unpredictability, lack of control, slow reaction time and unsafe actions due to panic, greatly reducing safety. Furthermore, any system that relies on the driver prevents safe disengagement, and hence, is not AHS. Another group was concerned about the ability of technology to ever be able to make the sophisticated judgments that are second nature for humans, such as pattern recognition and inferencing. Examples are natural driver reactions to seeing a deer about to enter the roadway, or swerving cars several vehicles ahead. To be acceptable, the system must work at least as well as a human at these and other tasks. The drivers may insist on keeping some level of control, such as a panic button.

This is another major issue area. The Team recommends significant study in this area during C2.

5.2 INSIGHTS FROM EVALUATIONS

5.2.1 National and Local Decisions

The team found that many of the characteristics that were originally defined as concept differentiators are actually local decisions that must be accommodated by the national AHS system. These include all of the physical infrastructure issues, such as whether to use a dedicated ramp or a transition lane, and the layout of ramps, barriers and other concrete configurations. Vehicle class mixing should also be a local option since it is tied to physical configuration.

More generally, the stakeholders have expressed a range of needs that indicate that the level of AHS functionality within a broad range must be a local decision. Perhaps platooning or free agency should be a local option; these alternatives will be further studied in C2.

The national decisions center around the vehicle as the common element. Any equipped vehicle needs to be able to travel seamlessly across the country, even as physical configurations, level of functionality and level of control change.

5.2.2 The Layered Approach

This need to support a range of local options suggests an open architecture and a flexible architecture that allows adding on capabilities. This flexibility is approached in terms of adding on, rather than in terms of selecting building blocks, for the simple reason that large scale systems tend to evolve over time. We visualize this as a series of layers, each of which overlays and adds functionality to the ones below.

This idea first surfaced from the Safety Team analysis. They recommended layers for robustness relative to failure. In fact, they essentially rejected any option that did not use Infrastructure Managed, the richest approach and one which includes all the underlying intelligence approaches. It soon became clear to the Concept Team that this approach had other key benefits. The layered approach is shown in the Figure 5.2.2-1. It allows a smooth evolution without throwing away anything from the original system. It also provides a range of compatible local options.

The quantitative results, described previously in Section 4.6, pointed to potential growth paths by taking the best-rated concept within each cost category. It turns out that this suggests families of concepts with the additive characteristic of a layered architecture. These families have several desirable characteristics.

- There is a wide range of price-performance choices, affording local flexibility

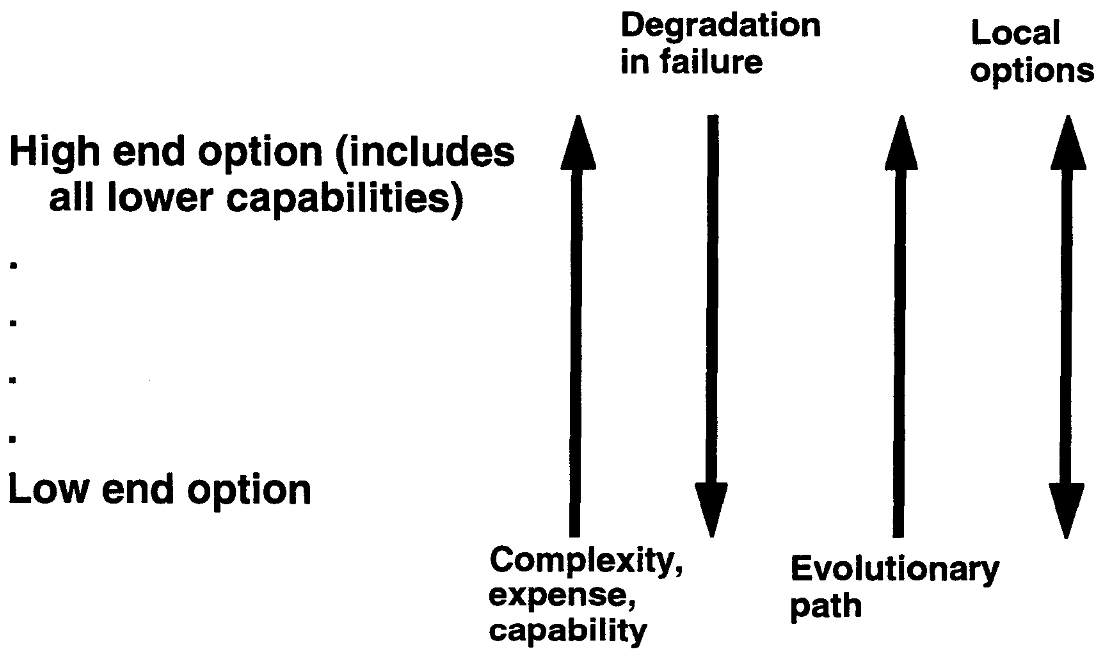

Figure 5.2.2-1. The layered approach to concept architecture

- Options are available for rural, inter-urban, suburban and urban areas
- The early steps were rated highest in flexibility
- The later steps were rated highest in performance
- In every case, the initial step has a good cost-benefit ratio, so individuals and agencies will be motivated to initiate the system
- Each successive step has a good cost-benefit ratio, so there is incentive to expand
- The system can be built up gradually, lowering risks and supporting acceptability
- The development is robust relative to funding changes and other risks to continuation

One of the key items at the System Requirements Review was the definition of a "concept family." There was agreement that the outcome of Task C2 should be six concept families, but there was no initial agreement on what constituted a family. The attendees broke into working groups to decide this question, as well as to make recommendations for the six concept families. Three alternatives were presented. The "downselect" approach picks six specific single concepts. The "issues" approach builds the families around key issues. The "options" approach defines families of compatible concepts each with a smooth growth path.

The "options" approach was selected by the working groups. The motivation for this approach is that it supports evolutionary deployment and local tailoring, each of which is called for in the NAHSC Mission Statement. Further, it allows safe degradation in a failure if the family is built in layers. This allows the level of complexity of the AHS at any time and at any locale to be based on the need of the situation. For example, light traffic areas have no infrastructure support, moderate traffic areas use some infrastructure support, and heavy use areas have infrastructure management. Different options are allowable for different conditions. For example, a basically autonomous system advances to infrastructure assisted as traffic requires, and platooning may be used in urban areas, while free agents are used in rural.

5.3 ISSUES AND CONCLUSIONS

The goals of Task C1 were to identify the most important unresolved issues, the most important new issues, and a viable range of options for each, and to develop six new system concept families to serve as a framework to address these issues. These results are to be based on the conclusions, lack of conclusions, and recommendations of the synthesis and evaluation of 23 concepts.

The 23 concepts originally developed and evaluated for C1 were not "downselected." The reasons for this are:

- Some of the dimensions were determined to be local options rather than discriminators
- The AHS solution will not be a single concept, but a range of options to satisfy a variety of regional needs, as well as a feasible growth path
- The 23 concepts were not a complete set of alternatives, but were chosen as representative of the range and intended to suggest improvements.

C1 resolved some issues and highlighted others. The decisions that were made:

- Infrastructure control (the infrastructure gives brake and throttle commands to the vehicles) was eliminated as a candidate
- The slot concept was eliminated
- Physical configuration (ramps, transition lanes, barriers), as long as it is safe, is a local option. For example, virtual barriers (painted lines) are not safe between platoons and manual roadways.

- Concept families will be defined as families of compatible options with a growth path, and hence, are not necessarily mutually exclusive.

5.3.1 Major Issues and Dimensions

There were several key issues that were either unresolved in C1 or were newly raised in C1.

5.3.1.1. Infrastructure Involvement

The options that survived the analysis are Autonomous, Cooperative, and Infrastructure Supported. A new option was developed, namely Infrastructure Assisted. Further analysis and definition will determine exactly how much infrastructure management is necessary in this option, so it is referred to as Infrastructure Assisted/Managed.

This issue of allocation of intelligence, the level of involvement of some intelligence outside the vehicle making decisions based on more global knowledge, is generally seen as the key discriminator of concepts. The working groups at the System Requirements Review as well as the stakeholders at the Workshop suggested this as the framework for defining the six concept families, which is essentially what was done.

5.3.1.2. The role of the driver

Ideally, the driver should be disengaged at all times, but there may be situations in which he is asked to take over, or situations in which he demands to take over. Some early implementations may require a totally engaged driver. There are many issues here. Should he be totally engaged always in some implementations, and if so, how do we ensure that he stays engaged? Should he have the option of taking control? Should he be a backup obstacle sensor? Should he ever be required to take control? Can the technology do the whole job no matter what happens?

The options here are engaged, partially (conditionally) engaged and totally disengaged. Partially engaged, if it is appropriate, will need to be defined based on determining situations in which the driver will demand or require control.

5.3.1.3. The optimal amount of layering (options)

The above section discussed the benefits of layering information and control. However, there is certainly a limit to this. Additional layers add cost and complexity. There is a trade-off with compatibility. The evolution may take place by spreading geographically, rather than building on previous systems. In other words, wherever the AHS is deployed, it is essentially fully functioned, and the growth occurs by extending the road network that constitutes the AHS.

The team recommends that the six concept families include families that include narrow ranges of options as well as wide ranges.

5.3.1.4. Separation policy

There are now two options here, platoon and free agent. As discussed before, the issue revolves around assumptions on safety policy and performance characteristics (especially braking) for the target vehicle mix. It is likely that both options will be accommodated, but further analysis needs to be done to understand when and where each should be applied.

5.3.1.5. Manual and Automatic Vehicle Mixing

There are two choices here, to support a mixed option or not. Certainly the fully functioned AHS will use dedicated lanes. The issue is whether this should be a requirement on all AHS lanes. Feedback from stakeholders and the use of early mixed implementations in many of the contracted concepts indicate the need to reopen this issue.

Table 5.3.1.5-I summarizes the conclusions and issues.

5.3.2 The Issues and the Selected Concept Families

All of the alternative solutions to the major issues discussed above are represented in the concept families selected, which are described in Section 7. There are two vehicle-oriented options, Vehicle Centered (based on Autonomous) and Cooperative Plus (based on Cooperative). The other four combine the vehicle and infrastructure. Driver Involvement is based on the premise that the driver must be involved, either because the technology cannot do everything or because human nature demands it. Infrastructure Supported Platoons and Infrastructure Assisted Platoons address high-end systems with varying levels of infrastructure involvement. Maximally Layered is designed to maximize the options available.

The main issue defining alternatives is and always has been the allocation of intelligence. The four options listed are the main definers for the concept families. However, autonomous and cooperative, as originally defined are too limited to be full AHS systems, so they are represented as starting points for more complex concepts.

With the elimination of slots, the remaining choices are platooning and free agent. Further analysis with realistic and broad assumptions must be undertaken to resolve this issue. However, if platooning is feasible, free agent may be considered a special case and hence, an option.

The driver role ranges from fully engaged to fully disengaged, with intermediate roles as a backup sensor or responding to emergencies. A related issue is whether or not the AHS vehicles can operate in AHS mode in the same lane as manual vehicles. There is one concept specifically developed around a partially engaged driver, while others never allow a disengaged driver, even early in the evolution.

The amount of layering determines both the complexity and the flexibility of the AHS. The alternatives range from Maximally Layered, with full layering through all allocations of intelligence to Assisted Platooning, which may have only one underlying layer. The Vehicle Centered family ranges from very rudimentary to fully functioned in only three steps.

Table 5.3.1.5-I. Conclusions and Issues

Major conclusions	Local decisions	Major issues for C2
• Infrastructure Controlled should not be continued in its present form. • The most robust, powerful and flexible concepts are layered. • Slotting should not be continued as an overall approach. • High end implementations for dense traffic must have dedicated lanes with physical barriers and some sort of unified control of vehicles within an area. • Concept families each are to be defined as collections of compatible concepts through which there is a smooth evolutionary path.	• Platooning or free agent (if both are viable) • Ramp configuration, use of transition lanes, types of barriers, and other physical characteristics, within safety guidelines • Class mixing	• Separation policy, and its implications for throughput and safety • Mixing of automated and manual vehicles in the same lanes • Obstacle detection and avoidance • The role of the driver • The level of infrastructure involvement • The optimal amount of "layering"

6. SOLICITED CONCEPTS

In counter point to the Consortium's internal efforts to define, develop, and evaluate a set of initial concepts, the NAHSC conducted a national solicitation for AHS concepts. As a result of this solicitation, seven concept development contracts were awarded and completed during this task.

The goals of this solicitation were many, not the least of which was to satisfy the clearly stated requirement in the Request for Application for a "national solicitation for" "identification and description of multiple, feasible AHS concepts". In addition, the NAHSC desired to capitalize on the work done during the Precursor Systems Analysis phase where many organizations had studied a wide variety of AHS issues and in the process developed well founded ideas on the necessary and desirable features of an AHS concept. In fact, many of our contracts were let to organizations involved in the PSA effort and strong and surprisingly consistent concept themes came from this source. Even beyond the NAHSC and PSA work, the Consortium expected, and found, that other organizations had looked at the problems afflicting highway transportation and had developed conceptual solutions involving automation.

Solicitation for Proposals

Following April 1995 Workshop #1 in Fort Lauderdale, Florida, the NAHSC released through the Commerce Business Daily (CBD) a solicitation for concepts. The solicitation asked for proposals of complete AHS concepts rather than proposals of a specific technology. The solicitation asked for proposals on AHS concepts which had the following major characteristics:

- provide fully automated driving of motor vehicles on limited access highways
- provide significantly increased throughput and safety over conventional highways
- operate with automobiles, buses, and trucks
- incorporate a non-contacting, electronic guidance system
- be feasible and affordable
- allow AHS equipped vehicles to be operated manually on non-AHS equipped highways
- contain an aggregation of technologies sufficiently mature today to be integrated into a fully functional prototype ready for field testing in the year 2001

The solicitation also asked for an initial description of the concept and an initial evaluation of the concept against the requirements of the AHS System Objectives and Characteristics document prepared under Task B1A and provided to each interested organization.

In addition to the CBD announcement and the AHS System Objective and Characteristics document, each interested organization was given a Statement of Work (SOW) for the concept development effort. This SOW was based on the SOW for the Consortium's own concept development work and was so designed to focus the work of the contractor towards a concept description and evaluation which was roughly equivalent to the Consortium's internal efforts. This would maximize the Consortium's later ability to compare internally and externally generated concepts on an approx-imately equal and fair basis. The SOW established a time frame for the studies (approximately 3 months) and the products of the study including briefings and a final report.

Evaluation of Proposals and Award of Contracts

In response to the CBD solicitation, the Consortium received twenty-seven responses. One was a duplicate copy, and two were not considered to be responsive under the terms of the solicitation. The remaining 24 were initially evaluated to determine whether or not they were proposals for development of a full AHS concept, for a partial concept, for concept evaluation, or for a specific technology. Twelve of the 24 were determined to be proposals for full AHS concept development. These twelve proposals were from:

Battelle / Ohio-State
Calspan
Convergent Technologies
George Washington University
Haugen Associates
Honeywell
Penn State (2 proposals)
SRI International
Toyota
Unduluda Associates
Virginia Polytechnic University

To further evaluate these twelve concepts, and to make the final selections and awards, the Consortium established an evaluation board. The board in turn, established a set of evaluation criteria and a process for ranking each of the 12 proposals against each other. The four categories of evaluation criteria were:

- Overall scientific and/or technical merits of the proposal. Is the concept being proposed unique, reasonable, technically credible, and does it meet the characteristics listed in the solicitation?
- Offeror's responsiveness to the technical requirements of the solicitation and demonstration of technical competence as reflected in the proposed approach and supporting technical description. This was evaluated on:
  - Whether the proposed research plan is complete, systematic, logical, practical and clear
  - Sufficient detail to assess the reasonableness of the proposed methodology
  - Demonstrated knowledge of the critical issues concerning AHS concepts
  - Identification of potential problem areas and means for overcoming them
  - Awareness of the practical considerations and constraints
- Ability to perform technical work. Offeror's resources to complete the contract requirements satisfactorily and on schedule, including
  - Education, experience and competence of research team in the areas of AHS, concept development, system architecture, and oral and written communications
  - Education, experience and competence of the principal investigator or project manager
  - Adequacy of the management plan, including organization, manpower allocation, work schedule, and monitoring to insure success. Adequacy of the proposed allotment of time, overall and on a task-by-task basis.
  - Adequacy of facilities, equipment, and support to conduct this study.
- Past performance. Offeror's relevant and successful experience.

In the final evaluation process, the uniqueness of the proposal was considered separately in order to assure ourselves that unique and feasible solutions were not being rejected just because their uniqueness made them appear too risky.

The evaluation board members first evaluated each proposal separately, them met, discussed both the criteria and the proposals, and developed a composite ranking for each proposal for each criterion. The result of this evaluation was that the proposals divided into two distinct groups, a group of seven with generally high rankings and a group of five with generally lower rankings. A decision was made to award contracts for the seven proposal with the highest rankings. The board then assigned each of the seven selected contractors to one Consortium Participant for management of the contract. The proposals selected and awarded were:

- Battelle / Ohio State, assigned to Lockheed Martin
- Calspan, assigned to Hughes
- Haugen Associates, assigned to General Motors
- SRI International, assigned to PATH
- Toyota, assigned to Carnegie Mellon University
- Virginia Polytechnic University, assigned to Lockheed Martin

Brief Description of the Concepts

Each of the seven concepts is described, in the words of each contractor, following:

6.1 AN INTEGRATED AUTOMATED HIGHWAY SYSTEM (AHS) CONCEPT WITH SPECIAL FEATURES FOR BUSES AND TRUCKS

BATTELLE/OSU

The Integrated System Concept (ISC), being developed and evaluated by the Battelle/ OSU Team with its subcontractors TRC and BRW, is a concept which includes a multi-tude of operating procedures and infra-tructures, and a special emphasis on trucks and buses. The different operating proce-dures and infrastructures issue is especially relevant to providing the level of flexibility needed to accommodate differing Urban, Rural, and Fringe situations even in a fully deployed AHS implementation. This flex-ibility also helps in both local and partial implementability of AHS technologies, and multi-stage deployment.

The ISC is based on a vehicle heavy distribution of intelligence. The ISC concept involves a "smart" vehicle and a minimally instrumented infrastructure in Rural areas, and increased levels of sensing and communication to provide additional functionality in the Fringe and Urbanenvironments. This Concept is being developed assuming the availability of passive roadway-based markers and passive vehicle-based indicators. Currently, the concept features (1) OSU's radar reflective stripe as the roadway marker which facilitates lateral (and other) vehicle control functions, and (2) OSU's Radar Reflective Patch as the vehicle-based type of indicator which facilitates follow-the-leader or convoy operation of heavy duty vehicles. One key aspect of these technologies is the ability to function well in a variety of situations - i.e., in inclement weather, in tunnels, on metal bridges, etc. Additionally, the Radar Reflective Stripe technology can provide a "look ahead capability".

The ISC specifically considers truck convoys in Rural areas and bus convoys in Urban areas. These special applications are woven into the main Concept and evaluated as a whole. Special attention is being given to allowing the owners/operators of AHS capable vehicles to derive the maximum benefit of the vehicle heavy distribution of AHS intelligence in all driving scenarios - e.g., various evolutionary stages of AHS deployment, mixed traffic, and even on non-AHS roadways.

6.2 CALSPAN AHS CONCEPT FAMILY: MIXED FLOW THROUGH DEDICATED FLOW

CALSPAN

Three concepts are grouped together to cover the range of participation from near zero to near one hundred percent. Thus, they can cover the evolution from first deployment to some future mature nationwide network. These also cover the range of application scenarios from high-capacity urban freeways to four-lane intercity freeways. All three concepts move vehicles as individual free agents rather than groups. When a lane is dedicated to automated mode use only, the vehicle class description would include a mass ratio specification (heaviest allowed to lightest allowed) and a maximum width specification. Vehicles outside the class would have the opportunity to use the automated mode in the other lanes mixed with vehicles operating in the manual or partially automated mode.

The three concepts can be termed mixed flow, mixed transition lane and dedicated flow. The mixed flow concept applies with few physical modifications to all freeways including four-lane freeways. The mixed transition lane concept applies to the range of freeways six-lanes wide and wider. The dedicated flow concept applies to maximum throughput applications on freeways with generous rights of way.

6.2.1 Concept 1 - Mixed Flow

In the mixed flow concept, the automated mode can be used in any lane. Modest driver comfort, convenience and safety benefits can be predicted for this concept, if the automated vehicles operate in the same lane, pairing up if the opportunity arises. The concept applies to all freeways at all participation levels but does not significantly increase the throughput capability of a given roadbed width. It applies, even in the long term, to four-lane freeways because it allows manual vehicles the opportunity to pass. Automated heavier vehicles would normally operate in the right lane. The infrastructure would monitor and advise. The driver would, in early deployment, be particularly alert for foreign objects and the behavior of manual vehicles. However, the driving experience would be much improved because of the automated gap regulation and lane following.

6.2.2 Concept 2 - Mixed Transition Lane

The mixed transition lane concept evolves from the mixed flow concept on six-lane and wider freeways when participation[1] grows to the point where only a few vehicles are displaced by dedicating a cruise lane to automated use. The cruise lane should be wide enough to be able to park a disabled vehicle to one side of it and still safely pass on the other side. This extra width is necessary to manage malfunctions and would also be helpful in maintenance. The mixed lane adjacent to the cruise lane becomes the lane selected by automated vehicles when desiring to access the dedicated lane - a transition lane. To maximize the throughput of vehicles of all sizes, automated heavier vehicles would cruise in the rightmost lane mixed with manual traffic, using the transition lane to pass if necessary. As participation builds over time and the flow in the dedicated automated lane increases, a physical barrier would be used to protect the automated cruise lane from the other traffic and foreign objects. The barrier would move to the right by one

[1] Participation is the percentage using and seeking to use the automated mode in a specific section of freeway.

lane width at sections where the access and egress lane changes actually occur. The vehicle itself would be responsible for:

- lane regulation
- gap regulation
- vehicle malfunction management
- driver malfunction management
- surface condition
- obstacle management.

and through a limited-range, random access communications link to other vehicles:

- access/egress execution
- emergency braking
- obstacle management
- surface condition
- space regularization[2] (optional)
- incident detection.

Infrastructure remote control stations through sector broadcasts would be responsible for

- speed gap commands by sector
- regularization by sector
- traffic sensing
- obstacle detection (shared with vehicle and driver)
- weather sensing (including surface condition), and
- management of driver malfunction.

The Freeway Traffic Operation Center (TOC) would be responsible for:

- normal cruise flow management
- accesslegress flow management
- entry/exit flow management (in conjunction with regional TOC)
- incident management
- weather factor integration.

It would operate the remote control stations and receive information from them using a two-way data link. The freeway TOC also communicates with the regional TOC to the extent dictated by freeway entry/exit flow increases that eventually would be the result of higher cruise lane flows.

The driver would have much more opportunity to divert attention since no manual vehicles would travel in the cruise lane. However, the driver would be required to remain alert and "on-call" to manage malfunctions that require some driver role. Examples are: change of exit selection, selection of the breakdown side of the lane and vehicle stoppage due to vehicle fire, control roughness, shut down of a failed nonessential subsystem, monitor vehicle automatic management of a malfunction, etc. The driver should assist in detecting and avoiding obstacles by causing a bias in the lane tracking position using a slow drift rate on/off controller with lane position override at the edge of the lane.

6.2.3 Concept 3 - Dedicated Flow

The dedicated flow concept removes manual vehicles from the transition lane. With a dedicated transition lane and sufficient participation to justify the cost of substantial midway modification, large access and egress flows can be managed. This would include demerging and merging of high flows at the intersection of two AHS's. It also would include connecting the transition lane

[2]Space regularization is the automatic arrangement of space available in the lane to add more vehicles efficiently.

with a manual freeway entry/exit so that the entire process becomes automated. In this concept, a mature AHS might allow the driver even more freedom of activity.

6.2.4 Concept Relationships

All three concepts regard the interfaces between an AHS and the existing manual system to be the freeway entries and exits. Since flows must balance, these points are the important coordination hand-offs between the freeway TOC and regional TOC. Concepts such as dynamic route assignment and demand management become highly important to realize the full benefits of AHS in a high-demand urban region. Also the placement of new dedicated entry/exit involve highly important regional social, economic and environmental issues which are not AHS-specific and truly belong at the interface of AHS concept development.

The deployment plans follow market developments. As the market and participation builds, Concept 2 and eventually Concept 3 are deployed. Concept 1 might be used for intercity travel, even in the mature network. Some site-specific requirements might drive the deployment of Concept 3 earlier.

Lane throughput capacity is tied to safety through an analytical approach that proceeds from a Safety Policy to vehicle density at given conditions and speed range. The existing roadbed construction and the existing right of way are exploited using automation, communication, and software rather than use concepts requiring extensive infrastructure modification. This strategy should minimize cost while obtaining marketable benefits.

6.3 PAC-ITS
Packet Autopiloted Cruiseway-Intelligent Transportation System

HAUGEN ASSOCIATES

6.3.1 What Is PAC-ITS?

- A packet train is a mix of 15 or 20 vehicles - personal cars, low profile buses and freight units - mechanically coupled together for intercity travel
- A professional "pilot" controls each packet train from a special lead vehicle
- All vehicles in the packet train are guided by a high-tech lateral guidance system controlling them to keep precisely the same path
- The power trains and brakes of all vehicles are interconnected so they accelerate and brake as one unit
- PAC-ITS trains might initially operate on the Interstate; eventual operation on new high speed guideway using reserved time slots with high safety margins

6.3.2 Why the PAC-ITS Concept?

1. Personal car users can have the confidence of mechanical links and a trained human pilot, rather than relying on complex electronic sensors and logic.
2. Drivers and passengers use their personal vehicles but have zero driving responsibilities while part of the packet train; can relax, sleep, watch movies, etc., with personal privacy.
3. PAC-ITS simplicity minimizes personal car modifications and driver adaptation; no airplane cockpit equivalent needed for AHS operations.
4. The aerodynamics of PAC-ITS trains can achieve a factor of 5 or 10 reduction in aerodynamic drag, with major reductions in energy use and emissions.
5. PAC-ITS trains will permit faster travel between cities - with speeds raised by 5 mps every 2 or 3 years as safety and energy savings goals are met.
6. The overall simplicity of PAC-ITS should allow its deployment in mixed traffic to begin within the next decade.
7. Mechanically linked packet trains can achieve the highest possible roadway capacity with greatly enhanced safety.
8. PAC-its can raise productivity sharply; a pilot can control a train of 20 specialized freight vehicles, thereby creating a new class of high paying jobs.
9. Intercity bus economics, and thus, bus service, can be greatly improved with the PAC-ITS pilot controlling several buses as well as a profitable mix of freight and personal vehicles.
10. High-speed PAC-ITS links can take pressure off airports by reducing the need for short haul flights; increase remote airport feasibility.

6.4 THE HONEYWELL-BRW-UNIVERSITY OF MINNESOTA CONCEPT

HONEYWELL

This section uses the definitions of the various dimensions from Section 2.13.2.

6.4.1 Distribution of Intelligence

This concept is a hybrid of infrastructure-supported and infrastructure managed intelligence. Whereas lane changes are requested from and managed by the roadside system, it has no authority to reroute vehicles--vehicle navigation is controlled by each individual vehicle, based in part on information supplied by the roadside system (e.g., about accidents).

6.4.2 Separation Policy

Vehicles travel as platoons in the urban setting. Vehicles in the rural setting are free agents.

6.4.3 Mixing of AHS and Non-AHS Vehicles in the Same Lane

In the urban setting, there are dedicated lanes with continuous physical barriers to

separate the automated lane from the manual lanes. In the rural setting, full mixing of automated and unautomated vehicles is allowed.

6.4.4 Mixing of Vehicle Classes in a Lane

In both settings, the various vehicle classes are mixed in all lanes. However, in the urban setting, special lanes and/or large-scale bypasses are provided for poor performance vehicles where there are (1) significant grades in the roadway, and (2) areas of consistently high density traffic.

6.4.5 Entry/Exit

In the urban setting, dedicated on- and of-ramps are used, with an inspection site at each on-ramp. In the rural setting, there are non dedicated on-ramps with inspection sites; there are no dedicated off-ramps.

6.4.6 Obstacle Detection and Avoidance

In both settings, automatic sensing and automatic avoidance maneuver (if possible) are used.

6.5 EVOLUTIONARY AHS CONCEPT BASED ON PRECISE POSITIONING, IMAGE RECOGNITION, AND INTELLIGENT AUTONOMOUS CONTROL

SRI INTERNATIONAL

SRI, under contract to NAHSC through UC Berkeley and PATH has developed an evolutionary approach to AHS that, with minimal infrastructure requirements, provides selected interim capabilities and utility to ensure a viable and mature system upon completion of a phased development effort. The evolutionary stages include: (1) A follow-the-leader capability in which the lead vehicle is manually driven and multiple automated vehicles follow in a platoon. The primary beneficiaries of this phase may be long haul freight operations. (2) An advanced cruise control system that allows properly equipped vehicles to stay within surveyed highway lanes, maintain safe separation distances, and avoid collisions with obstructions and other vehicles. Vehicle drivers on long trips may be the beneficiaries of this phase which should dramatically reduce the number of single vehicle road departure accidents. (3) A completely automated system with autonomous vehicles operating on, eventually, dedicated AHS highways.

There are four key aspects to the concept: (1) The ability of each vehicle to measure its absolute position on the road to within a centimeter or two. When combined with vehicle sensor data and road database information, this high-precision location capability provides the information required for safe and reliable control and maneuvering, especially in emergencies. (2) The integration of data from multiple active and passive sensors to ensure reliability and form a dynamic model of the environment around the vehicle for situation awareness. (3) A supervisory control system for each vehicle that can recognize and efficiently act to critical events. (4) The majority of the sensors and system control resides in the vehicles so the infrastructure changes are minimal. The dominant technologies chosen to provide the required capabilities are: The Global Positioning System (GPS) for position location, image recognition using multi-spectral sensors (optical, infrared, radar and LIDAR) for situation awareness and guidance redundancy, and artificial intelligence and intelligent controllers for sensor fusion and supervisory control.

The absolute precise positioning supplied by this concept is a major step in the development of practical Roadway Powered Electric Vehicles (RPEV). Precise positioning allows the power to be transferred to the vehicles at very limited distribution points. The ultracapacitor, currently being developed, allows the vehicle to take on a large amount of electrical energy in a small fraction of a second.

6.6 LIGHT AHS CONCEPT SUMMARY

TOYOTA

This is a summary of the concept of a LIGHT CAR that, together with a LIGHT INFRASTRUCTURE, forms a LIGHT AHS. The LIGHT AHS arises both from the vehicle orientation of an auto manufacturer and from the need for AHS to be fundamentally market-driven to succeed. Through an evolutionary development approach, the LIGHT AHS is intended to be light in terms of the cost of modifications to the existing infrastructure, light in the complexity of the vehicle, light on the wallet of the car-buying and road-building taxpayer, and light in the effect of implementation on society. It features the use of light (Photonics) technologies where appropriate to sense, communicate, and control.

The LIGHT CAR uses precise measurements made by onboard optical sensors to guide the vehicle. The LIGHT AHS Concept also includes a magnetic marker lane reference and a roadway-to-vehicle communications system, which are essential parts of the LIGHT INFRASTRUCTURE. The LIGHT AHS Concept extends the LIGHT CAR to include an on-board map database for coarse road geometry information and roadway features. The combination of these technologies makes possible a near-term, realizable, robust, redundant, fullfeatured vehicle that can be used on any AHS segment in the US.

The LIGHT AHS Concept maximizes the use of currently existing highway infrastructure over the course of the AHS evolution. Infrastructure modifications may be limited to a roadside communications transmitter and receiver for road geometry updates, climate, and traffic information dispersal and acquisition. In areas of frequent poor weather, more frequent periodic passive markers on the roadway will be installed for fine motion control. Passive reflective or magnetic markers have been selected for the LIGHT AHS Concept but other technologies may also be applicable. Deployment is done in phases to "think and learn while running" in an attempt to focus investment on high return areas of AHS' promise. Putting as much of the technology on the vehicle as possible will continually renew AHS with each succeeding car model. As technology progresses, the LIGHT AHS will become lighter, particularly in the infrastructure.

- **Allocation of Intelligence**
  The allocation of intelligence evolves with the deployment of the LIGHT AHS. Initially, as components of the LIGHT AHS are deployed for mixed traffic, the vehicle will be fairly independent of the infrastructure, relying on passive elements. As more AHS features are deployed, the vehicle and the infrastructure become more interdependent, with a balance of intelligence. Ultimately, the LIGHT AHS is an "Infrastructure Supported" concept. The control decision making is left primarily in the vehicle. The infrastructure supports this decision making by providing additional information that is difficult to obtain with onboard sensors.
- **Separation Policy**
  Both "Free Agents" and "Platoon Operation" are permitted in the LIGHT AHS Concept to give the driver an element of control and freedom of choice.

Mixing of AHS and non-AHS Vehicles Some features of the LIGHT AHS will be available in mixed traffic on all conventional highways throughout the evolution of the AHS which will improve the safety and performance of conventional highways.

- **Mixing of Vehicle Classes in a Lane**
  The LIGHT AHS Concept will accommodate any vehicle which meets the minimum performance and equipment standards.
- **Entry/Exit**
  Dedicated entry and exit ramps are preferred, but shared on-ramps and off-ramps with transition lanes are feasible for the LIGHT AHS Concept, causing a slight degradation in

the overall system performance. A retractable, soft barrier at the entry can discourage non-AHS vehicles from entering without causing a traffic delay or hazard.

- **Obstacle Detection and Avoidance**
  Obstacle detection is primarily automatic using both onboard and infrastructure-based sensors. Initially, infrastructure-base sensors will be needed since current sensor technology does not cover all possible road conditions. As the technology advances, the LIGHT AHS will be less dependent on infrastructure elements. The driver interface will provide the driver with a limited ability to alert the system of obstacles not detected by the AHS. However, control actuation will still be automatically controlled by braking and/or steering.

6.7 COOPERATIVE INFRASTRUCTURE MANAGED SYSTEM (CIMS)

VIRGINIA POLYTECHNIC

The Virginia Tech Center for Transportation Research Concept is a cooperative infrastructure/vehicle based automated management approach referred to as a "Cooperative Infrastructure Managed System (CIMS). There are many possible AHS concepts and each has its individual strengths and weaknesses. The "Coopera-tive Infrastructure Managed System (CIMS)" builds on the various strengths of several systems in a cooperative fashion. The CIMS system is neither a totally vehicle-based system nor a totally infrastructure-based system. It relies on cooperation between processors on the roadside and on the vehicle and shares command decisions between the vehicle and the infrastructure. The concept uses communi-cations to integrate the vehicle with the roadside. In addition, this system does not need complex roadside sensors to detect and manage the vehicles. Instead, it uses cooperation between the vehicle and roadside infrastructure to determine the best path for each vehicle on the road based on a global knowledge of location of all the vehicles in an area. Through this coopera-tion, the tasks best suited for the vehicle are performed on the vehicle and the tasks best suited for the infrastructure are performed at the roadside.

The system fuses together the multiple sources of sensory data from both the vehicles and infrastructure into a layered management algorithm designed to optimize the safety of the system while maintaining designed throughput potential. A new solid state ultra-wideband communications system is used for precise vehicle and roadside waypoint location and simultaneous information sharing. The location from this sensor can be fused with on-board sensors to provide an accurate picture of the surroundings in which to develop an integrated control strategy.

This design approach attempts to fully exploit the opportunity of cooperation between the roadway and the vehicles to simplify the sensors and processing required for autonomous vehicle operation. By tak-ing some of the bulk of the processing and sensing load off the vehicle and distributing it throughout the infrastructure, added vehicle costs are minimized with little added infrastructure. All sensory input the vehicle has to offer can be communicated top the infrastructure and integrated with the global information set.

6.8 EVALUATION OF THE SOLICITED CONCEPTS

By design, the Contractors were given a broader task in defining their concepts than was attempted with our internally defined concepts. Internally, we specifically focused our study on a limited number of architectural and operational questions, as described in detail elsewhere in this report. Although our concept teams did identify specific technologies as part of their concept definition work, we did not press a detailed analysis of implications of those technology selections on the resulting concept. Further, the selected technologies played almost no role in the subsequent evaluation of the concepts.

The contractors, in their analysis, were asked to use the same evaluation criteria, and were asked to describe their concepts in terms of our architectural and operational questions. But beyond that, they were given freedom to raise and address any other architectural, operational, or technology questions. And they did.

Technical Issues

This resulted in a spectrum of useful work which will be valuable to the Consortium over a much broader period of time than just this initial concept development effort. Several of the contractors analyzed and evaluated specific technologies as part of their concepts. Battelle and Ohio State University featured the use of radar reflective stripes to define the roadway and radar reflective patches to identify other vehicles. Haugen Associates based their concept on mechanical links between vehicles and trained professional drivers rather than relying on complex electronic sensors and software logic. SRI included in their concept carrier phase GPS to provide vehicle position information to within a centimeter or two. Toyota emphasized the use of on-board optical sensors. Virginia Tech included in this concept an ultrawideband communications which can provide both communications and precise vehicle and roadside waypoint locations. Most of this effort will be extremely useful in the near future when the Consortium integrates our concepts with specific technologies to build a working prototype. Some of the contractor's proposals already have spawned work under our Enabling Technologies task.

Architecture Issues

With respect to the architecture question we raised internally, the contractors were relatively consistent in their own conclusions. Almost all the contractors considered a combined vehicle/infrastructure architecture, but with variation in the relative degree of intelligence allocated to each component. Still, almost all felt that some AHS infrastructure was necessary to achieve maximum capacity and safety. The Battelle concept is based on a vehicle-heavy distribution of intelligence, with a "smart" vehicle and a minimally instrumented infrastructure in rural areas and increasing levels of sensing and communications to provide additional functionality in the fringe and urban environments. Calspan likewise advocated a vehicle/infrastructure architecture with infrastructure remote control stations and a Traffic Operation Center. Honeywell suggested a hybrid between our infrastructure-supported and our infrastructure managed architectures. SRI formulated a vehicle intensive architecture with a minimal control infrastructure. Toyota's concept included an interesting approach of evolving first from a mode where the vehicle is fairly independent of the infrastructure to one where the vehicle and the infrastructure became more interdependent, to an ultimate architecture where again the vehicle becomes more capable and less dependent on the infrastructure. Virginia Tech proposed a more infrastructure dependent architecture relying heavily on wide band communications with the vehicles.

Operational Issues

It was in the area of operational issues that the contractors provided the most useful help for this phase of concept development. Indeed, their conclusions had a very strong impact on the selection of the concepts for the next phase of our investigations. The most enlightening aspect of the contractor's effort was their consistent, and strong, emphasis on deployment scenarios and regional application scenarios. All of them felt that a viable AHS concept must satisfy an incremental deployment scenario where there is a gradual introduction of increasingly capable AHS functions. They also felt that a successful AHS would have to be adaptable in a variety of urban, intercity, and rural applications.

In this specific area of deployment scenarios and regional adaptations:

- Battelle described a concept with different operating procedures for rural and urban areas. For rural areas they proposed mixed traffic operation, on non-dedicated AHS lanes, with a minimum of infrastructure, possibly none at all. They viewed this system as an advanced version of adaptive cruise control, possibly with GPS based speed alerts for hazards. They also felt that simple, leader-follower truck convoys would be a viable addition. For urban areas where the system has to start dealing with increasing and eventually stifling demand, Battelle proposed dedicated lanes (link HOV lanes) and bus convoys, supported by a more complex infrastructure.
- Calspan proposed three levels of capabilities, which could be applied either as deployment stages or as regional adaptations. The first stage provided the capability for some automation in mixed traffic lanes. Modest gains in driver comfort, convenience and safety would be experienced. The second stage provides dedicated cruise lanes with access via mixed transition lanes. Barriers would be introduced to protect vehicles in the automated cruise lane. In the final stage, dedicated entry/exit ramps are introduced to further smooth the flow of increased traffic.
- Haugen focused on intercity applications. This was a natural consequence of their design, since the mechanical coupling approach involves considerable entry and exit delays (when compared to electronically coupled designs) and these longer delays only make sense if time then spent on the AHS is longer. That is, the benefits of this concept are more apparent with longer distance intercity routes than with shorter commute routes.
- Honeywell likewise foresaw mixed traffic rural applications and dedicated lane urban operations. They also shifted functions from the infrastructure to the vehicle as they contrasted their urban and rural assumptions. They proposed that vehicles on a rural AHS highway would operate as individuals but that on an urban AHS they would operate in platoons.
- SRI International proposed a more vehicle centered approach where the vehicles had primary responsibility of maintaining a spatio-temporal situational awareness based on communications with other vehicles and suite of on-board sensors. They felt that three evolutionary steps would be required. The first provided follow-the-leader concept where instrumented vehicles would be able to lock on to and follow manually driven lead vehicles. In the second stage, individual vehicles would have advanced cruise control with automatic lane keeping. Both of these phases involved mixed traffic operations. In the third and final stage, they added an infrastructure control system and operation on dedicated AHS lanes.
- Toyota also talked of three phases but in a context of pre-AHS, AHS, and beyond AHS evolution. Their first phase is a driver assisting, vehicle based system with adaptive cruise control, collision warning and control, and lane departure warning and control. The second phase is a full AHS system and incorporated vehicle and infrastructure elements. Their third phase looks at a time when all automobile travel is entirely automated and intriguingly predicts that the system will evolve back into the vehicle with no infrastructure component.
- Virginia Tech developed a concept which also starts with mixed traffic operations then evolves into dedicated lane deployments. This, they feel, would provide safety and convenience

benefits early with throughput enhancements coming at the later stage. Further, they see intercity uses as the most natural early deployment venue. They differed however, with some of the other contractors, as seeing a global control infrastructure being required from the beginning.

On the issue of separation policy, most of the contractors felt that a free agent, independent vehicle policy would be appropriate in their light duty, rural, mixed mode operations and that a platooning capability would be necessary to achieve high capacity in congested urban areas. Many felt that both of these capabilities should be incorporated in the AHS design. Most felt that if platoons were supported that they should be limited to platoons of a single vehicle class. One contractor, Calspan, offered a different solution. Their analysis caused them to reject platooning as less safe than maintaining a constant minimum spacing between vehicles, and as not necessary to achieve the same high gains in throughput (up to 4 times today's highway throughput).

On the issue of mixing different classes of vehicles, that is, on building an AHS which can support different classes of vehicles operating in the same lane at the same time, all the contractors felt that it would be unreasonable to build an AHS without this capability. Some (Calspan and Battelle) warned against mixing of vehicle classes within a platoon. These two also recommend incorporating an ability to operate with segregated classes to allow localities to address specific performance goals. One, SRI, went even further and felt that although the capability was necessary it should be rarely used. Toyota felt that all vehicles would have to meet certain minimum performance and equipment requirements.

On the issue of the two types of entry/exit configurations (transition lanes or dedicated on/off ramps) there was a little more variation between the contractors. Calspan, Battelle, and Toyota felt that both types would be necessary, either because of right-of-way considerations or to meet different throughput needs. They concluded that transitions lanes would be more appropriate in rural or lower demand applications and dedicated ramps would be more appropriate in urban or higher demand applications. Honeywell felt that dedicated on-ramps, which would allow for vehicle inspection, would be necessary but that dedicated off-ramps would not be required. SRI and Virginia Tech opted for transition lanes.

On the final issue of obstacle detection and avoidance, most contractors, with the exception of Haugen, wanted to see automatic obstacle detection and avoidance. Haugen's concept used trained professional drivers. Two contractors, Calspan and Toyota, felt that the drivers should be allowed to intervene if they saw an obstacle, and Calspan commented on the issue of ensuring the driver stayed attentive to this role.

Conclusions

The effort and thought that the contractors gave to this work, and the ideas, concepts, and recommendations they provided us have strongly influenced the concluding effort of this task, that is, selection of the issues on which the 6 concept families would be based. Further, they have given us their insight on various other technical approaches to AHS which have broadened the range of enabling technologies we will consider. A few of the more important recommendations we got from these contractors are:

- We should consider using a suite of different types of sensors, both on the vehicle and along the infrastructure, along with sensor fusion algorithms to increase the probability of maintaining a true situational awareness.
- We should have a flexible design to address a wide variety of market opportunities in addition to the congested urban application. Indeed, there was a healthy difference of opinion as to which application would be the first the market would embrace.
- We should include introductory systems to stimulate the market for more advanced and higher performance fully Automated Highway Systems.
- We should design the system to operate with a minimum of infrastructure

in areas where maximum throughput performance was not needed.

- We would need an infrastructure component to achieve maximum throughput performance.

In final conclusion, this effort achieved its goals. We solicited for strong, helpful concepts and we got them.

Rejected Concept Suggestions

Although the majority of the ideas for concept coming to us in the solicited concepts were evaluated and accepted by NAHSC, either for incorporation or for further consideration, a few ideas were evaluated and rejected. In some cases, the rejected ideas were contrary to conclusions we had drawn from our own concept development and the arguments were not sufficient to warrant reconsideration. In other cases, the rejected ideas, although novel, were not of sufficient merit to warrant further investment of NAHSC resources. Of the rejected concept ideas which were central to a solicited concept, two stand out.

Infrastructure Control -- As documented in Section 5 of this report, the NAHSC came to the conclusion that infrastructure control, as we defined it for our internal concepts, was not viable because it made the infrastructure-to-vehicle communications link safety critical. Although they didn't push the concept as far as we did, Virginia Tech seemed to place too much reliance in the infrastructure-to-vehicle communications link in their proposed concept. As a result, they did not include any discussion of what the concept would do if this link was not available. In our opinion, a viable concept must include a clear description of its capabilities when communications fails. Degradation when communications fails should be gradual, minimal, and safe. When considering this, the concept developer may have cause to reconsider the allocation of functions between the vehicle and the infrastructure. A different allocation may result than that which had looked attractive when communications were not allowed to fail.

Mechanical Coupling of Vehicles -- The concept advanced by Haugen and Associates had, as its most noticeable technical feature, and as the feature around which its salient operational characteristics were developed, the idea of mechanically linking platoons of vehicles. Their rationale for selecting this approach, along with the use of professional platoon drivers, was to minimize the complexity of sensor and system electronics and to minimize the technical problems and risks of a AHS. On this basis, Haugen developed the operational aspects of their concept to take full advantage of these assumptions about technology. After evaluation of this concept, as described in the contractor's Final Report (an appendix to this document), the NAHSC decided that it would not pursue research on mechanically coupled vehicles for the following reasons:

- In part, Haugen proposed using mechanical linked vehicles based on the risk that the technology to implement an electronic link is not presently viable and presents too much risk to the Program. The NAHSC does not share this view, nor did it find any public support for this view among AHS stakeholders.

- Mechanical linking requires off-line platoon coupling and uncoupling with attendant delay. This delay becomes more noticeable when trip times are shorter, as would be the case for commuting trips. Any concept the NAHSC can accept must be flexible enough to address urban congestion.

- The cost of providing paid professional drivers to lead each platoon is a serious drawback, and becomes more of a drawback with shorter trips times (commuter trips).

- The inconvenience and time delay incurred when a vehicle, and the platoon of which it is a part, traveling in an intercity trip (say from Chicago to St. Louis) needs to stop for an unexpected reason (traveler becomes sick, young children need to use a rest room, etc.).