7. CONCEPT FAMILIES

7.1 RECONCEPTING PROCESS

The development of the concepts was based on an early recognition that the 6 concept families selected in C1 would not simply be down selected from the 23 concepts in chapter 3. Instead, the lessons from the evaluation were synthesized (chapter 5), and a set of six new concept families incorporating those lessons were generated.

There were four steps in the development of these concept families. The first step, discussed in Section 7.2, took place at the System Requirements Review of September 19-21, at which the evaluation results and the solicited concepts were presented, and working groups discussed recommendations for the concept families. The next step (7.3) was to form candidate concept families from these discussions. The third step (7.4) was to fuse these alternatives into a smaller number of concept families. The final step (7.5) was the selection and definition of the six families. Section 7.6 describes the concept families.

7.1.1 Requirements for the Set of Six Reconcepted Concept Families

Before actually selecting the six concept families, an attempt was made to set requirements the set of concept families would meet. Suggested requirements are discussed below.

- Must consist of six concept families. (This was followed, and drove selections.)
- Must be available for presentation to the AHS System Concepts Workshop October 18-20. (This set a schedule to fully decide on the six concept families, which slipped somewhat. That slip left insufficient time to fully educate the consortium members on the six selected concept families, resulting in some confusion at the Workshop.)
- Must include concepts families with platooning, and concept families without platooning. (The C1 analysis was insufficient to make a final decision on platooning vs. free-agent, and thus both must be represented in the set of concept families. This was followed.)
- There must be concept families with layered levels of control. (A key issue was determining features on which different concept families with layered control could vary.)
- There must be a concept family with only one layer of control. (This was not followed (all concept families included concepts with multiple layers of control), but some concept families included concepts which have only one layer of control.)
- Some felt there was some requirement in terms of how much the concept families are defined in full deployment and in operational test. Despite that, no such requirement was made or followed in the reconcepting, largely due to time limitations.
- Concepts may be technology-specific, if the technology is central to the concept. This was followed, but the concept families were not initially defined in technology-specific terms.
- Each concept family may be described within it's own point of view of what defines a concept family. In other words, the different concept families do not have to be defined using the same schema. This was followed, most notably in Driver Involvement (7.4).

7.1.2 Concepting decisions made generating the set

- 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) is a local option
- Class mixing is a local option (but impact needs to be better understood)
- A layered approach has merit and should be considered further, although it is not the only approach
- Concept families will be defined as families of compatible options with a growth

path (and hence are not mutually exclusive).

7.1.3 Issues areas to be addressed in this reconcepting set

- Platoon vs. free agent
- The role of the driver (Should he be totally engaged always? Should he have the option of taking control? Should he be a backup obstacle sensor? etc.)
- The optimal amount of layering
- The level of infrastructure involvement
- Mixing with manual

7.2 EVALUATION RESULTS AND RECOMMENDATIONS

The System Requirements Review, held September 19 -21, 1995 in McLean, Virginia, was in large part a forum for concepts and concept evaluations. Specifically, September 20th included presentations on the solicited concepts, which were discussed in Section 6, and the evaluations of the candidate concepts relative to throughput, safety and cost (Section 4). The evaluation results continued the next morning with flexibility and acceptability. Most of the day was a working session. The attendees, which included core team members, solicited concept teams and associates, broke up into working groups to discuss dimensional decisions, new dimensional correlations, additional dimensions, clustering within an evaluation factor and comparisons across evaluation factors. The groups were then asked to make recommendations in terms of the meaning of concept family and the specific concept families to pursue. The groups reconvened and presented their conclusions to the others. Many of the conclusions emphasized the need to address various stakeholder groups and highway scenarios. The associates, especially, as stakeholder representatives provided insight into the range of situations the concepts must address. There were also general recommendations for concept families. The group agreed that concept families will be defined as compatible sets of concepts with a smooth evolutionary path among them, but the group did not make specific recommendations for the six concept families.

7.3 STRAWMAN PARTIAL SETS OF RECONCEPTED CONCEPT FAMILIES

The next step was to fuse the results of the meeting into a set of recommended concept families, from which would come the six families. Various team members developed lists of candidates from their notes and recollections of the various recommendations from the meeting. In particular, a set of six concept families was built on the prevalent recommendations that the concepts be defined by the allocations of intelligence. Also, it was clear to the concepts team that to achieve the diversity of candidate concepts that was recommended there should be at least one free agent concept.

7.3.1. The Allocation of Intelligence Set

The matrix in Figure 7.3.1-1 identifies the six concept families built on the key allocations of intelligence. There had been general agreement at the meeting that allocation of intelligence is a major concept discriminator. Each number in the matrix represents a distinct concept. The check marks indicate an option for the concepts in the same row. So, for example, number 1 is autonomous free agents that can operate in mixed (or segregated) traffic with manual vehicles, and the driver has partial control (or possibly less). Concepts 3, 4 and 5 are all infrastructure supported, but they differ in the level of driver involvement, the ability to operate mixed with manual and whether or not they support platoons.

One weakness of this set of concept families is that it excludes any concept families that are driving disengaged mixed in manual traffic. Nor were there any platooning concept families that do not require infrastructure electronics. Nonetheless, the broad sweep of the concepts captured a reasonable sense of how the different concept factors may correlate, and several of the selected concepts fit within this broad sweep.

Figure 7.3.1-1. Six Candidate Concept Families

	Platoons		Manual and Automated Traffic		Driver Roles			
	Platoons	**Free Agents**	**Mixed**	**Segre-gated**	**Partial Control**	**Malfunc-tion Manage-ment**	**Routine Obstacle Detection**	**Panic Button**
AUTONOMOUS (No communications other than ITS)		1	1	√	1	√	√	√
COOPERATIVE (vehicle-vehicle communications added)		2	2	√	2	√	√	√
INFRASTRUCTURE SUPPORTED (VRC [Vehicle to Roadside Communications] added, broadcast both ways)	5	3, 4	3	4, 5	-	3	4	5
INFRASTRUCTURE ASSISTED/ MANAGED (2-way VRC added, comm. to individual vehicles on dedicated channel)	6	√		6		..		6

*Each number refers to a concept

7.3.2 The Free Agent Set

This consisted of three concept families, which were also three stages of an evolutionary path, and one alternative concept family requiring dedicated lanes for all operations that was isolated in the development flow.

Figure 7.3.2-1 diagrams these concepts and their evolutionary relationship. The first three concept families (labeled 1, 3, 2 in deployment sequence) are shown below:

In selecting the six concepts, it was ultimately decided to merge these concepts 1, 2 & 3 into a single concept family with an evolutionary path, with the focus on the middle point of the evolution as the evaluatory "full deployment." (The final phase is simply indicative of a future growth path.)

Also suggested was an alternative concept, the "Insta-Platoon" on Dedicated Lanes

Urban and Interurban Goal: Platoon on dedicated lanes. Full infrastructure involvement in forming of platoons, merging of vehicles, directing & managing of traffic.

Rural Goal: None, unless capable of having dedicated lanes.

Evolutionary Path: None. Instant drop of capability.

- No AHS capabilities until dedicated lanes are available
- Platoons, heavy infrastructure involvement in forming of platoons, merging/ demerging of vehicles, traffic management
- Vehicles do not have autonomous capability except for degraded modes

7.3.3 The Issues - Oriented Set

This set developed only 5 concept families. They were:

7.3.3.1 <u>Preferred Platooning</u>

The intent of this concept family was to capture the best system concept, given that it

Concept 1 - Autonomou›latooning-Evolution Autonomous

Urban Goal: Free Agent autonc
dedicated lanes wer throughput gains by reducing
disengagement vays. Requires extensive & highly
le vehicle to vehicle
Interurban Goal: Same as urban
ıunications capability

Rural Goal: Vehicles with gre:
features/stress reli as urban
engaged. Respon:ve throughput gains by reducing
Trucking platoons vay - not to the extent seen in urban
vehicle driven, fol ›nment
driver disengaged

Early deployment
Full mixing, no dedicated lanes

Adaptive Cruise Control, Lane Departure Warning, Obstacle Warning

Driver engaged

Urban

Ns (~1 meter?), long platoons
avy electronic infrastructure
bns. Vehicle to vehicle
k Possibly routing control
crences sent to vehicle for
ıaking). All lessons-learned
R latoons in prior rural
In lementations incorporated

Rural

s (~5 meters so other
ntrude), moderate/limited
ructure - no managing of
Tr platoon size very limited
in cles), manual traffic still
fu requires vehicle/vehicle
pc voluntary platooning only,
ed AHS capability vehicles

*Trucks have added incentive to v
vehicle communications capabilit

operates only on fully dedicated lanes, and strongly supports platooning. It was thought that concepts 9 or 14 from Appendix H might best represent this option. The purpose of this concept family, however, was to allow the advocates of limited systems optimized for high throughput through platooning, designed to operate brain-off only on dedicated, physically isolated lanes, to select their preferred system.

7.3.3.2 Preferred Free Agent

The idea for this concept was to select the free agent concept that seemed most promising. It was not clear what the selection would be, but the advocates of free agency would be the ones to decide.

7.3.3.3 Fully layered

This concept was intended to support every level of intelligence, from autonomous through infrastructure managed, as well as platooning, mixing of vehicle classes, and the physical layout of the roadway and entry/exit, as local options. The vehicles would be capable of operating autonomously, but if there were multiple vehicles around, their cooperative layer would naturally emerge. The purpose of this concept is to leave nearly everything possible as a local option.

7.3.3.4 Brain-Off mixed with manual

All the other proposed concept families seemed to require fully dedicated lanes, or driver involvement. This concept family starts by saying that the driver may fully disengage on the highway when mixed with manual traffic. It is expected that would be the driving requirement on the system, and thus significantly different from the others.

While technically very challenging, this is dramatically preferred from a flexibility and deployability standpoint. It would still be able to operate on dedicated lanes, and might accrue significant advantages (such as the ability to platoon for high throughput) when doing so.

It was suspected that the preferred member of this family would also be nearly identical to "fully layered" in those cases where it was operating on dedicated AHS lanes.

7.3.3.5 Full physical isolation from check-in to check-out

In this concept family, the driving characteristic was that the vehicles were restricted to dedicated roadways that physically bar intruders for their entire length. It might also provide substantial roadway markings, such as radar-reflective markers along the walls. This provides a very coddled environment for the vehicle, which should allow substantial off-loading of cost and complexity.

7.3.4. The Representative Set

The final set of recommended concept families was designed to cover the range of alternatives that looked viable following the evaluations.

- Platoon, no mixing with manual ever, range of intelligence from cooperative to infrastructure assisted, supports free agent, various barrier configurations (but not virtual barriers.)
- Free agent (as exemplified, for example, by ongoing work at CMU)
- Some human involvement at all times. Ranges from lane keeping, headway keeping to high end with human as in Calspan
- Supervehicle. Cooperative pushed to the limit. The SRI concept seemed to fit here.
- Single layer (infrastructure assisted). Just stops in failure or goes to autonomous. Revolutionary, not evolutionary.
- Assisted mixing. Allows mixing of AHS vehicles with less-than-AHS vehicles (may include concepts for partial automation with a diversity of automation capability in different vehicles)

7.4 THE MERGED RECONCEPTING SET

This set was developed by merging the various reconcepting sets. It was circulated among various members of the C1 team, and the six concept families selected were derived from this set.

These nine candidate concept families were defined based on the decisions and key issue areas from the Concepts meeting at the SRR. Suggestions for concept families that came out of the break-out sessions were also included. These families are summarized in Table 7.4-I.

Table 7.4-I. Summary of the Merged Reconcepting Set

	Layered	Vehicle Options	Autonomous Free Agent	Driver Involvement
Allocation of intelligence	autonomous, cooperative, infrastructure supported, infrastructure assisted, infrastructure managed	autonomous, cooperative, infrastructure supported, infrastructure assisted, infrastructure managed	autonomous, infrastructure supported (without vehicle-vehicle comm)	autonomous, cooperative, infrastructure supported, infrastructure assisted, infrastructure managed
Separation policy	platoon, free agent	platoon, free agent	free agent	platoon, free agent
Mixing with non-AHS	Yes, no	yes, no	Yes, no	Yes, no
Mixing of classes	Yes, no	Yes, no	Yes, no	Yes, no
Entry/exit and barriers	Transition lane, dedicated ramp, full, partial or virtual barriers	Transition lane, dedicated ramp, full, partial or virtual barriers	Transition lane, dedicated ramp, full, partial or virtual barriers	Transition lane, dedicated ramp, full, partial or virtual barriers
Obstacle detection	Manual or automated detect, manual or automated avoid	Manual or automated detect, manual or automated avoid	Manual or automated detect, manual or vehicle avoid	Manual detect and avoid in conjunction with optional automated detect or avoid
Role of the driver	Completely or partially engaged or disengaged	Completely or partially engaged or disengaged	Completely or partially engaged or disengaged	Completely or partially engaged; bears responsibility

	Super Vehicle	**Dedicated Platoon**	**Mixed with Manual**	**Fully Isolated**
Allocation of intelligence	Autonomous, cooperative	Infrastructure assisted	Autonomous, cooperative, infrastructure managed	Autonomous, cooperative, infrastructure supported, assisted or managed
Separation policy	Platoon, free agent	Platoon	Free agent	Platoon, free agent
Mixing with non-AHS	Yes, no	No	Yes	No
Mixing of classes	Yes, no	Yes, no	Yes	Yes, no
Entry/exit and barriers	Transition lane, dedicated ramp, full, partial or virtual barriers	Dedicated ramp, full barriers	Transition lane, virtual barriers	Dedicated ramp, full barriers
Obstacle detection	Vehicle or manual detect, vehicle or manual avoid	Automated detect and avoid	Automated or manual detect, automated or manual avoid	Automated or manual detect, automated or manual avoid
Role of the driver	Completely or partially engaged or disengaged	Disengaged	Completely or partially engaged or disengaged	Completely or partially engaged or disengaged

-	Dual Layer
Allocation of intelligence	Infrastructure assisted
Separation policy	Free agent
Mixing with non-AHS	No
Mixing of classes	Yes, no
Entry/exit and barriers	Transition lane, partial or virtual barriers
Obstacle detection	Vehicle or manual detect, vehicle or manual avoid
Role of the driver	Completely or partially engaged or disengaged

7.4.1 Layered

This concept family supports the wide range of promising options, including free agent as a special case. In fact, it includes any concept developed by defining combinations of the acceptable options for the dimensions. Specifically, it includes the range of intelligence from autonomous to infrastructure assisted (or managed if needed), supports free agent or platoon, and various barrier configurations and mixing options. This family appears to include elements of all of the solicited concepts. It is layered to support a phased deployment and multiple local options. In fact, there are multiple growth paths, which are themselves local options. There are two questions that this family is addressing: (1) What are the costs and benefits of a layered approach? (2) What are the costs (financial, standards, complexity, compatibility, etc.) of maintaining a wide range of options?

<u>One approach: Fully Layered, Infrastructure Options, Designed from the Bottom Up.</u>

This concept is influenced by a vehicle design philosophy; the architecture is grown out of the vehicle. First, a fully functional autonomous vehicle is designed and debugged. Then vehicle-to-vehicle communications (with margin) are designed so that the vehicles can share a common traffic picture and coordinate their actions. Then, infrastructure support messages are defined, along with the architecture for how vehicles respond to this information. Finally, infrastructure management commands can also be detected and followed. Particular members of this concept family are distinguished by a roadway-vehicle specification (possibly specifying, for example, a particular pattern of magnetic nails or radar reflective strip), a logical architecture, and a communications specification, and implicitly by the vehicle architecture. The vehicles drive in a [driver] brain-off manner, autonomously when alone, cooperatively when there are other vehicles around. They also can receive and use infrastructure support information, and receive and follow infrastructure management commands. Vehicle platoons are formed when directed by the highest available decision level.

<u>Another approach: Fully Layered, Infrastructure Options, Designed from the Top Down</u>

This concept is influenced by the system design philosophy; the architecture is defined outward from the vehicle-infrastructure interface. First, a vehicle-infrastructure interface is designed, which, when supported on both sides by the vehicles and the infrastructure, allows the vehicles to drive in the system. Then, the vehicles are given additional functions so they can operate where there is only infrastructure support. After that, cooperative and autonomous modes are added. Particular members of this concept family are also distinguished by a roadway-vehicle specification, a logical architecture and a communications specification. The highway can operate at any level, from infrastructure managed to autonomous, letting vehicles run in brain-off mode. The infrastructure manages the vehicles, which are robust enough to operate with only infrastructure support. With no infrastructure support the vehicles devolve to cooperative, or even autonomous, mode. Vehicle platoons are formed when directed by the highest available decision level.

7.4.2 Vehicle Options

This is an expansion on Layered, with a range of vehicle options as well. This double layered concept family supports automated driving on the highway, with the location able to decide on any level from cooperative through infrastructure managed. Vehicle platoons are formed when directed by the highest available decision level. Buyers have the option of purchasing vehicles with limited options (for example, a vehicle which cannot platoon, and thus is not allowed on the platooning lanes). An open question to be determined by further work is "what is the set of option packages for AHS from which buyers may select?" A particular issue is "what is the least expensive AHS option one may select?" Another open question is what vehicle options, if any, are there in which the driver is in the automated driving loop (for example, possibly performing as a hazard spotter). Another issue is whether capability mixing is allowed on a lane or whether all admitted vehicles must be equipped to operate at the level of the lane or higher.

7.4.3 Autonomous free agent

In this concept family, vehicles are autonomous, with no transmit capability, but able to receive ITS features such as real-time traffic information. Thus, they can operate at the infrastructure supported level without cooperative capability. Early implementation on non-dedicated lanes provides some automated vehicle functions while traveling mixed with manual traffic, but requiring the driver to remain in control. Where dedicated AHS lanes are provided, AHS vehicles travel in Free-Agent mode with high throughput. In some locations the infrastructure may establish roadside sensors, particularly for obstacle detection, and broadcast that information in the immediate area. This concept is based on PSA analysis that indicates that free agent has throughput comparable to that of platooning. The question here is (1) the comparison between the platooning and free agent under various vehicle mixes, infrastructure configurations, assumptions and safety policies and (2) whether there are requirements for intensive infrastructure involvement.

7.4.4 Driver involvement

This family includes the full range of options in Layered, with a major exception. Each of the concepts in this family have some human involvement at all times. Examples range from lane keeping and headway keeping with the driver fully responsible to high end concepts with the human acting as a backup sensor, as in the Calspan concept. This also includes Battelle's concept of a lead truck. The basic premise behind this approach is that no automated system will in the near future match the pattern recognition and inferencing capabilities of the human. In the very long term, such concepts may evolve to fully automated systems as the obstacle detection technology matures. The question being addressed is the cost, risk, safety and benefit comparisons of relying on, allowing or forbidding driver intervention.

7.4.5 Supervehicle.

This concept family is heavily vehicle-oriented, with very little infrastructure. Specifically, the infrastructure includes at most sensor-readable lane markers, digital ITS traffic information and GPS. In the high end variation, the oversight and management activities that might otherwise by carried out by the infrastructure are distributed among the vehicles, so that the vehicles in an area together become a virtual local processor. This may involve extensive message passing over large areas and sophisticated data fusion and inferencing. This family includes autonomous and cooperative pushed to the limit. It also includes the SRI concept. This family is based on the issue of vehicle versus infrastructure, with the maximum possible in the vehicle.

7.4.6 Dedicated platoon

This is a single element concept family with some local options within it. The motivation here is to pick the best solution and avoid the expense of the underlying layers and of a gradual upgrading. This is a revolutionary, not evolutionary, approach. The thought behind this is that the AHS will be put in place in finished form, one area at a time, and that the evolution will be geographic only. The choice of free agent or platooning as well as class mixing may be set locally or dynamically. Physical configuration (ramps, transition lanes, etc.) is a local decision. There is one level of vehicle automation; any vehicle not so equipped may not use the AHS. The design will determine whether there are underlying layers for failure. All options in this family have a completely disengaged driver, based on the assumption that any manual activities on the AHS are dangerous. The comparisons to be made here are between the benefits, risks and costs of an evolutionary and layered approach and a revolutionary approach and between the benefits and risks of keeping the driver out of the loop.

7.4.7 Mixed with manual

This concept family allows automated vehicles to drive in a brain-off mode when mixed with manual traffic. Particular members of this concept family are primarily distinguished by the level of infrastructure and vehicle activity allowed when mixed with manual traffic, and the range of allowed operational modes when automated traffic is in dedicated lanes. Note: This may not be a concept family or even a concept in its own right, but a possible enhancement to concepts that allow mixing with manual traffic.

Assisted mixing is a variant on this concept; it allows mixing of AHS vehicles with less-than-AHS vehicles. For example, the less-than-AHS vehicles may be equipped with reflectors and/or communications. They are not automated, but may share the AHS roadways if they are equipped to support the automated vehicles. The question here is the cost, risk and benefit of mixing with traffic that is not fully automated.

7.4.8 Full Physical Isolation

This concept family requires that the Automated roadway be fully physically isolated from manual traffic and other preventable hazards from check-in through check-out. It guarantees vehicles this restricted environment, which the vehicles exploit to simplify the automated driving problem. To make the down-select from 6 to 3 might require a technical case to be made within this concept family, showing a particular member which achieves some major advantage (e.g., low user costs) from exploiting the simplified environment that the AHS Vehicles operate in. Particular members of this concept family are largely distinguished by the vehicle-roadway interface (specified down to the level of the particular implementation of the particular technologies used).

7.4.9 Infrastructure-Assisted Free Agent

This is a single element concept family with some local options. This is an infrastructure-assisted system where the vehicles operate autonomously except at merge points; here they receive directions from the infrastructure. The autonomous layer also serves as a failure mode, a geographic option, and an evolutionary stepping-stone to the full concept. Infrastructure-to-individual vehicle communications is supported, but there is no vehicle-to vehicle communications, and vehicle-to-infrastructure communications is limited to driver alerts for obstacles and emergencies. There is no mixing with manual traffic; the choice of class mixing may be set locally or dynamically. Barrier options are limited to virtual barriers and barriers with gaps. Obstacle detection and avoidance could be either manual, automatic, or a combination of the two. This concept offers a compromise between the expense of a fully-layered system, and the inflexibility of a single layer approach.

7.5 FINDING THE RECONCEPTING SET

The nine candidate concepts were sent to the core team members for review. The Hughes and PATH teams then convened a meeting at PATH to select the six concepts, based on all candidates and all feedback and suggestions. In selecting the six concepts, Layered turned into Maximally Layered. It was decided that Vehicle Options, was a design option to be worked out within the development in C2 of Maximally Layered. Autonomous Free Agent was incorporated within the Vehicle Centered concept family. Driver involvement continued as a selected concept family. Supervehicle was essentially captured within Cooperative Plus.

Dedicated Platoon was carried forward as two separate concept families, Infrastructure Supported Platoons, and Infrastructure Assisted Platoons. This allowed a continued extensive comparison of these answers to distribution of intelligence within the context of a concept of platooning on dedicated lanes. Mixed with Manual was dropped, although the rural implementation of Vehicle Centered includes the same capabilities. Cooperative Plus may develop into a concept with brain off driving mixed with manual traffic, and Driver Involvement should also look at mixing with manual traffic. Full Physical Isolation was dropped as a concept, but may be partially embraced by Infrastructure Supported Platoons and Infrastructure Assisted Platoons.

Finally, Infrastructure Assisted Free Agent was dropped, although it remains a local option within Maximally Layered.

7.6 THE SELECTED SIX CONCEPT FAMILIES

7.6.1 Overview of the Six Concept Families

In summary, the six concept families selected were as follows.

7.6.1.1 Vehicle Centered

This architecture focuses on maximizing the performance that can be obtained from lone vehicles, while at the same time holding down cost by eliminating the cooperative layer. It may be minimally supplemented with infrastructure assistance to improve throughput. It also provides an early benefit for urban users in the form of driver disengagement, and for rural and intercity users in the form of driver-assisted truck and bus platoons.

7.6.1.2 Cooperative Plus

This concept family focuses on obtaining the maximum performance achievable without requiring infrastructure electronics. This is done by using extensive vehicle-to-vehicle communication to pass messages over extended ranges, and by providing the vehicle with substantial on-board processing.

7.6.1.3 Driver Involvement

All members of this concept family make use of man-in-the-loop operations. The exact areas of human involvement are design options, and may include obstacle detection, obstacle avoidance, and handling catastrophic hardware/software failures or other unexpected problems. This range of design options will be refined later, based on technology studies which reduce the uncertainty regarding man vs. machine performance.

7.6.1.4 Infrastructure Supported Platoons

This concept family focuses on the throughput and safety implications of driver disengaged platooning, in the framework of an infrastructure-supported system where the infrastructure does not communicate with individual vehicles. Since the Infrastructure Assisted concept family is similar but has an Infrastructure-Assisted architecture, this concept family pair will also provide an excellent comparison of the benefits and cost of infrastructure-supported vs. infrastructure-assisted.

7.6.1.5 Infrastructure Assisted Platoons

This concept family focuses on the throughput and safety implications of driver disengaged platooning, in the framework of an infrastructure-assisted system where the infrastructure communicates with individual vehicles when appropriate (for example, merge points). Since the Infrastructure Supported concept family is similar but has an infrastructure-supported architecture, this concept family pair will also provide an excellent comparison of the benefits and cost of infrastructure-supported vs. infrastructure-assisted.

7.6.1.6 Maximally Layered

This concept family focuses on providing a family of choices, with full layering for geographic, deployment, and failure options, and numerous alternatives in the other dimensions. This architecture has the flexibility to evolve as experience is gained from early deployments, and has robustness in the case of failure, but it may be costly to implement and maintain, and it raises issues of the transfer of control from one layer to the next.

7.6.2 Summary Table

The concepts, in their deployment phases, are summarized in Table 7.6.2-I.

Table 7.6.2-I. Summary of Six Concept Families

Concept	Deploy Phase/ Geogr. Option	Distrib of Intelligence	Mixing with Manual	Driver Engagement	Separation Policy	Comments
Vehicle Centered	1	Autonomous	Rural only	Rural only	Lead driver-engaged truck and bus platoons in rural	Truck and bus platoons in rural
	2	Infrastr. Assisted with Autonomous backup	Rural only	Disengaged	Autonomous truck and bus platoons in rural	Disengaged driver
Cooperative Plus	Early	Cooperative (autonomous backup)	Begins with engaged driver in mixed traffic, and progresses...		Platooning where dedicated lanes are available	Option for early benefits
	Late	Cooperative (autonomous backup)	...toward disengaged driver on dedicated lanes		Platooning where dedicated lanes are available	Maximize perf. of totally vehicle based architecture; Disengaged driver; mixed with manual and platooning are local options
Driver Involvement	1	Autonomous to Infrastructure Supported inclusive	Yes	Engaged	Free agent	Explores role of engaged driver
	2	Autonomous to Infrastructure Supported inclusive	No	Engaged	Free agent	Dedicated lanes for performance gains
Infrastructure Supported Platoons	1	Autonomous to Infrastructure Supported inclusive	No	Disengaged	Platoons	Explores platooning with infrastr. support in dedicated lanes; use all techniques possible to improve perf.
Infrastructure assisted platoons	1	Autonomous to Infrastructure Assisted inclusive	No	Disengaged	Platoons	Explores platooning with infrastr. assistance in dedicated lanes
Maximally Layered	Early	Autonomous	Yes	Engaged	Free agent	Explores early benefits with evolution path
	Intermed. example	Cooperative with underlying autonomous	No	Disengaged	Geographic option	Platooning option
	Late example	Infrastructure managed with underlying infra-structure support, cooperative and autonomous	No	Disengaged	Platoons	Maximum flexibility and degradation options; explores interaction of layers

Each of these families is defined by the characteristics which the members of each particular family share. There remain a host of important issues that are undecided within each family. The different possible answers define the different members of each family. Some important issues may not yet be identified.

There are two sorts of variability within each concept family. The first is "stakeholder options." These are choices that people will have if a particular concept is chosen and deployed. For example, local officials may have a choice between having platooning traffic on a lane or free agent traffic on that lane. The choices provided to individuals, such as between different packages of AHS capabilities to buy, are also "stakeholder options."

The second sort of variability is "design options." These are choices that still need to be made by the consortium about exactly what concept will be implemented. For example, AHS may be designed so that is allows platooning, or so that it does not allow platooning. As the individual concepts are discussed below in detail, the distinction between stakeholder options and design options will be emphasized. Note, it may be a design option to offer a stakeholder option.

Finally, these six concept families are merely the point of departure for future work. If it is later found that the best refinement to one of the six is to make a choice that is outside the formal definition of that concept family, a refinement that makes sense will still be selected.

7.6.3 Descriptions of the Concept Families

7.6.3.1 Vehicle Centered

This concept family is based on a particular vision of AHS evolution. This is also the only concept family which has already developed explicit and distinct goals for urban and rural areas. It is expected that before AHS is deployed, the fielded capabilities will be as follows: driving with adaptive cruise control, lane departure warning, and obstacle warning, but with the driver engaged. Lower end vehicles may not have all these features. It will be technically possible to combine adaptive cruise control and lane keeping in the same vehicle, but this will not be done, because drivers would then in fact disengage, which would be unsafe when obstacles and emergencies come up.

The first AHS phase thus focuses on safely, providing driver disengagement in the urban areas when dedicated AHS lanes are established by reducing hazards and providing automatic obstacle avoidance. The goal in the rural areas is to continue and enhance driver engaged free agent driving, mixed with manual traffic on non-dedicated lanes. Vehicle Centered offers a stakeholder option in this phase for truck platoons on mixed rural roads, where only the lead driver needs to be engaged.

In the first phase of Vehicle Centered in urban areas, vehicles travel on dedicated lanes with the driver disengaged. The vehicles include lane keeping and obstacle avoidance. There is some infrastructure assistance and infrastructure support, as appropriate to support the goal of driver disengagement. The exact details are design options, but infrastructure assistance to support vehicle merging at entry is expected. As a stakeholder option, there may be roadside sensors supplementing system performance. One use would be to look into the "blind-spots" to warn of hazards, keeping vehicles from having to slow down.

The second phase of this AHS is most clearly distinct in the rural areas. While autonomous vehicles may already travel mixed with manual traffic on non-dedicated lanes, in Phase 2 of Vehicle Centered the goal is to disengage the driver. This is safely accomplished with improved sensor and processing capability on the vehicle. As a design option, it may also be necessary to require all vehicles (not just AHS vehicles) to carry simple transponders. This is the primary concept family for examining driver disengaged vehicles mixed with manual traffic, and the only one where this is a firm concept goal rather than a possible design option.

The second phase of Vehicle Centered is less distinct in urban areas. There, infrastructure is progressively added, increasing the safety and throughput capabilities of the system.

There is a well-defined follow-on evolutionary path in this concept family. That third phase would add vehicle-to-vehicle communications and supports platooning.

7.6.3.2 Cooperative Plus

This concept family focuses on obtaining the maximum performance from a totally vehicle-based architecture. The mature vision is of platooning AHS vehicles on high-throughput dedicated lanes, coordinating their short and long-term maneuvers using vehicle-to-vehicle data links, with longer-range data being passed up and down the traffic stream by on-board data reduction and message rebroadcasts. This scheme could, for example, allow vehicles throughout a large metropolitan area to all have on-board maps with real time traffic information, which is fine-grained near the vehicle and increasingly coarse-grained for areas further away.

The details of the vehicle-to-vehicle communications are design options. Particular questions include "Is it non-line-of sight?"; "What is the communication range or ranges?"; "What is the bandwidth?"; "What is the basic network protocol?"; and "What spectrum is used?"

A major conceptual task in developing this concept family is to take the specific infrastructure functions, as they are developed for the Infrastructure Supported and Infrastructure Assisted concepts, and try to determine how to implement equivalent functions using only on-board processors and vehicle-to-vehicle communications.

Cooperative Plus spreads across a continuum of capabilities that will be available for deployment sooner versus later, and is represented in the summary chart in Table 7.6.2-I by two distinct phases. Early capabilities include platooning, coordinated merging and lane changes, and some extended message passing. Capabilities which may take longer to field include creating a more intelligent extended network, inference from multiple vehicles, and wide area coordination. Uncertainties in technical development rates make this continuum somewhat fuzzy. The sequencing of capabilities over deployment are design options.

Design options include the possibility of providing driver-engaged operation mixed with manual traffic as an early capability, and the possibility of providing brain-off driving mixed with manual traffic later. Providing repeater stations to connect vehicle-to-vehicle communications in sparse traffic, as either a requirement or a stakeholder option, are design options. Another design option would be to provide some stakeholder options for electronic infrastructure involvement.

7.6.3.3 Driver Involvement

The fundamental assumption for this concept family is that the driver will be required to perform some functions.

The exact nature of the driver involvement remains a design option, but the driver is always more involved than simply having a panic button. Choices vary along two related dimensions. One dimension is the degree of driver engagement in the driving process. A second dimension is the degree of driver control over the automated driving process.

A clear breakpoint in the first dimension is whether or not the driver ever can fully disengage. In one case, the driver is continuously engaging with the driving task, at least to the point of knowing without warning when certain actions are required. Examples of such driver involvement include being responsible for seeing and recognizing approaching obstacles, continuously monitoring for something else like system failures or other problems, and performing a major continuous task, like lateral or longitudinal control.

In the other case, the driver may fully disengage from driving until notified otherwise. Options here include automatic obstacle detection and avoidance approaches, which ask the driver to examine and decide on uncertain obstacles, and vehicles, which come to a halt when obstacles are encountered and ask the driver to then manually circumvent the obstacles. A major issue with this category is the ability of drivers to reorient and respond quickly enough when they are concentrating on something other than driving.

Vehicle versus driver control is a distinct dimension of driver involvement. For example, one design option might let the driver take control of the vehicle at any time, but still allow the driver to usually disengage. Another design option may require the driver to be continuously engaged in routine obstacle detection, but may maintain automated control of the vehicle even when obstacles are detected.

In Driver Involvement, vehicles will be able to travel automated both on dedicated lanes, and when mixed with manual traffic (i.e., this is a stakeholder option). Many design options, such as the exact driver involvement tasks, may vary between dedicated and mixed lanes. Platooning is not a design option.

The distribution of intelligence option for this concept family is autonomous, cooperative, and infrastructure supported layers, but that may be changed if further analysis were to show that a different distribution of intelligence is necessary for driver involvement to make sense. Infrastructure support is a stakeholder option in rural deployments. It is the involvement of the driver to some extent which is not subject to change in this concept family.

7.6.3.4 Supported Platooning

In this concept family the vehicles travel in platoons on dedicated lanes, with the driver disengaged. The infrastructure provides general support, such as speed directives and data distilled from roadside sensors, but no assistance directed to particular vehicles. The vehicles will have capabilities to operate in a degraded mode.

Platooning is for increased throughput. When traffic is sparse, the vehicles would operate as free agents. The platooning details, such as platoon size, intra- and inter-platoon spacing, and speed, are design options.

This is the first of the concept families that definitely does not evolve from engaged drivers in mixed traffic, but starts with disengaged drivers in dedicated lanes. This concept does not support operations on mixed lanes with manual vehicles.

7.6.3.5 Assisted Platooning

The focus of this concept is safely maximizing throughput, using every compatible method available, and standardizing all implementations of AHS on a single national scheme, with minimal concept level stakeholder options.

In this concept family the vehicles travel in platoons on dedicated lanes with the driver disengaged. The infrastructure provides support, and provides assistance directed to particular vehicles, such as vehicle-by-vehicle instructions for merging two streams of traffic. The vehicles will be capable of operating in a degraded mode, for example autonomously if vehicle-to-vehicle communications is lost.

The platooning details are design options, and may vary from the platooning details in Infrastructure Supported. Many lower level design options for safely maximizing throughput are probable. When traffic is sparse, the vehicles would operate as free agents.

This concept does not support operations on mixed lanes with manual vehicles.

7.6.3.6 Maximally Layered

The focus of this concept family is in providing the largest compatible and useful set of stakeholder options possible. The single national standard for AHS vehicles and infrastructure set in this concept family would have tremendous local flexibility built in.

The concept is expected to include an early deployment option of autonomous vehicles on non-dedicated lanes, with the driver engaged. In early deployment there is a risk of accidentally creating and locking in a standard that is inappropriate in the long run. The evolutionary path and sequence of standards is an important issue in evolving concept families like this one.

In the standard version of Maximally Layered, vehicles will be able to drive autonomously. On dedicated lanes they will be able to travel with the driver disengaged. Where there are multiple vehicles they will automatically cooperate. Local traffic authorities will have the option of deploying infrastructure support processors and communications, and infrastructure assistance processors and communications, along with optional infrastructure sensors. Local traffic authorities will be able to set AHS roadway policies, including speed levels, whether or not platooning is allowed, platooning parameters, and minimum vehicle standards for roadway sections and lanes.

There is a design option of giving customers the stakeholder option to buy less capable AHS vehicle packages, foregoing the corresponding AHS vehicle opportunities. For example, a vehicle might not have the equipment to perform infrastructure assisted platooning, and would not then be allowed onto an infrastructure assisted platooning lane. A high-end vehicle would be able to drive on every AHS lane.

Vehicles will be able to drive mixed with manual traffic, but only in a driver engaged state.

An important design option is setting the minimum standard for roadways on which disengaged driving is allowed. Another design option is deciding on how many different standard packages of capabilities for AHS vehicles customers may choose between, and what they will be. An important design issue is trying to develop a passive layering protocol, so vehicles and the infrastructure are not responsible for recognizing and actively switching between different layering states.

There is an implicit expectation that actual deployment will evolve, starting with autonomous vehicles operating with the driver engaged and mixed with manual traffic, and progressing to dedicated lanes, higher levels of distribution of intelligence, and higher thoughput. Thus, the deployment phases for this concept family shown in the summary table are notional examples of local implementations, not required sequences. The prior levels continue to exist as degraded modes and as options for less crowded parts of the National Highway System. The rural areas are expected (but not required) to generally stay behind the urban areas in terms of deployed infrastructure.

8. CONCEPTS WORKSHOP

The AHS System Concept Workshop, October 18-20, 1995, in San Diego, afforded an opportunity for interested stakeholders outside of the Consortium to review the state of Consortium AHS thinking near the end of the C1 task, and to provide feedback.

To elicit and collect that feedback, this workshop included three breakout sessions, one on system requirements, one on concept development and evaluation, and one on the six concept families. In each case the format was a plenary session reviewing the subject, and then six parallel breakout sessions, divided by stakeholder group and led by a moderator, who discussed the subject.

The stakeholders brought well-informed and diverse outside opinions into this process. Their feedback in these breakout sessions is discussed below.

8.1 SYSTEM REQUIREMENTS BREAKOUT SESSIONS

This breakout session was driven by a desire to capture from the stakeholders the "proper" AHS weightings desired in the effort described in section 4.6. The charts for this session consisted of a large number of pairwise comparisons, asking the workshop members, "Goal A is _________ as important as Goal B," where Goals A and B could be Safety, Enhancing Mobility and Access, Providing More Convenient and Comfortable Highway Travelling, Reducing Environmental Impact, or Increasing Throughput, and the blank could be filled in with "Extremely," "Very Strongly," "Strongly," "Moderately," or "Equally" (in either direction). Also, there were questions asking for percentage improvements in vehicle accidents, fatalities and major injuries, driver stress, fuel economy, emissions, cost/benefit ratios, and competitive AHS benefits (compared to other transportation alternatives).

Some stakeholder groups did work through all the comparisons and were able to present their summary conclusions. Others addressed only a few comparisons, but attempted to clarify the meaning of the terms, in light of their own stakeholder interests and needs.

The feedback from these breakout sessions are summarized below.

8.1.1 Vehicle Industry and Electronics Industry

- Safety vs. Throughput:
  - Without safety, AHS is not saleable
  - Public cannot perceive throughput
  - Vote showed that safety is more important
- Safety vs. Mobility and Access:
  - If AHS safety is at least as good, with higher efficiency for the driver, the public will accept AHS
  - If trip times were somewhat longer, but more predictable, some driver would find that acceptable
  - Vote showed that safety is deemed more important
- Safety vs. Convenient and Comfortable:
  - Safety sells -- up to a point
  - People willingly use cellular phones and navigation systems (to say nothing of eating in their cars) even though these activities compromise safety
- Safety vs. Reducing Environmental Impact:
  - No widely accepted comments on this issue
  - Vote showed a belief that safety is more important
- Throughput vs. Mobility and Access:
  - No widely accepted comments on this issue
  - Vote showed no bias
- Throughput vs. Convenient and Comfortable:
  - People will but AHS because of convenience and comfort, not because of throughput
  - Vote showed bias towards convenient and comfortable

- Throughput vs. Convenient and Comfortable:
  - No widely accepted comments on this issue
  - Vote did not show bias
- Mobility and Access vs. Convenient and Comfortable:
  - Mobility and access is a societal issue
  - Vote showed no bias
- Mobility and Access vs. Reducing Environmental Impact:
  - No widely accepted comments on this issue
  - Vote showed no bias
- Convenient and Comfortable vs. Reducing Environmental Impact:
  - No widely accepted comments on this issue
  - Vote seemed to show a slight bias in favor of convenient and comfortable

8.1.2 Commercial Operations and Trucking

The commercial vehicle operations stakeholder community is driven very strongly by economic considerations, and all AHS objectives and characteristics are therefore translated into cost and benefit terms by them. Their overwhelming priority for AHS is productivity improvement, which combines the safety, throughput and mobility/access objectives. This group believed that those are so intimately intertwined with each other that it does not make sense to try to separate them. Environmental issues took second priority in their ranking, followed by comfort and convenience, which they believed should be treated separately rather than being lumped together. Since their vehicle drivers are paid employees, these latter issues did not carry much weight by themselves except inasmuch as they could be translated into trade-offs against the salaries they must pay or into reductions in employee turnover.

This group believed that relief of urban congestion would be beneficial to them by improving their productivity, but they thought the benefits would be very hard to quantify and to factor into an economic justification for equipping their vehicles with AHS capabilities. They did not think that throughput in vehicles per hour was a relevant consideration for them because it is rare to find a roadway where the present-day truck volume exceeds the capacity of the system. They were more interested in the rural long-haul operations. Here, they were very conscious of the competition that AHS might offer to intermodal TOFC/COFC operations, which are already well established and cost-competitive for hauls exceeding about 400 miles. They cautioned against "reinventing the wheel" by trying to duplicate the railroads' TOFC/COFC or RoadRailer types of service or overemphasizing the very long-haul operations. They believe that the primary advantage that trucks enjoy today is their higher trip-time reliability, and want to make sure that this is preserved. At the same time, they do not gain that much by further increasing that reliability, since that is already their competitive advantage relative to the railroads and they have already captured the business that is sensitive to this.

There was considerable interest in the concept of the truck convoy, with automated trucks following a manually-driven leader, if they would be able to operate long enough convoys to significantly increase productivity. However, this interest was tempered by the reality that the tractor unit is the most costly element in their consist, and that this still does not let them reduce the number of tractors to nearly the extent that TOFC does. They were interested in energy and emissions savings from the drag reduction in closely-spaced convoys, as well as the possibility of lower pay rates or longer duty time limits for the inactive drivers of the automated follower units. They were concerned about the political and labor sensitivities associated with such a new service, as well as the perceptions of automobile drivers who are likely to feel intimidated by a long convoy of large trucks next to them on the highway.

This group was able to indicate what their quantitative goals were for AHS, in many cases without significant controversy. The most controversial goal was associated with reduction in number of crashes, and this eventually arrived at selection of the 50-75% reduction range, which was what they thought would be needed to warrant the investment in AHS. For serious/fatal crashes, the same range was also chosen, but it was agreed that the goal here was to be toward the upper end of that range rather than the lower end (and therefore higher than for total number of crashes). They insisted that throughput be converted to productivity or travel time and then be evaluated in cost/benefit terms since these were more meaningful to them as vehicle operators rather than system operators. They chose a 0-25% improvement goal for trip time predictability, since they do not believe that the highway is the source of their predictability problem but the local streets they use for access are the real problem here. They would like to see stress reduction in the 25-50% range, assuming that this can be translated into relaxed regulations on driver duty time. They would like to see fuel economy and emissions improvements in the 25-50% range. Overall, they would expect to see a benefit/cost improvement of 25% and a payback period for any investment within two years.

8.1.3 Transit Operations

The planned agenda for this series of breakout sessions was to conduct a simple survey to compare the relative importance of various pairs of benefits, such as safety, throughput, mobility and access, convenience and comfort, and environmental impact. This group could only address a very few of the pairs due to the need to extensively expand on each benefit in order to have a common and reasonable basis of evaluation.

- Safety vs. Throughput
  The group quickly understood that they were being asked to compare the importance of an *increase* of safety to the importance of an *increase* of throughput. The transit operators present quickly pointed out that theirs was a relatively safe operation to begin with, primarily because of the size of a bus compared to passenger vehicles and because of their use of trained professional drivers. The largest safety problem in the transit industry is in the stop-and-go areas with a city. The express routes are by far the safest portions of their operations now. Although they expect AHS lanes to be much safer than today's freeway lanes, the difference to transit operations may not be noticeable.
  Increasing throughput, or the capacity, of highways, on the other hand, might be considered a negative from a transit view point. The public might be more inclined to see the increased capacity as an incentive to switch back to the convenience of a private auto.
  At this point, the side issue of driverless buses was brought up. Although the cost savings potential is attractive, the public reaction may be negative because the driver (or any on-board transit system employee) is seen as a deterrent to the dangerous actions of other passengers.
- Safety vs. Mobility and Access
  The use of AHS to increase mobility and access, from a transit perspective, proved to be very attractive. The discussion centered around using electronically coupled platoons of buses (smaller buses) which could split apart to better service suburban and central city neighborhoods.
- Convenience and Comfort vs. Environmental Impact
  Environmental impact is very important when planning a transit system but when a customer considers using the transit system, over some other alternative, comfort and convenience is paramount.
- As a final note, transit operators reminded the Consortium that near-term spin-offs were necessary to keep their interest in AHS alive.

8.1.4 Highway Design and Environmental

- The group responded principally as highway design stakeholders due to the individuals present at the session, although selected comments were offered on various environmental issues. In this context a third stakeholder group was suggested for future outreach and workshop activity: highway operators, including both public and private (i.e. toll road operators) operators.

- The group expectation was that a fully deployed AHS would carry with it the perception of being "extremely safe"; any evidence to the contrary, however small, would create a disproportionate negative public reaction. Safety was judged as strongly more important than throughput. Operational efficiency was seen to be a key evaluation metric in the nearer-term.
- Throughput ranked second only to safety. There is a perceived environmental concern regarding throughput as it relates to induced demand. The group judged it to be quite difficult to link throughput to mobility and/or access. The group advised that NAHSC pay special attention to assessment of total network carrying capacity limitations where an AHS segment is only part of a larger network of arterials and other secondary roads.
- The group indicated that the general criteria of "mobility/access" was not clearly enough defined yet to be usefully evaluated. In general, "convenience/comfort" was given a lower ranking since the current perceived level of these factors was considered generally acceptable. More delineation is needed for the "rural/urban" criteria before it can be properly evaluated.
- The group advised caution when specifying explicit safety-related metrics since there is considerable disagreement over which metrics are the best. For example, the raw number of safety incidents tabulated is a much different metric than a metric of relative severity of incidents. Existing bodies of knowledge related to safety codes in current design practice can provide guidance for the cost/safety trade-off.
- Regarding a comparison of AHS with other transportation alternatives, the group felt that such comparisons are best done in the context of relative benefit/cost. The decision-making focus should be at the MPO level. AHS can be classified for comparison purposes as a major "operational highway improvement." Public expectations are such that AHS benefits will need to be well understood and obvious to prospective users.

8.1.5 Transportation Users and Insurance Industry

SAFETY

- If AHS is at least as safe as today's highway system, the user gives more weight to enhancing mobility, comfort and convenience, and reducing environmental impact.
- Use caution in promoting a fail-safe system because the user may assume that it is a sure attribute of the system.

THROUGHPUT:

- Throughput is perceived as a concern for transportation planners and highway providers, not for the users.
- Users care more about mobility and accessibility.

MOBILITY/COMFORT AND CONVENIENCE:

- Both are rated as highest priority of the system objectives from the user's perspective.

ENVIRONMENTAL IMPACT:

- Participants have doubt about AHS's ability to reduce overall environmental impact.
- Reducing environmental impact is more important than enhancing highway safety and throughput.

OTHER ISSUES:

- The AHS design and deployment should be "widely embraced" by users.
- Stakeholders' input is crucial and outreach is the key to solicitation.
- Success of the 1997 demo is crucial to future AHS research and development; any failure during the demo will be devastating.
- The Consortium must develop evolutionary deployment strategies.

- Deployment must be embedded in TIPs (MPO); seed funding is important.
- Do not overlook the liability issues.
- Emphasize the concept of "contract with the driver": driver relinquishes vehicle control in exchange of user benefits.
- Cost must be a major consideration during AHS R&D.

Measures of Acceptance (MOA's) for the technology, either available or being developed, should be assessed and used as a major input to the design and evaluation process.

8.1.6 Governmental Agencies and Other Institutional Organizations

The group of representatives from government agencies and other institutional organizations discussed the AHS objectives and characteristics. The group used the materials provided describing the AHS objectives and characteristics as a point of discussion. The following were discussed as areas of issues and needs:

- AHS must support intermodal transportation.
- AHS must foster partnerships between the different agencies (i.e., federal, state, local and international)
- Agencies have the need to balance transportation systems (i.e., AHS, transit, rail, etc.) to provide overall service to users.
- We need to ensure flexibility and adaptability of the AHS due to the different environments, applications and agencies involved in its implementation.
- The Consortium will need to show the benefits of an AHS as an alternative to other transportation options.
- AHS must be deployed incrementally.
- We should not overlook the law enforcement regulations and other societal/institutional issues.
- How to ensure the safety of the system?
- Owner-operators expressed the concern for operations, maintenance, and resources required for something as high-tech as AHS.
- The relationship between ITS and AHS?
- How to get from test track to deployment in a financial sense.
- Compatibility with other ITS developments.

In discussing the level of importance or priorities between the system objectives, the following overall points were made:

- We need to separate the "musts" versus the "wants"
- The priorities of objectives will depend on the application. For example in an urban setting the priority may be on throughput while in the rural setting the priority may be on safety.
- AHS will be sold on its benefits

The discussion regarding the safety objectives included the following points:

- Safety is to be considered a "must" - we assume that the system will be safe. Improved safety is a want.
- The AHS should be designed for zero accidents.

In discussing the throughput objectives the following points were made:

- Throughput benefits are dependent on location - benefits will be lower in a rural area
- AHS needs to be equal or better than HOV alternatives in throughput improvement.
- We need to remember that we are interested in the throughput of people and goods, not vehicles.

In discussing the reliability and trip predictability objectives the following points were made:

- AHS must be market driven. The users must see the need and trust the safety of the system.
- AHS needs to be integrated into the total transportation system.
- Need to consider the comfort of the public.

In general, the group thought that the objectives and characteristics captured in the

AHS System Objectives and Characteristics document was a good set and definition of the top-level needs.

8.2 CONCEPT DEVELOPMENT AND EVALUATION BREAKOUT SESSIONS

The Plenary before this breakout session reviewed the process the Consortium went through to select the initial set of concept characteristics, to define the range of options within each, to develop the 23 concepts from these characteristics, to evaluate each concept, the results from the seven solicited concepts developed by outside contractors, and the general conclusions drawn from the internally and externally developed concepts.

The feedback from these breakout sessions are summarized below:

8.2.1 Vehicle Industry and Electronics Industry

Objective: Determine viable dimensions from industry viewpoint

Results:

- Agreed on (1) distribution of intelligence, and (2) mixing with manual vehicles as dimensions.
- Separation policy is not a dimension, but an open cross-cutting issue.
- Group believes that a knife-edge cutover from mixed lanes to dedicated lanes is necessary. A policy decision will govern the changeover. This decision will require extraordinary cooperation between industry and government.

8.2.2 Commercial Operations and Trucking

Distribution of Intelligence

They would prefer more vehicle-oriented concepts for intercity uses and more infrastructure-oriented for urban use. They would expect to see progress over time toward more infrastructure management functions as this becomes economically justified (but not as far as infrastructure control). Those who had experience with existing truck inspection and weigh-in-motion stations raised important questions about whether these large and costly facilities would be needed at every AHS entry location. This is a valid issue to be considered as part of the check-in function evaluation.

Separation Policy

This group is interested in truck convoys or platoons and believe that these would require at least the cooperative level of intelligence. They would like to see both free agents and platoons considered, depending on the level of demand and variability in performance among vehicles. The aerodynamic drag reductions in platoons were seen as a potentially significant advantage. The major concern about platoons was the large variability in performance among different trucks (especially braking), particularly considering the contrast between empty and full-loaded trucks. There was a strong preference for platooning “on the fly” in order to avoid queuing and delays associated with formation of platoons before access to the AHS. Truck convoys mixed with manual traffic were seen to be a desirable early application if these could be found feasible.

Mixing with manual traffic

Separate automated lanes were seen to be very desirable, but the key question for this group was when they would become economically justifiable based on the volume of automated traffic. They thought that physical barriers between them and the manual traffic would help gain public acceptance because of higher perceived safety. There was uncertainty about whether the automated lanes should be the inner or outer lanes, because there are problems with both alternatives. If the AHS is in the innermost lanes, the trucks would then need to cross multiple lanes to enter or exit the AHS, which increases stress, vulnerability to problems with the rest of the traffic, and potential for crashes. If the AHS is in the outer lanes, the trucks would need to coexist with all the complications of entering and exiting manual vehicles. They would like to consider truck platoons in mixed traffic, with specially trained drivers for the lead vehicles.

Mixing of automated vehicle classes

The commercial vehicle group urged the NAHSC to find ways of safely mixing the vehicle classes within the same automated lanes. They saw themselves as likely early adopters of AHS because of the economic (productivity) incentives and their corps of specially trained drivers. However, they thought there would be very few locations with sufficient truck traffic to justify a separate lane for truck use. The one special case where they thought separation would be needed was for operations on steep grades, where the limited performance of trucks would be a significant impediment to the rest of the traffic stream otherwise.

Entry and Exit

The choice of transition lanes or separate ramps would need to depend on local conditions. The truck operators were comfortable with having truck access limited to certain locations because of the cost and space implications of the longer ramps they would need for acceleration and deceleration and the cost of flyover ramps that could accommodate their vehicles.

Obstacle Sensing

Automatic obstacle detection was considered to be very desirable if it is feasible. Truck drivers are more skilled than the general driving population, so they may be better equipped to override an automatic system when needed, but it was not clear how much override capability would be desirable. This group was intrigued with the idea of premium pay for specially trained drivers of the lead vehicle of a platoon, who would have full obstacle sensing responsibility, with lower pay for the sleeping "drivers" of the following vehicles, who would not have any obstacle sensing responsibilities. In neither case would the vehicles have any obstacle sensing.

Other issues

A number of other issues arose in the discussion, which did not fit into the pre-defined categories. The most important of these is the observation that everything is driven by the economics of obtaining competitive advantage for this stakeholder group, so they can be very "objective" and dispassionate decision makers, looking closely at the "bottom line." Other specific issues that are worth citing are:

- the automated lanes will need to provide access for incident and emergency response functions, which could be challenging with barriers separating them from the rest of the roadway;
- what, if any, special training or licensing would be required for drivers, especially at the earlier stages of development of the system?
- need to ensure close integration of the AHS work with the ITS-CVO services, which are becoming widely accepted because of their economic benefits;
- there are likely to be special check-in condition monitoring issues for trucks associated with the condition of the couplings and the loads they carry (especially if there are open loads);
- truck convoys may need special terminal facilities unless they can be assembled entirely "on the fly."

8.2.3 Transit Operations

This breakout session focused on uncovering features or capabilities that could be included in AHS which would be uniquely useful for transit operators and might not otherwise be a part of the system if only automobile applications are considered.

- The first feature addressed was the need for aids in lateral positioning of buses for level platform loading. Transit operators are looking at the use of level platform loading to speed loading, especially in station areas, and as a way to facilitate loading of disabled passengers. Low platform buses are another approach which can be used where high level platforms are not practical. The desire is to find a way to help the driver close to within an inch or so of a platform without ever hitting it. Although not a major problem, the group did see this as a application where an early spin-off of

AHS lateral control technologies could be used to solve a present problem.

- The next topic was the relationships between roadway powered electric vehicles and AHS. Roadway Powered Electric Vehicles, or RPEV, proved to be a very interesting topic to transit operators. The San Diego Association of Governments recently studied the application of RPEV, both to transit operations in San Diego and to long haul truck operations from the Mexican border north to a rail intermodal facility near San Bernardino. In both cases they found an number of attractive features in RPEV. In transit operations, it would cost far less that light rail, could share its right-of-way with other vehicles, and could go places (inside buildings) where internal combustion vehicles cannot. For long haul operations (as well as transit operations) they found that only 6 to 10% of the lane miles need to be powered to provide unlimited range. They felt that a combination of RPEV and AHS technologies could be a very strong combination. AHS would allow them to maximize the capacity, and therefore the payback, on their investment in an RPEV lane. As an after thought, it was pointed out that automated control of electric vehicles is simpler than automated control of internal combustion vehicles.
- As a final topic in this series, the use of AHS in line haul applications was discussed. Line haul refers to the long distance part of a trip. In any trip, the longer the AHS segment, the larger the benefits. Since the AHS segment will also be the highest speed segment of a trip, the importance of a long distance AHS segment is magnified. Ron Fisher proposed the application of AHS technology to beltways (the beltways around Washington, DC being a good example) as a way to service long distance travelers. The I-15 truck corridor that San Diego is looking at is another good example. A third good example is the HOV lane transit operations of Houston Metro.

8.2.4 Highway Design and Environmental

- Regarding the "Distribution of Intelligence" criterion, the group felt that the "Infrastructure Supported" option might satisfy most performance expectations for maximizing throughput, and at much less cost by comparison to other options such as "Infrastructure Managed." The "Infrastructure Controlled" option was judged to be too revolutionary for early deployment -- evolutionary approaches to deployment were felt to be much more appropriate. Close coordination across political jurisdictions was emphasized as critical regarding this criterion.
- Regarding the "Separation Policy" criterion, the group expressed a clear preference for intermediate and gradual steps to evolve the optimum platoon formation characteristics. In this regard, liability concerns were emphasized. The so-called "brick wall" standard for guiding safety policy and stopping distances was seen to be a crucial constraint by some of the group.
- Regarding the "Mixing with Manual Vehicles" criterion, the group wanted to alert the Consortium that near-term technical innovations may modify some of our basic design assumptions. A specific example cited was the continuing evolution in physical barrier design and fabrication. Mixing was not seen to be completely undesirable, especially if it was selectively tested in an evolutionary deployment strategy with clear understanding of its implications.
- Regarding the "Mixing Vehicle Classes" criterion, the group felt that the trucking industry may be the first to use AHS extensively and thus their concerns were critical. Whether or not we allow mixing within a platoon needs to be studied further before a final decision is made. The notion of time-based segregation of truck platoons should also be studied.

Dedicated AHS truck lanes would have infrastructure cost implications that must be studied.

- Regarding the "Entry/Exit Alternatives" criterion, the group was concerned that multiple transition lanes might substantially reduce throughput; this issue needs careful study. Another key study area is whether dedicated transition lanes could have their own less conservative geometry by comparison to conventional lanes.
- The group suggested renaming the "Obstacle Sensing" criterion to "Obstacle Sensing and Avoidance." There may be hybrid alternatives we can develop for partial driver control under certain conditions.
- As an additional feature for further study, the group offered the possibility of using AHS to assist in dynamic lane changing for purposes of peak traffic counterflow and emergency use.

8.2.5 Transportation Users and Insurance Industry

- The inputs to the process seem to be from a requirements standpoint rather than a user standpoint. We need to address the end user needs and problems. For example, the end user doesn't care about throughput; he is interested mainly in his own trip time. The driver doesn't care about distribution of intelligence; he only cares about his own role. All of the technical terms need to be translated into terms that the general public can understand. This is necessary to get any meaningful feedback from the ultimate user, the driving public. A town hall meeting is highly recommended. The driving population also needs to be considered in the design. AHS must be designed for the full range of drivers, not just the most expert or technically knowledgeable.
- An open architecture is recommended to allow "plug and play" capability for various options. There are a range of needs, and so it needs to be flexible. ITS will be in place before AHS, and so AHS needs to be defined to be compatible with ITS and to take advantage of its capabilities.
- From the user's viewpoint, the only issues on separation policy are those that affects his role. Specifically, spacing comfort is an issue. Tests (Iowa simulator) show that a spacing of 1.88 m is not comfortable. Other issues are entry/exit ease, who controls the spacing (driver or system? Can the driver ask for more spacing from surrounding vehicles if he is uncomfortable?) and privacy from the prying eyes of nearby motorists.
- It was felt that the system will need a high degree of adaptability to user preferences to be acceptable. Specifically, the driver should not be forced to endure tight separations that make him uncomfortable. The trick is to prevent such driver choice from destroying throughput. One option may be to allow selections based on driver familiarity, so that new AHS drivers may be given bigger spaces until they become more comfortable. Another possibility is to give the driver some acceptable options; he can't select the size of the gap, but could be asked whether or not he would accept a gap.
- It was not clear to the group what the users would want in the way of barriers. Initially, they would probably want the protection of a solid barrier, but might change their minds if they understood the high costs, or the fact that this would mean large distances between access points. A major issue in dedicated lanes is getting the incremental acceptance of something not used by all; there is an elitism concern. The only issue for the driver in entry/exit is the procedure he has to use.
- The public is resistant to mixing with trucks, so acceptance needs to be built gradually. Automated buses in the HOV lane may be a start. Dedicated lanes are not an option everywhere; you have to mix classes wherever there are few lanes.
- There should be options to do any of the alternatives for obstacle sensing and avoidance. It must be totally

automated in tight spaces since can't react fast enough manually. But there first will need to be a big sales job to convince the driver that "the system can do this better than you can." If the system knows about an impending problem, it should warn the driver well in advance so that he knows what to expect. The big deal is getting the users to trust the system and to believe that it will take the proper action to prevent mishaps. To build this trust, the demo should show the system responding to hazards. False targets need to be considered as well, since they will erode user confidence.

- The hardest part is getting the initial users. One option is to use regular HOV users. The first in-vehicle equipment may need to be provided free to the users. There may even need to be a monetary incentive. In the long term, however, things will actually get easier. Barriers and other design issues will go away as the highway system and the vehicles become completely automated.
- Another issue area is routing. Is it automated? How are platoons handled in routing? The eventual system will include interchanges; how is freeway-to-freeway platooning done?

8.2.6 Governmental Agencies and Other Institutional Organizations

The group explored the different dimensions used to define the concepts.

Distribution of intelligence

- The question was raised, does the vehicle orientation have less liability on the infrastructure?
- A concern was expressed as to the maintenance of the infrastructure for the concepts that require infrastructure control. An example is the heavy infrastructure requirements for the FAA system.
- It was mentioned that deploying AHS in an incremental fashion may result in different solutions along the way. For example, you may start with a vehicle orientation initially but eventually may have more infrastructure.
- They recommended that "one size won't fit all."

Separation Policy

- The free agency scenario should be considered a fall back to platoons in graceful degradation sense. Currently our concepts come across as you have either free agency or platoons but not both. They recommends both.
- The group expressed a concern about the difficulty of exiting around long platoons that might be blocking the exit.

Mixing with Manual Vehicles

- The group felt that this was an evolutionary deployment issue. That initially you need to have vehicles mixed.
- The use of physical barriers to separate manual and automated traffic is a hot political issue in some parts of the country dealing with separating HOV traffic.
- We need to do a better job of defining what AHS vehicles can do with regards to improved performance on normal, non-automated highways.

Mixing Vehicle Classes

- This was seen as a user acceptance issue. Most people feel uneasy being stuck in a platoon with close headways with buses and trucks.
- There is of course the safety issues with having different vehicles with such different dynamics.

Entry/Exit Alternatives

- The key recommendation of the group was to minimize the infrastructure required, for example, flyover ramps. Local DOTs can't maintain the current inventory of bridges.

The group made the following conclusions following the discussions of the concept dimensions:

- The conclusions made by the consortium are reasonable.
- Incremental development is a must. All of the concepts need to reflect a growth path versus a point solution.

- With an incremental development we need to consider:
  - That there will be benefits along the way. Our concepts need to recognize/advertise these.
  - We need to identify the early winners to help create market demand.
  - The concepts need to emphasize the spin-off technology.

8.3 BREAKOUT SESSIONS ON THE SIX CONCEPT FAMILIES

The plenary before this final set of breakout sessions discussed the important and unresolved issues that existed at the end of this task and a description of the 6 concept families that were developed to address these issues.

The feedback from these breakout sessions are summarized below:

8.3.1 Vehicle Industry and Electronics Industry

Objective: Determine appropriateness of concepts to industry

Results:

- Given the 6 concepts, it was decided that "Infrastructure Supported" and "Infrastructure Assisted" concepts were on an evolutionary path. It also appeared that "Cooperative Plus" is an evolutionary step from "Vehicle Centered".
- It was not clear how "Driver Involvement" and "Maximally Layered" fit on any evolutionary path.
- There was much debate over what "Driver Involvement" actually is. Is it a concept family, or is it an attribute? No conclusion was reached.
- Platoons vs. Free Agents was seen to be a cross-cutting issue that appears with <u>every</u> concept family. There should be a framework for considering this issue within each concept family. Family designations that have the work "platoon" in them should be reworded to "formation".
- "Cooperative Plus" was seen to be troublesome if vehicles are not "fully-equipped". For instance, a vehicle with Intelligent Cruise Control and lane-keeping might raise driver expectations beyond its capabilities.
- Safety sells now; will "green" sell later?

8.3.2 Commercial Operations and Trucking

The group used the review of the concept families as a starting point for discussion of more general AHS issues, and gave limited attention to the differing attributes of the alternative concept families. Some of the families did not receive sufficient attention to produce any recorded comments.

<u>Cooperative Plus</u>

The group thought that in general vehicle-oriented concepts would be better for the trucking industry than concepts that would be reliant on public infrastructure improvements. They already have significant communication capabilities to support intermodal linkages, and this communication-intensive concept family led them to point out that we need to be clear that all of our concepts assume the baseline availability of ITS information and communication services. This is important to this stakeholder group because of the extent to which they have come to rely on the ITS-CVO services.

There were concerns about the viability of a concept as communication-intensive as this, based on questions of cost, technical feasibility and spectrum availability.

<u>Driver Involvement</u>

This was seen as a cross-cutting issue rather than a distinct concept family. There are also deployment issues here associated with the level of training and experience that drivers will need to have in order to develop confidence in the AHS system. The driver involvement question was seen to affect the formation of truck convoys or platoons. If these were formed while parked at a queuing station it would not be necessary to have a driver in each cab, but if they were formed "on the fly" it would require a driver in each cab.

Infrastructure Supported and Assisted Platoons

The group had problems with the jargon used to name these, not being able to make clear distinctions among "assisted," "supported" and "managed."

Maximally Layered

The group struggled with the purpose of this family and there was substantial sentiment for eliminating it as a distinct concept family. It was alternately perceived as having great value for regional tailoring or being technological overkill (or a "high-tech industry panacea"). It also elicited the concern that it would take too long to achieve, and that it was necessary to get some winning concepts available for use quickly.

General Cross-Cutting Issues

Much of the time was devoted to more generic AHS issues that cut across the different concept families. These included:

- The AHS must be economically competitive with railroad intermodal services in order to be adopted by the trucking industry. If the truck convoys still need a substantial ratio of power units to trailers it may be harder to be cost competitive. On the other hand, if AHS enables the truckers to extend from triples to combinations of four to seven trailers, their productivity could be greatly enhanced.
- The AHS does not need to be truly "national" in order to be viable. It may only be needed to link multimodal transfer points within specific corridor applications in order to be worth implementing for trucks.
- Highway designs may need to be modified to accommodate increased wear from truck tires consistently following the same track lines, or else the vehicle control systems may need to deliberately vary the tracking of the vehicles within the lanes to distribute the wear more evenly.
- Trucks are likely to need dedicated lanes for entry ramps and locations with significant grades because of their substantially limited acceleration capabilities. This may mean that grades should be limited on AHS roadways if such extra lanes are not provided. It may be acceptable to impose minimum performance standards for AHS trucks, but the efficacy of this will be driven by cost/benefit considerations.

8.3.3 Transit Operations

- The session started with a description, by Loyd Smith, of Houston Metro's transit operations and how they might use AHS features. A prominent, and AHS like, feature of their operation is use of 68 miles of HOV lanes to link the CBD with park-and-ride facilities. This has proved so successful they plan to expand it to more than 100 miles in the near future. The HOV lanes are single, reversible lanes. At the park-and-ride stations they have a dedicated on/off ramp which feeds directly into the HOV lane and is used both by passenger vehicles and the buses. Houston uses the HOV lanes today primarily as a high speed link between various suburbs and the CBD. They would like to extend the operations to connect suburbs but the radial structure of the highway and HOV network is a limiting factor. AHS technology is seen as a way to handle increasing congestion on the HOV/bus lanes, congestion which today does occur and is handled by instituting more restrictive HOV policies.
- The next topic was the cross-cutting issue of driver involvement. The normal concerns of safety and the safety implications of relying on the driver (which today is the biggest safety problem in driving) were raised. It was noted that there is hardly a system now in existence where, in emergencies, a person has no capability to intervene (even though that capability is rarely used). The group also felt that some level of driver training, specifically oriented to the AHS driving tasks, may well be required and would not differ from today's situation where drivers are

specifically taught freeway driving techniques. The discussion then turned to the interface problems between AHS and arterial/freeway highways. The problem is of radical different capacities. However, it was again pointed out that the problems are not insurmountable, that such situations exist to day in freeway planning and are being handled by highway designers.

- When the group considered the question of operating in mixed traffic (automatic and manual controlled cars on the same highway, the reaction was that such a capability was obviously required for any reasonable deployment scenario. Perhaps, the group thought, transit and CVO could become the catalyst in starting an AHS deployment.
- Similar thoughts occurred when discussion a platooning capability, that perhaps platoons of trucks or buses would be where to start.
- Two thoughts occurred when discussing the last issue, flexibility and the "Maximally Layered" concept family: that we should consider transit and CVO evolution paths as well, and that the Consortium must keep their proposals in sync with other ITS developments as they occur.

8.3.4 Highway Design and Environmental

- The group suggested the following generic deployment scenario as a starting point and common basis for all future analysis of concepts: first, vehicles are equipped with individual AHS hardware features; second, AHS deployment begins with dedicated but mixed lanes; third, restricted lanes are marked as volume grows. The group identified several precedents to guide AHS in evolutionary deployment, in whatever form it may take, including precedents related to HOV deployment and TOC development. Finances and budgets make force deployment to be evolutionary, with clear and continuing documentation of benefits.
- Regarding AHS "cross-cutting" issues, as they pertain to this stakeholder group, it was felt that physical infrastructure capital cost assessment was a critical task that needed special care. A large part of these costs might lie with entry/exit area design and construction. The nature of separation between automated and conventional lanes was also seen to be a critical factor. Properly understanding the burden induced on arterial roads from an operating AHS segment was again emphasized.
- In critiquing the six concept families, the group did not have a clear understanding of the "vehicle centered" concept, and how it different from the "cooperative plus" concept. More explanation is needed, and in general this was true with regards to all the concepts, especially as they related to the prospective impact on bus and truck platoons. Obstacle avoidance also was not clearly enough defined. Driver involvement as a generic design issue should resolved outside of the mainstream of the concept down-select process. The group needed further clarification of how much intelligence would be contained in the vehicles under the "supported platoon" concept. The group again emphasized the need to carefully study evolutionary deployment strategies for all surviving concepts.
- Summary group feedback during this session focused on the following concerns: a more explicit description of the process by the Consortium of how we downselect from six to three concept families; an emphasis on eliminating undesirable features verses simply eliminating entire concept families; explicit rationales, clearly explained, regarding why certain concept groups were being dropped; and explicit addition of evolutionary deployment scenarios for all surveying concepts.
- Finally the group could not reach an internal consensus on whether NAHSC

should spend roughly equal resources studying all six concepts families prior to making its downselect decision.

8.3.5 Transportation Users and Insurance Industry

- The concept descriptions and distinctions were not clear to the group. In particular, it was difficult to take a given concept (such as one of the contracted concepts) and see where it fit in.
- The group saw two cross-cutting issues: What is the driver involvement? How do you use the infrastructure. The group recommended a concept development starting from the end goals of AHS, and then determine how to get there. It appears that the concepts chosen were stepping stones. From the user's viewpoint, there are really only two themes that separate the concepts from each other: What is the level of control relinquished? How close are the spacings? Education of the driver must be an integral part of each concept. So must outreach. To succeed, the system needs to give the users a perception of simplicity, and the confidence to use. Any additional certification is a negative, since it gives an impression of complexity.
- Remember the "ilities" (reliability, maintainability, availability). They drive cost, availability of service to the user and ease of use. The public is used to the reliability levels of current cars, and will not see the AHS vehicle as an improvement if it offers less reliability, no matter what else it does.
- Driver involvement was seen as a cross-cutting issue rather than a concept. There were strong, differing views on this issue among the group. On the one hand, some said that if the driver is involved, this is ITS, not AHS, and that the system is unsafe if he can take over. On the other hand, it was stated that drivers see, think and act, and that it is impossible to let them see and think but not act; they need to be able to override to save their own life. There were differences of opinion on what the driver should be allowed to do in a "panic button" situation.
- In any case, the cost and evolutionary impacts of disengagement need to be weighed. The driver role may be different in different regions, especially depending on traffic density. The answer might be to give the driver a perception of a role, rather than a real role. The important thing is that he needs to be convinced that it's safe. We need to be able ultimately to tell him that the system can do it better. (Is this always true?) Let him do something and have an effect, but restrict it so that whatever he does cannot mess up the system.
- The next concept families discussed were Vehicle Centered and Cooperative Plus, with the emphasis on the latter. Cooperative Plus would benefit from taking advantage of the ITS infrastructure communications that will be out there anyway. There were technology and communications concerns about this concept. The group was not convinced that data aggregation would cut the communications load down to a manageable level. One advantage is that the technology will update faster since it is all vehicle-based, and vehicles are replaced more often than is infrastructure.
- There was a major concern with Cooperative Plus in that it operated without benefit of a traffic operations center (beyond what will be there for ITS). The public will not trust other cars to be properly maintained to perform the cooperation. There will be fear of "automotive anarchy" and the public would actually prefer a more familiar "big brother." It comes down to an issue of who you trust, and the public is more likely to trust a transportation agency than that jerk next to them in the old pickup truck.
- Supported and Assisted Platoons may be two steps in an evolution. The choice will probably come down to cost. Supported platoons have been used successfully in a marine environment. During the Gulf War,

GPS was used to get ships quickly through the Strait of Hormuz. The ships communicated via satellite, giving location and warning of obstacles. This allowed a spacing of 2 ship lengths, as opposed to the usual 7-ship spacing (brick wall stopping distance).

- Maximally Layered was said to be "what we want." The high end of this evolution is what we mean by AHS. There was concern that this looked like 1 through 5; the others seem to be just evolutionary steps in this family.
- There was some discussion about free agent vs. platooning. People will prefer free agent to start, until they get comfortable with it and start to see the benefits. Platooning was thought to be inherently more uncomfortable (psychologically) for the driver, and so it should not be used when it isn't needed. But this causes a problem if a driver who is not comfortable with platooning unexpectedly finds that the system is suddenly changing from free agent to platooning. The motorist wants predictability.
- The other main issue discussed was the user's desire for simplicity. He does not want to be burdened with any more administrative requirements. He already has to worry about registration, smog checks, etc., and does not want to add to this. The AHS should make life easier, not harder. The group voted on the six concepts and whether they are good choices. The results are:

Concept Number	Yes	No	No Opinion
1	4	3	5
2	1	7	4
3	3	7	4
4	9	0	3
5	9	0	3
6	10	0	2

8.3.6 Governmental Agencies and Other Institutional Organizations

Overall Comments regarding the six concepts:

- The concept families seem to represent attributes not concepts. For example, the driver involvement concept is an attribute that is applicable to all of the concepts. Recommend that the Consortium further refine/re-concept the families.
- Incremental deployment is captured by the concept families but it is not effectively communicated. We need to do a better job for each of the concepts to show the incremental development/ deployment path. Need to include the phasing, timeline, incremental deployment critical components. The concepts need to reflect anticipated improvements that will be in the market place in the future.
- The concepts look too stand-alone. We need to integrate in ideas associated with ITS, ATMS and spin-off technologies.
- The group felt that the concept families would be more effectively communicated as representation of the distribution of intelligence. At this time, it seems to be the only discriminator between concepts. The other dimensions are still attributes and options available for any concept.
- Driver education and training will be critical. How do the education and training requirements change for each concept?

Specific comments included:

Concept #1

- It appears that it will be market driven, which is critical for deployment.
- There are some concerns about the technical issues associated with platooning in this concept.
- It seems to lack a global, well integrated transportation system view.
- Provides the best near term option.
- Best option suited for rural.

Concept #2 -

- This concept does not provide an opportunity to take advantage of infrastructure related technologies that are likely to be in place. Lacks ITS emphasis to get information from the infrastructure to the driver.
- This looks like a deployment step in an incremental process versus a stand-alone concept.

Concept #3

- Driver training will be critical
- This is not a family of concepts but a feature applicable to all.

9. THE NEXT STEPS

The end of the C1 effort is not the end of concept development for AHS. After incorporating the stakeholder comments to create a revised set of concept families, the Consortium will continue with a C2 effort that takes those concept families as inputs, studies and evaluates the underlying issues in more detail, and creates three preferred concept families.

9.1 REVISED CONCEPT FAMILIES

9.1.1 Response to Stakeholder Feedback

The Workshop elicited much valuable and insightful feedback from the stakeholders. It gave the Consortium further insight into the needs and priorities of the stakeholders, and will greatly help shape the continuing AHS development. This section highlights specific feedback received on the six concept families and on the five underlying issues which the six concept families were structured to address. The Consortium has incorporated these ideas into the revised concept families. In many cases, there were conflicting and incomplete suggestions from the stakeholders. This is not surprising in light of the diverse nature of the stakeholder community, but it meant that the Consortium needed to thoughtfully and carefully consider each major concern to strike a balance across the feedback; it was not possible to provide a simple reaction to all comments.

Following are the major comments received on the six concept families:

9.1.1.1. Eliminate the driver involvement concept family, and address this as a cross-cutting issue across several concept families

This was probably the most prevalent comment received The general feedback was that it was more fruitful to study this issue across several concept families than to devise a concept family specifically to study it. The Consortium accepted this comment in full. The concept family was eliminated, and an engaged driver role will be one of the identified cross-cutting analyses. Furthermore, this issue will be studied in concept families 1, 2 and 6, each of which has an engaged or partially engaged driver in an early phase.

9.1.1.2. Combine concept families 4 and 5 (infrastructure supported/assisted platoons) since they are very similar, and 4 may be a precursor to 5

While this was a strong suggestion from several groups, it was offset by even stronger stakeholder feedback that the concept families should be distinguished by and developed around allocation of intelligence. These families will be kept separate as representatives of infrastructure supported and infrastructure assisted respectively. Further, the Consortium is not yet convinced that 4 (infrastructure supported) is a precursor to 5 (infrastructure assisted), and to combine them now would close off further inquiry.

9.1.1.3. Eliminate concept family 6 (maximally layered) since it is just the combination of all the others

Some of the stakeholders saw this as a redundant concept family, which would be constructed at the end by putting together all of the others. They felt that it was included only as a test of the interoperability of the others. While it may seem that way from the cursory overview, that was never the intent. This concept family is actually a single unified approach that provides beneficial functionality at every level of deployment and regional use. Thus, it may be significantly different from the other five independently developed concept families. The Consortium agrees that interoperability is a cross-cutting issue for all of the concept families, and that any concept selected only as a test of interoperability is not worth considering.

Many of the stakeholder groups rated this as the most promising concept family in informal polls. There was also feedback that Concept #6 agreed with stakeholder ideas of what the AHS should be like. The Consortium felt that this feedback more than offset the suggestion to eliminate the concept.

9.1.1.4. Eliminate all the concepts and start over based on allocation of intelligence

One focus group suggested that all of the concept families be eliminated. Their suggestion was that everything except allocation of intelligence should be a parameter within the concept family (e.g. platooning, free agent, etc.). While not stated so strongly, other groups also felt that the concept families should include more degrees of freedom. There was general agreement that allocation of intelligence should be kept as the key concept distinguisher.

The Consortium is following this suggestion. Each of the remaining five concept families has been recast in terms of allocation of intelligence. These concept families were originally developed around the allocation of intelligence, so it is not really necessary to start over. Specifically, Vehicle Centered is Autonomous pushed to the limit, Cooperative Plus is Cooperative pushed to the limit, and Infrastructure Supported and Infrastructure Assisted are self-evident. Maximally Layered includes all allocations of intelligence. Aspects that were formerly concept differentiators are now cross-cutting issues, specifically platooning vs. free agent, and the role of the driver.

9.1.1.5. Eliminate Concept #2 (Cooperative) as it appears to require too much communication, promote anarchy and pose technical risks

The Consortium received considerable valuable feedback on the technical and social risks involved in this approach. Many important issues were raised, but no definitive evidence of infeasibility has yet been assembled. The Consortium agrees that this approach is risky, but has not yet done the analysis to see if the risk can be contained. Hence, this concept will be retained so that the necessary analysis can be done, emphasizing and focusing on the issues raised by the stakeholders.

9.1.1.6. Combine Concept Families 1 and 2 as steps on an evolutionary path

This was a natural comment based on the high level presentation of the concept families. Had the concept families been conveyed more fully, the audience would have seen that the two concept families are inherently different, and in fact have no common evolutionary steps. This and other stakeholder comments made it very clear to the Consortium that not enough time had been used to present the concept families, and that the moderators should have been given more extensive background in the concept families. These are lessons learned that will be carried forward to the next Workshop. The confusion about the difference between these two concept families also pointed out problems with concept names. The names often led listeners to make unwarranted assumptions, which were very difficult to erase. This is a general problem with names of ideas, not specific to AHS, but it underscores the need for thoughtful naming. Hence, the Consortium renamed the concept families to reflect their key attributes, as well as to incorporate the changes in the concept families themselves, as discussed above.

The new names for the five concept families are:

- Independent Vehicle (formerly Vehicle Centered)
- Cooperative Vehicle (formerly Cooperative Plus)
- Infrastructure Supported (formerly Supported Platoons or Infrastructure Supported Platoons)
- Infrastructure Assisted (formerly Assisted Platoons or Infrastructure Assisted Platoons)
- Adaptable (formerly Maximally Layered)

Note that Driver Involvement, formerly the third concept family, has been eliminated.

9.1.1.7. Accept mixing of classes in a lane in all concepts

The AHS must be available to all stakeholders. But limitations in right-of-way are severe, so all concept families must permit the sharing of lanes by various types of vehicles if the local transportation agency so desires. All of the five concept families now include this capability in all evolutionary stages.

9.1.1.8. All concept families will assume the existence of and the use of ITS capabilities

Many of the stakeholders present at our workshop are involved in the Intelligent Transportation System Architecture and other ITS activities. They stressed the importance and benefits of our close involvement with these related activities. They also informed us about the ITS services that will be in place by the time the AHS is fielded. The Consortium will increase their involvement in ITS activities, build on the ties established with this community, and build the concepts around these services.

9.1.2 The Revised Concept Families

The Workshop comments led to the five revised concept families, based on the original six, as described in Section 7. The first task of the second phase of concept development (C2) must be a thorough documentation of these concept families. The authors will take into account all of the stakeholder feedback as they are refining these approaches, so it is expected that these concepts will change further. In fact, changes have already been seen in initial C2 task concept descriptions.

9.1.2.1. Independent Vehicle

The only real change here has been in the name. The new name was chosen to suggest that the vehicle is making its own decisions, though it may be supported by information from other vehicles or from the roadway.

9.1.2.2. Cooperative Vehicle

This new name was chosen to distinguish it from the Independent Vehicle concept, while still emphasizing that it is a vehicle-based concept. The concept itself is relatively firm. The challenge now is to provide enough design detail to demonstrate feasibility.

9.1.2.3. Infrastructure Supported

The key difference here is that this concept is no longer centered on platoons. Platoons are part of a cross-cutting issue. The challenge here is in filling out details starting with little more than the allocation of intelligence.

9.1.2.4. Infrastructure assisted

Here, too, the emphasis on platoons has been removed. This represents a high-end system, but otherwise there is still much to be defined. Even the allocation of intelligence is not determined at this point. The team developing this concept will need to decide exactly where and how infrastructure management is used.

9.1.2.5. Adaptable

The name has been changed to emphasize the tailorability to a range of needs. The term "layered" meant too many different things. This concept has not changed, but requires descriptions of what exactly these layers are.

9.2 THE NEXT PHASE

The report documents the AHS C1 effort. It is to be followed by the AHS C2 effort, which will expand upon the five concept families and ultimately select three preferred concepts. At the end of C1, the plan for C2 was as follows.

9.2.1 Flesh Out Five Concept Families

Develop "best" conceptual designs for each family, to achieve goals and objectives and perform required functions while optimizing MOE value. Define end state system for each, together with realizable intermediate steps, local deployment options and potential degraded modes of operation. Describe each in about 20 pages of text (largely qualitative, rather than quantitative).

9.2.2 Define Applications Scenarios

Select real-world reference sites to serve as bases for concept evaluations, coordinating with Outreach, Societal and Institutional, and Tools teams. Collect data needed to characterize each site sufficiently for purposes of the concept down select evaluation, which is assumed to be at a highly aggregate, rather than detailed, level.

9.2.3 Cross-Cutting Studies

The major concentration of activity should be here, in analyses of cross-cutting issues that will determine the strengths and weaknesses of the alternative concepts. The concepts may be revised along the way, based on the knowledge that is gained from these cross-cutting studies. The working groups that conduct the initial generic studies may later work on the evaluations of the concepts (in the Task described in 9.2.6).

9.2.3.1. Human Factors/Driver Roles

The role of the driver is an important discriminator among the concept families, as well as among the intermediate deployment stages. It is essential that the constraints imposed by driver capabilities be understood as early as possible so that these can influence the concept development and selection:

- driver attentiveness under partial automation
- driver ability to detect obstacles at long range
- driver ability to resume control in emergency
- transfer of control to and from driver
- driver acceptance of close vehicle following

9.2.3.2. Separation Policy Implications For Throughput And Safety

Define the spacings that should be required between consecutive vehicles, based on whether they are operating autonomously, cooperatively or in platoons (both inter-platoon spacings). These must be based on analyses of safety, using supportable assumptions about vehicle performance and probabilities of occurrence and possible consequences of various failures. This work will require collection of data on real vehicle and roadway conditions, analyses of crash severities, and evaluations of acceptability of different frequencies and severities of crashes.

9.2.3.3. Cost Assessment

Make a first attempt to define a supply curve for AHS, including vehicle and infrastructure unit cost estimates as a function of quantity (or production volume) for a variety of assumed technical solutions within the six concept families. This would be the first step toward defining the cost effectiveness of AHS.

9.2.3.4. Market Elasticity Evaluation

Make a first attempt to define the demand curves for AHS services, identifying how much people would be willing to pay for the different levels of AHS functionality. This would be the second step toward the cost-effectiveness evaluation. It should be based on focus groups of representative stakeholders (primarily private vehicle purchasers, but also some trucking and transit representative), and can gain some synergy with the Task 7 (see 9.2.7) activities.

9.2.3.5. Technology Capabilities Relative To Concept Needs

Conduct a first-level assessment of the feasibility of delivering the capabilities required by each of the AHS concepts, based on technology to be available at the "affordable" price in future years. Consider this in five year increments from 2005 forward to evaluate realism of implementation of each concept in each year. Link this activity to Technology Team work (Task B3).

9.2.4 Define Concept Evaluation Framework, Requirements And MOEs

Select a systematic approach to evaluate and compare alternative concepts for use throughout the C2 activities. Refine the definition of requirements and MOEs, based on the overall AHS objectives and characteristics so the concepts can be distinguished from each other.

9.2.5 Canvass For Stakeholder Representatives

Authentic and truly representative stakeholder representatives will be needed to provide input to the selection of weighing factors for the various MOEs and requirements and for more general feedback about the strengths and weaknesses of the alternative concepts (contributing to Tasks 3d [see 9.2.3.4] and 7 [9.2.7]). No resources are allocated here, based on the assumption that these will be provided as a byproduct of the Outreach and S&I activities. This must start early enough to have representatives available by March 1996.

9.2.6 Evaluate Concepts

Based on what has been learned in the cross-cutting studies of the Task described in 9.2.3, as well as use of the tools that are available by Spring 1996 and inputs from the S&I studies, evaluate the strengths and weaknesses of the alternative concepts. This is the heart of the C2 activity, but it must build on much of the work that has been done before in C1 as well as other parts of the AHS workplan. The evaluations will cut across the concepts, following the general outlines already defined in the Task 3 (see 9.2.3) breakdown.

9.2.7 Solicit Stakeholder Reviews, And Develop MOE Weightings

Using the stakeholder representatives identified in the Task described in 9.2.5, conduct focus groups to obtain feedback on the alternative concepts and the importance to them of the various MOEs. Use the weighting factors derived in the chosen evaluation framework to identify the preferences of each stakeholder group for the concept. Seek to identify a supply-demand equilibrium point for each stakeholder group for each concept, based on the supply and demand curves derived earlier.

9.2.8 Workshop #3 (July/August 1996)

Extensive participation by people throughout NAHSC, especially those working on C2. This includes advance preparation of documentation, briefing materials and breakout facilitation materials.

9.2.9. Documentation Of Three Concepts And Process

Characterize the three selected concepts in approximately 50 pages each, to serve as the basis for advancing to the C3 concept development work. Document the results of the evaluations, with the reasons for selection and rejection of the concepts that were considered.

10.0 LESSONS LEARNED

This C1 task, called "Develop Initial Suite of Concepts and Workshop #2", was the first of a series of three concept development tasks that will take place during the first 4 years of the AHS Program. The "lessons learned" during this first phase are of great importance and will help in all future work, both in concept development and in other tasks. The lessons are grouped into two categories: lessons related to conduct of the workshop, and lessons related to the scope of the work on the task itself.

10.1 CONDUCT OF THE WORKSHOP

- Preparation for Workshops

Prepare those who will brief the stakeholders. In Workshop 2, this was particularly a problem in the stakeholder breakout sessions where the moderators were not given sufficient time to become familiar with the six selected concepts. Because of the short time between the definition of the concept families and the Workshop, the moderators were not sufficiently familiar with the concepts to give the stakeholders the information that they needed in order to give meaningful feedback. While there was much good general feedback that allowed an understanding of the various views of the stakeholders, the value of the feedback sometimes was degraded by the misconceptions of the moderator. For the concept related breakout sessions in the next Workshop, perhaps people who are more familiar with the concepts and the underlying issues would be a better choice for briefing these sessions than the designated stakeholder moderator, even if they brief nothing else. One thing that was done right for this Workshop, and which needs to be repeated for all future Workshops and Forums, is preparation of complete book of briefing charts which is distributed to attendees at the start of the meeting. This is just a matter of a little self discipline but adds an important and obvious note of professionalism.

- Content of the Stakeholder Breakout Sessions

More thought needs to be given to the agenda for the stakeholder breakout sessions. The moderators need to prepare specific agendas for each session, either based on the preceding plenary briefing sessions or on the specific needs of this stakeholder group. Either way, the agenda cannot be Ad Hoc. The moderators need to ensure that the stakeholders will be given the information they need to respond with useful and informed feedback. The moderators have very little time to spend with the stakeholders. They must be sure this time is used wisely.

- Involving Stakeholders in Selection Process

Workshop 2 was conducted at the very end of the task. The stakeholders at the Workshop felt they were receiving a debriefing on the results of the initial concept selection task instead of feeling they were being made a part of the decision making process. Even though the Concept Team made significant changes to the concepts after the Workshop (reducing from 5 to 6, for instance), this feeling persisted. As a result, the plan for Workshop 3 is different. Workshop 3 will be held before the three new concepts are established and will present the results of the Team's evaluations rather than their decisions on new concepts. If stakeholder buy-in can be obtained for the conclusions stemming from these evaluations, then formulation of the new concepts should be much more understandable and acceptable.

- Reporting the Results of the Workshop

Thoroughly capture and disseminate all stakeholder inputs. At the conclusion of Workshop 2, there was confusion about who was responsible for writing up the minutes from each section (the moderator or secretary) and who was collecting them. Because of this, some of these were delayed, which meant that they were not available to the teams in a timely manner and, possibly, some of the comments or the thoughts behind the comments were lost. In the future, there should be a clear procedure with a tight schedule so that the comments are captured immediately after the meeting. Even comments that seem off-base or things that the stakeholders say they do not understand need to be captured, since the Concept Team need to understand what's behind the misunderstandings.

10.2 THE TASK WORKSCOPE

- Managing the Work

The Concept team had 23 concepts to compare across five general evaluation categories. The Team considered assigning teams to an overall evaluation of a few concepts each, but for consistency assigned teams to evaluate all concepts relative to a single evaluation category (throughput, safety, cost, flexibility, acceptability). This worked well, allowing the teams to focus on the issues for the assessed characteristic and produce directly comparable evaluations. These evaluation were not done to the depth desired, but that is in the nature of the first iteration of the spiral approach. The process worked well and should be continued.

Large groups hamper, rather than support, decision-making. The Concept Team was most productive when small (3 to 5 people or so) subteams, with a clearly identified leader, were given a particular, clear assignment and a date to report their findings to the group (both written and oral). This focused the subteam between meetings, kept the meetings on target, and provided written documentation of the decisions made.

Telephone conferences are an effective way to supplement meetings once the members know each other well enough to recognize voices and picture the person speaking. There must be regular face-to-face meetings so that the team members get to know each other to this level, but once a month or so seems to be sufficient. The telecon needs to have an agenda and any materials to be discussed sent out ahead of time. E-mail has also proven to be a very good way to communicate, although this medium is still hampered by garbled enclosures in some cases.

- Seeing Concepts as Stakeholders See Them

Some stakeholders repeatedly said that what the Concept Team was presenting were not concepts. It took a while to understand this, but different stakeholder groups view "concept" to mean something relevant to their problems and concerns. Most often, these stakeholder groups were looking for operational concepts rather than technology or architectural concepts. Specifically, stakeholders were looking for an application to a particular situation, such as a dedicated truck lane concept, or a transit concept, or an urban concept, or a rural concept. The Concept Team, on the other hand, was viewing these as applications of their architectural concepts. This hampered communication. For example, in Workshop 2, when discussing the six candidate concepts, the stakeholders repeatedly asked for a trucking concept, a transit concept, and so on, when what the Team was presenting were six system alternatives, any one of which could be configured for a trucking application, a transit application, and so on. It is probably too late to change our terminology, but we need to be aware of this in any communications with the stakeholders.

This points out the general problem with stakeholder communications. The NAHSC needs to realize we do not yet speak their language. There are unfamiliar words or approaches in documents on transit or trucking, even those that advocate AHS. All of us need to get inside the stakeholder's heads, to learn to speak their language.

- Concepts vs. Issues

The concept development plan, as described in the Proposal, was based on a down selection process of going from many, to 6, to 3, to finally one concept. This original plan proved far too simplistic as we came to understand the complexity of an AHS system. In this complexity, all of the aspects of an AHS, including technology, architecture, functionality, and operations each have a staggering variety of conceptual possibilities. In the beginning, a concept can only address a little bit of this complexity and in only a limited set of aspects. Therefore, concepts at any level of development, only deal with a subset of the aspects of a complete system. For those aspects which a concept does address, the concept makes a very good framework within which the issues of a particular aspect can be addressed, and can lead to a decision on that issue. This resolved issue can now become part of the given requirements for a new set of concepts aimed at resolving a new set of issues. This periodic formation of new concepts, rather than a downselect of existing concepts, is the way the concept development process must work. This has disappointed some stakeholders who have seen a favored concept disappear as concepts evolve even through all the resolved issues of that concept were carried forward. The Concept Team needs to make this facet of the process clear to the stakeholders to avoid these types of misunderstanding. The term "re-concepting" was coined to describe the process and it fits very well.

- Value of Outside help

In this first round of concept development, the NAHSC let seven contracts to outside organizations for development of concept ideas. The concept ideas provided by these contractors was of tremendous help in focusing the Concept Team on issues which must be addressed in the next round of concept development. In addition, several of the contractors demonstrated a depth of understanding that the Concept Team clearly should plan to tap in the future, especially in the areas of operations and functional requirements.

- Links between Concept Development and Concept Evaluation

Starting with essentially a clean slate, the Concept Team attempted to evaluate all alternative approaches to an AHS. But there was a dimensional explosion from 14 choices for allocation of intelligence, platoons, free agents or slots, various kinds of barriers and entry/exit configurations, and so on. Each dimension was assessed individually, but that could only be carried so far because of the interrelationships; full concepts need to be evaluated. The Team selected 23 representative concepts that spanned the alternatives. Descriptions of each of these were written and used in the evaluations. The descriptions of the 23 candidate concepts were not worth the effort, at least not to the depth that they were done. It was time-consuming to write these documents, and the effort produced about 200 pages that were difficult to read and sometimes redundant. The evaluation teams, overwhelmed and short on time, in general based their evaluations on the dimensions rather than these descriptions. It would have been better to concentrate our energy on a few representative concepts with a discussion of what the impacts of changing the various alternatives would be.

More review was needed between the evaluators and the concept developers. Because of the short schedule, the evaluation teams did not have time to validate their conclusions with the concept developers. This was also due to the fact that there were 23 concepts to be evaluated. Hence some of the evaluations were based on misunderstandings of the concepts or lack of relevant information that was known by the concept developer. Future evaluations should schedule time for the concept developers to do at least a sanity check on the evaluations, or, better yet, contribute to them.

- The Magnitude of the Problem

For many on the Concept Development Team, this first round of concept definition and evaluation was an enormous learning experience, both of the range and complexity of the challenges posed by a safe automated vehicle/highway, and the breadth of possible solutions which are attractive to stakeholders. And the various stakeholders have conflicting demands, the requirements of which can only be stated in broad and general form. In addition, there are the constraints of evolving technology, and the demand for a realistic (whatever that might be) deployment plan. Originally it was thought that the right answer would bubble up through consensus building. But it has been very difficult to resolve the issues and reach consensus. The Concept Team needs to continue its efforts to define and justify the requirements of the AHS.