4. CONCEPT EVALUATIONS

Five teams were formed to evaluate and compare the 23 candidate concepts. (Seven External System Concepts are being independently developed by outside contractors. The evaluations of these concepts are discussed in chapter 6.) Rather than assign each team to some group of concepts, each team was tasked to evaluate all of the concepts relative to a major issue area. This approach was chosen to allow greater depth in the evaluations and uniformity across all concepts. Teams were formed to address each of the major issues: Throughput, Safety, Cost, Flexibility/Deployability, and Acceptability. Each team consisted of members from multiple organizations.

Each of the Objectives and Characteristics was assigned to one of these teams, as indicated in the following Table 4-I.

The goals of the evaluations were to:

- Eliminate unpromising candidate concepts
- Eliminate unpromising key characteristics solutions
- Identify additional key characteristics
- Identify trade studies
- Suggest improvements to the candidate concepts
- Suggest additional promising candidate concepts
- Identify six promising concept families.
- Justify selections of the six concept families

Each team developed a plan for evaluation of the concepts that included, but was not limited to, an assessment relative to the Objectives and Characteristics. Each of the five viewpoints required a different approach to the assessment. The challenge was to formulate a plan that allows a broad evaluation of a large number of alternatives in a short period of time, with an eye toward more detailed comparisons in the next phase. The evaluations were performed according to the plans. In general, the evaluations were qualitative, but were reported as numerical ratings. The evaluation reports, including the plans, are included in the following sections, with detailed background data appearing in appendixes B through G

There was another team charged with ensuring clear and sufficient descriptions of the concepts. Yet another team merged all the evaluation results. This was necessary since the relative ratings of the concepts, as expected, varied across the five viewpoints. The selection and definition of the 6 concept was based on the five evaluation results, relative stakeholder importance of each of the five areas, and stakeholder feedback. This activity and its outcome are discussed in section 4.6, and chapters 5, 7 and 9. The concept definition teams continued to be available during the evaluation process to refine descriptions, answer questions, and generally support the evaluations.

The 23 concepts had been selected as representatives of the possible range of automated highway systems, and did not include all possible solutions. Hence it was seen as unlikely that the final six concepts presented in the Workshop would be exactly like any of the original 23. This meant that the team has gone through a process of re-concepting, rather than of down selection. The re-concepting has occurred through evaluation teams noting deficiencies in the concepts and suggesting ways to modify the concepts. The teams were asked not to reject a concept outright based on the evaluation, but to look for easy fixes that greatly improved the concept. Such ideas are normal by-products of the evaluation process, and greatly support the re-concepting process.

The goal of the evaluation was not just to compare alternatives. In the process of evaluating the alternatives, there were lessons learned about what characteristics drove performance. These lessons are just as important as the comparative evaluations, if not more so. Identifying uncorrectable "show stoppers" that make a concept unacceptable relative to some aspect is especially important, because this allows the elimination of alternatives before evaluating all dimensions.

The concept descriptions themselves generated insights even before the evaluations began. For example, the Infrastructure Supported concept write-ups generally included additional infrastructure, while Infrastructure Managed did not use all that it had. This indicated an intermediate level of infrastructure involvement that is probably superior to either of the two.

Table 4-I. Allocation of Objectives to the Five Evaluation Teams

AHS Performance Objectives and Characteristics	Page*	Evaluation Team to which this item is assigned
Improve Safety	17	Safety
Increase Throughput	18	Throughput
Enhance Mobility	20	Acceptability
More Convenient and Comfortable Highway Traveling	21	Acceptability
Reduce Environmental Impact	22	Acceptability
Operate in Inclement Weather	23	Flexibility
Ensure Affordable Cost and Economic Feasibility	23	Cost
Beneficial Effect on Conventional Roadways	24	Throughput
Easy to Use	25	Acceptability
Infrastructure Compatibility	26	Flexibility
Facilitate Intermodal and Multimodal Transportation	26	Acceptability
Ensure Deployability	27	Flexibility
Provide High Availability	28	Flexibility
Apply to Rural Roadways	28	Flexibility
Disengage the Driver from Driving	29	Acceptability
Support Travel Demand Management Policies	29	Acceptability
Support Sustainable Transportation Policies	30	Acceptability (with input from the Cost Evaluation Team)
Provide Flexibility	30	Flexibility
Operate in a Mixed Traffic with Non-AHS Vehicles	31	Flexibility
Support a Wide Range of Vehicle Types	31	Flexibility
Enhance Operations for Freight Carriers	32	Flexibility
Support Automated Transit Operations	32	Flexibility
Provide System Modularity	33	Flexibility

* Page on which description starts in the document, "Automated Highway System (AHS) System Objectives and Characteristics, 2nd Draft", May 22, 1995

It was also noted that two concepts that differ only in one characteristic may differ greatly in their evaluatory design, since they were intentionally assigned to different, independent teams. This indicates that there is great variety in the potential AHS solutions, and the candidate concepts and their evaluatory designs are merely representatives of this variety. Hence the evaluators could not merely assess the alternatives; the best solution may not be among them. A major evaluation goal was the identification of better alternatives. In fact, the evaluations supported this goal; very early in the process there were new characteristics surfacing from the analysis.

Besides looking for conceptual insights, the evaluations were made numerical to facilitate concept-to-concept comparison. This may not be an actual measure of effectiveness, and is more likely a qualitative rating. Each team evaluated the concepts relative to multiple factors, of varying levels of importance. Then they each found some way, such as weighting, to combine these evaluations into a single composite score for each evaluation area (throughput, etc.). This helped the other teams see which were the best and worst concepts in each of throughput, safety, etc. and to gain a better grasp of the results. This also supported the down selection.

4.1 THROUGHPUT

This team evaluated the ability of the different concepts to increase traffic capacity.

4.1.1 Introduction

This section summarizes the throughput evaluation findings as well as down-selection and reconcepting recommendations. AHS throughput, at least that of the mainline, hinges upon the safety spacings between two longitudinally adjacent vehicles. The Team also conducted a parametric study of such spacings (see Appendix B).

The rest of the section is organized as follows. Section 4.1.2 discusses the methodology, particularly the measures of effectiveness (MOEs) considered, the qualitative nature of the work and the relationship between throughput and other major measure of effectiveness. Section 4.1.3 discusses the throughput implications of the six concept characteristics and compares the impact of each of the solutions. Section 4.1.4 summarizes many potential throughput issues associated with the concept characteristics and solutions. Section 4.1.5 summarizes the evaluation findings for the 22 concepts. Down-selection and reconcepting recommendations are described in Section 4.1.6. Also included in Section 4.1.6 are some down-selection and reconcepting inclinations by the Throughput team members. Section 4.1.7 summarizes the study of the safety spacings.

4.1.2 The Methodology

4.1.2.1. <u>Team Composition</u>

The team composition was as follows:

PATH: D. Godbole, R. Hall, P. Ioannou, A. Kanaris, J. Misener, S. Shladover, J. Tsao

Bechtel: S. Sultan

Caltrans: A. Siddiqui

MITRE: W. Stevens

4.1.2.2. <u>The MOEs Used and Issues Investigated</u>

<u>Longitudinal capacity (vehicles per lane per hour)</u>

- light-duty vehicle
- heavy bus
- heavy truck
  - single-unit
  - tractor trailer
  - articulated truck
  - mixture
- lateral capacity
- merging of two traffic streams into one
- missed exits

<u>Entry rate</u>

- dedicated on-ramps

  - single check-in area and queue
  - multiple check-in areas and queues (light-duty & heavy vehicles)
- transition lane
  - continuous
  - limited to entry areas

Exit rate

- dedicated off-ramps
- transition lane
  - continuous
  - limited to exit areas

4.1.2.3. Stages

The evaluation task was divided into the following 4 stages.

1) Perform qualitative evaluation of all original twenty-two Concepts against two basic groups of MOEs, mainline MOEs and interface (entry, exit and transition lane) MOEs. (Note that those MOEs that depend heavily on Application Scenarios are not included in the evaluation but are expected to be evaluated later for the 6 selected concepts as part of Task C2.)

2) Select those concepts that deserve further quantitative throughput evaluation. Due to the limited time and resources, those Concepts not likely to survive the downselect process, either because of insufficient throughput or other reasons (e.g. safety), will not be given significant quantitative evaluation.

3) Develop preliminary models and tools to perform preliminary quantitative evaluation. Due to the limited time and resources, only preliminary models and tools were developed and hence preliminary evaluation performed.

4) Use of those existing or developing models and tools by Jacob Tsao of UCB, Randy Hall of USC, Petros Ioannou of USC and Bin Ran of U. of Wisconsin at Madison were attempted for the preliminary throughput evaluation.

Note the qualitative nature of the work: AHS throughput, at least the mainline throughput, hinges upon the spacings between two longitudinal adjacent vehicles. However, the main determinants for the spacings are safety and risk aversion. The former requires in-depth study of possible failure modes, their possible consequences, possible responses to them, and their frequencies. The latter involves public policies.

Failure modes, their consequences and responses, frequencies, and policies are beyond the scope of this early concept development work. Consequently, no precise throughout prediction can be made for C1. A parametric study on the safety spacings was performed and is reported in Appendix B. The evaluation of the 22 concepts was partially based on this parametric study. It was also based on other preliminary analysis and, more importantly, PSA results and other results in the existing literature. When accurate quantitative measures were lacking, engineering judgement was used.

4.1.3 Impact of Concept Characteristics on Throughput

This subsection describes the general impact of each of the concept characteristics and their solutions to AHS throughput. It also ranks the solutions, when appropriate, according to their throughput potential.

4.1.3.1. Distribution of Intelligence

In the context of Task C1, intelligence is referred to as what goes beyond ITS intelligence. The five solutions are autonomous, cooperative, infrastructure supported, infrastructure managed and infrastructure controlled. The first four solutions feature increasing vehicle intelligence while the last three involve increasing infrastructure intelligence. In general, the level of total intelligence increases with the the five solutions, except perhaps that the infrastructure controlled solution calls for less vehicle intelligence than infrastructure managed solution.

The total intelligence of a solution has a large impact on the achievable throughput. Since the first four solutions feature an increasing amount of total intelligence, they provide an increasing amount of throughput. However, the throughput achievable by the fifth solution - infrastructure control - hinges upon the technology. Since there is very little published literature on this subject and also very little on-going research into such technologies, it is very difficult to assess the achievable throughput and compare it with those achievable by other solutions.

4.1.3.2. Longitudinal Separation

There are three different solutions: free-agent, platoon and slot. Fair throughput comparison requires approximate ranges of spacing values, which in turn require thorough evaluation of their safety. At this early stage of concept development and evaluation, such evaluation is yet to be performed. Through an extensive literature review and much discussion between the team members, it was concluded that the platooning policy should provide more throughput than the free-agent policy but slot policy would provide the least throughput improvement over the throughput on conventional highways, if at all. It was concluded that the slot length would be much larger than the average intervehicle spacing required by either the free-agent or the platooning policies. For details, refer to Appendix B.

4.1.3.3. Mixing of AHS vehicles with Non-AHS vehicles

There are four solutions: continuous barriers between the AHS lanes and the manual lanes, physical barriers with gaps, virtual barriers and full mixing. Because of vehicle uniformity and the absence of interaction between the automated traffic and the manual traffic, the solution of continuous barriers offers the most throughput. For similar reasons, AHS with physical barriers with gaps provides more throughput than that with virtual barriers, which in turns offers more throughput than that with full mixing. Note that in all four solutions except the first, all the AHS traffic, including all heavy-duty vehicles, needs to access and egress the AHS lanes through the manual lanes. Therefore, the throughput of the AHS lanes is subject to the ability of the manual lanes to feed traffic into the AHS lanes and to absorb traffic exiting the AHS lanes. If the manual portion of the highway is congested, the congestion may have a tremendous negative impact on the throughput on the AHS lanes.

The interaction between the AHS traffic and the manual traffic incurred by the three latter solutions may necessitate a small to moderate speed differential between these two lane types. In those AHS with virtual barriers, spill-over of accidents from the manual portion of the highway may severely impact the throughput on the AHS lanes and vice versa. Full mixing of automated vehicles and manually driven vehicles will necessitate large spacings between an automated vehicle and its neighboring manually driven vehicles. Therefore, it offers minimum, if any, throughput gain over the conventional highways.

4.1.3.4. Mixing of Vehicle classes

The two solutions are full mixing and no mixing of different classes of vehicle in the same lane. We assume that AHS vehicles will be grouped into two categories - heavy-duty and light-duty vehicles. Due to the different braking capabilities of these two categories of vehicle, full mixing results in less throughput, in terms of number of vehicles per lane per hour. For details, refer to Appendix B. However, given the low percentage of heavy vehicles among current highway users, it may be difficult to justify dedication of even one lane to heavy vehicles.

4.1.3.5. Entry/Exit

There are two solutions - dedicated on/off ramps and transition lane. This concept characteristic is closely related to that of mixing AHS vehicles with non-AHS vehicles, at least from the throughput point of view. The solution of dedicated on/off ramps of the former can be combined with the solution of continuous barriers for the latter. The throughput implication of the transition lane depends on whether there are physical barriers with gaps or only virtual barriers.

4.1.3.6. Obstacle Detection

There are three different solutions - manual detection and manual avoidance, automatic detection but manual avoidance and automatic detection and avoidance. Since the feasibility of the latter two solutions is yet to be examined and compared to the first solution, it is difficult to make any judgement of their throughput potential and impact.

4.1.4 General Issues

This section summarizes some general issues associated with the concept characteristics and solutions. We group these issues in two categories: mainline and interface.

4.1.4.1. Main Line Issues

4.1.4.1.1. Lane-changing (including transition lane entry) with significant speed differential but without infrastructure assistance:

It is likely, if not inevitable, that there will be a significant difference between the speeds of two adjacent automated lanes. (The same is true between the transition lane and the adjacent automated lane.) In the presence of a significant speed differential, identification of a receiving gap and coordination for safety during a lane change are essential. Such coordination is most likely conducted through communication among vehicles and/or between vehicles and infrastructure. Without any infrastructure assistance beyond the current definition of infrastructure support in the individual lane-change maneuvers, it may be difficult for the lane-change vehicle to identify the neighboring vehicles with which it needs to establish communication. Even when the communication parties can be identified, it may be difficult for the lane-change vehicle to establish a dedicated communication channel (or multiple communication channels) to the communication parties. These issues must be studied in depth in due course.

4.1.4.1.2. Merging without infrastructure assistance

Merging of two streams of traffic into one will take place on AHS, e.g. at the merging locations where one lane is dropped. Note that merging locations often involve difference in elevation, e.g. the merging locations at highway-to-highway interchanges. Unlike lane-changing, which can be aborted and retried downstream at a later time, merging in general must be performed successfully within a limited amount of space and time. Failure to do so may result in safety hazards and disturbance to AHS traffic. Safe merging will likely require communication among vehicles. However, without any infrastructure assistance (beyond the current definition of infrastructure support), identification of communication parties could be a problem. Also, even if such identification can be made, establishing a dedicated channel (or multiple dedicated channels) could be a problem. If line-of-sight is needed for gap identification or communication, then long ramps or very sophisticated sensors (e.g. concrete-penetrating) will be required, especially for platooning concepts where two streams of long platoons may be involved. It is presummed in this preliminary throughput evaluation, without further analysis, that systems which lack infrastructure support for merging will thus be limited in throughput at merges.

This problem is particularly serious where the AHS has only one lane. Such a single-lane AHS may exist due to limited demand, which may occur at low-demand locations after widespread AHS deployment or occur at early AHS deployment stages. Merging takes place at any location where two streams of traffic are merged into one. Such locations include the merging points at highway-to-highway interchanges and any place where a lane is being dropped. It also takes place at on-ramps. We will use on-ramps as the example in the following discussion.

There exists virtually no literature on the effect of on-ramp merging on a single-lane highway (each direction), although there is a significant amount of existing literature on that effect on multi-lane highways. For multi-lane highways, it has been demonstrated by different research studies that on-ramp merging indeed has negative impact on the mainline throughput but the impact decreases as the number of lanes increases. In other words, the smaller the lane number, the higher the negative impact of such merging. Perhaps due to the fact that there exists virtually no single-lane highway in the US or elsewhere, no study has been done on the effect of such merging on a single-lane highway. It is also likely that the negative effect of such merging on the mainline throughput on a single-lane highway is so intuitively clear and large that no single-lane highway was even contemplated and no in-depth studies were warranted. As argued earlier, many reasons pointed to the need for a single-lane AHS. Therefore, the merging maneuver deserves much attention because if it is not performed efficiently and safely, the mainline throughput of a single-lane AHS may suffer a big loss. It is possible that safe and efficient merging will be best performed with some degree of infrastructure assistance. This issue should be studied carefully in due course.

A final note on the role of efficient merging in AHS. Unless the AHS can be designed so safe that there will be virtually no lane-blocking incidents and accidents, one needs to study the effect of lane blockage on the throughput of AHS. When a lane is blocked, the traffic already on that lane needs to be directed onto the adjacent lane or the breakdown lane, if any. Consider a multi-lane AHS where one lane is blocked due to an incident. This blockage requires merging of two streams of traffic into one. Note that, at capacity, traffic build-up on AHS is much faster than its conventional counterpart due to the large capacity of AHS. If merging before the blockage is not done safely and efficiently on the AHS, the effect will be exacerbated. This also points to the need to seriously treat the ability of a concept/design to safely and efficiently perform the merging maneuver as a fundamental issue. Note that, unlike the merging taking place at pre-determined merging locations, such merging at blockage may take place anywhere on the AHS. It is possible that safe and efficient merging at random locations on the AHS requires some infrastructure assistance beyond the infrastructure support as currently defined.

4.1.4.2. <u>Interface Issues</u>

Interface issues are grouped into those related to dedicated on-off ramps and those related to the transition lane.

4.1.4.2.1. <u>Dedicated On/Off-Ramps</u>

<u>Spacing Between Entry/Exit Points</u>

Preliminary but quantitative study has shown that frequent entry/exit points are needed to feed high flow rate on the mainline. Given the current trip length distribution, one automated on-ramp with a capacity doubling that of a manual on-ramp is needed for every mile on the AHS in order to feed a three-lane AHS. The same applies to the off-ramps.

<u>Effect of Manual-AHS transition on Ramp Throughput</u>

Since the manual-automatic transition needs to take place prior to entering the automated portion of the on-ramp (i.e. AHS entry lane), approximately two manual lanes are needed to feed one AHS entry lane. If new highway-to-street interchanges are to be built, then the AHS may lead to extensive infrastructure modification at the AHS-City Street interface. This will require augmented conventional on-ramps if the conventional on-ramps are used. However, this may lead to a shift of congestion from the highway mainline to the AHS-city street interface. Therefore, AHS design and deployment should be integrated with the whole roadway transportation system. A high AHS mainline capacity may not be fully used if the interface issues are not resolved. The same applies to the off-ramps.

<u>Effect of on-ramp merging, particularly for those AHS with only one lane</u>

As argued earlier, merging at on-ramps may have a significant impact on the mainline throughput, particularly for sections of the AHS where only one AHS lane is provided. Note that merging may take place on AHS mainline as well as on-ramps.

4.1.4.2.2. Transition Lane

Effect of Congestion on Manual Lanes on Entry Rate and Exit Rate

If the AHS is equipped with only transition lanes but no dedicated on-off ramps, then all AHS traffic needs to travel through the manual lanes in order to access and egress the AHS lanes. Therefore, the entry rate into and exit rate out of AHS hinge on the congestion level of the manual portion of the highway. Particularly, when the manual portion is congested, either due to recurrent congestion or non-recurrent incidents, the AHS lanes cannot be fully utilized and, more importantly, traffic may be spilled back from the congested manual lanes onto the AHS lanes. Note that the resulting blockage may have a tremendous effect on the mainline throughput, as argued earlier about the effect of lane blockage due to incidents or accidents.

Effect of Disruption to Manual Traffic by Traffic Accessing and Egressing Automated Lanes

The AHS can carry a high volume of traffic, including heavy-duty vehicles. The access and egress of the AHS vehicles through the manual portion of the highway may cause significant disturbance to the traffic on the manual lanes.

More importantly, if the transition lane is not continuous throughout the AHS (which is most likely the case if deployed), i.e. the transition lane is provided only at highway-to-street interface locations, the traffic on the ending transition lane at the AHS egress location needs to be merged with the traffic on the leftmost manual lane. Note that since the egressing traffic could be heavy and heavy vehicles also egress from the location, the merging activities at the location may cause much disturbance to the traffic on the manual lanes.

Also, note that providing a continuous transition lane throughout the AHS requires much right-of-way and dilutes the capacity gain of the AHS. If a continuous breakdown lane is also required, it further reduces the AHS potential for capacity gain.

Ability of Manual On-ramps to Feed Sufficient AHS Traffic

If no dedicated AHS on-off ramps or additional conventional on-off ramps are built, then all the AHS traffic, in addition to the manual traffic, has to access and egress AHS from the manual on-off ramps. This puts a heavy burden on the existing manual on-off ramps. Heavy congestion at the on-off ramps may result, unless they are augmented accordingly.

Effect of Speed Differential on Entry Rate

The AHS is expected to have stable and possibly higher speed than the manual lanes, particularly when the manual lanes are congested. This speed differential may lead to the necessity of a large reception gap for an entering vehicle, which in turn may lead to a lower entry rate into the AHS. Or alternatively, due to the interaction between the automated traffic and the manual traffic on or near the transition lane, the actual speed differential may need to be kept below a certain threshold for safety and efficient entry.

Effect of Merging/Lane-changing on Mainline Throughput

Due to the presence of interaction between the automated traffic and the manual traffic on the transition lane, merging/lane changing may have even higher negative effect on the mainline traffic than those AHS with exclusive dedicated AHS on-off ramps. Again, this effect is more serious when the AHS segment has only one lane.

4.1.5 Evaluation Of 22 Concepts

The focus was on normal operations. First described is the format in which the evaluation results are summarized. For individual concepts, concept characteristics and their solutions are first described and followed by the evaluation results. The results are summarized in the following 10 subsections. Note that multiple but similar concepts may be described and compared under one subsection heading. The following format is used in summarizing the results.

Concept #(s): -(The Subsection Header)

Concept Summary:

- common characteristic solutions
- distinct characteristic solutions

Maneuvers:

- longitudinal travel (vehicle following, speed following)
- lane-changing: disturbance to longitudinal flow
- merging: disturbance to longitudinal flow

Flow Optimization:

- optimization by vehicle
- system optimization

Interface:

Others Considerations: including, for example, system flow control functions in response to incidents

Throughput Rating:

1 less than conventional
2 similar to conventional
3 1 - 2 times of conventional
4 2 - 3 times of conventional
5 3 times or more of conventional

4.1.5.1. Concepts #1a & 1b

Concept Summary:

- Common: Autonomous, free-agent, full mixing with manual, mixed classes, transition lane
- Difference: 1a - manual sensing 1b - automatic sensing

Maneuvers:

- longitudinal
  - conservative control law anticipating erratic manual driver behavior
  - capacity similar to conventional
- lane-changing
  - no coordination at all
  - manual driver can be overly aggressive
  - automated vehicles cannot be aggressive by conservativeness of control
  - gaps may be too small for manual lane-changing; clusters hinder both manual and automated lane-changing
  - even if lane changing is manual, the automated vehicles cannot know the lane-changing attempts of vehicles in adjacent lane and hence won't yield, unless turn signal can be recognized and yielding is built in the control law
- merging
  - no coordination at all
  - sensing itself may not be sufficient and vehicle intelligence may not be adequate, unlike human vision and intelligence, especially for locations where there is only one AHS lane

Flow Optimization:

- no system-level flow control functions beyond ITS functions
- no lane assignment
- lane traffic condition information possibly part of ITS

Others:

- incident management flow control difficult if done automatically
- non-coordinated merging worsens the impact of incidents

Rating: 1a - 1 or 2 depending on technology. 1b - 1 or 2 depending on technology.

4.1.5.2. Concepts #18 & #4

Concept Summary:

- Common: cooperative, free-agent, mixed classes
- Difference: 18 - continuous barriers, dedicated on-off ramps 4 - gaps in barriers, transition lane

Maneuvers:

- longitudinal
  - 1 - 2 times conventional capacity
- lane-changing
  - coordination helps lateral flow
  - flow stability may suffer, if speed differential is significant
- merging
  - major problem because of lack of infrastructure support, e.g. no static geometry information about merging points like highway-to-highway interchanges

- merge area may have to be extended so that merging can be performed as lane-changing, particularly for those locations where AHS has only one lane; right-of-way and construction problems result

Flow Optimization:

- no system flow control functions
- no lane assignment
- lane traffic conditions possibly part of ITS

Interface:

- difference in throughput mainly because of interface (smaller speed differential between automated and manual traffic assumed for transition lane; limitations on throughput due to access/egress through manual traffic also assumed)

Others:

- no incident management flow control beyond ITS
- merging problem worsens the impact of incidents

Rating: 18 - 3. 4 - 2-3

4.1.5.3. Concepts #5 & 17

Concept Summary:

- Common: cooperative, platoon, mixed classes, transition lane
- Difference: 5 - gaps in barriers. 17 - virtual barriers

Maneuvers:

- longitudinal
    - flow could be twice as much as conventional or higher
- lane-changing
    - flow depends on lane-changing policy; if full platoon-splitting is required, flow and its stability suffers; "minimum-platoon-split" lane-changing helps flow and stability
- merging
    - without infrastructure support and without using vehicles as conduit for information, merging of two streams of platoons efficiently is difficult (particularly for those locations where AHS has only one lane)
    - note that merging of two streams of platoons is more difficult than merging of two streams of free-agents

Interface:

- physical barrier allows higher speed differential
- platooning with virtual barrier could be unsafe

Flow Optimization:

- no system flow control functions beyond ITS
- no lane assignment

Others:

- no incident management flow control beyond ITS
- merging without infrastructure support worsens the impact of incidents

Rating: 5 - 3. 17 - 2 or 3

4.1.5.4. Concepts #8a, 20, 8b, 6, 16

Concept Summary:

- Common: infrastructure supported, free-agent,
- Difference: 8a - continuous barriers, mixed classes. 20 - continuous barriers, no class mixing, (auto sensing obstacle but stop or manually avoid). 8b - continuous barriers, no class mixing (auto sensing obstacle and automatic avoid). 6 - gaps in barriers, mixed classes. 16 - virtual barriers, mixed classes

Maneuvers:

- longitudinal
    - capacity could be twice the current
    - 20 and 8b can have higher capacity due to non-mixing of classes
- lane-changing
    - coordinated
    - identification of communication parties could be a problem
    - establishing a dedicated channel could be a problem
    - merging
    - lack of infrastructure "assistance" at merging points could make merging inefficient, particularly at

those locations where AHS has only one lane

Flow Optimization:

- system flow control available
- lane assignment available

Interface:

- difference in throughput mainly because of interface

Others:

- incident management flow control is available but should call for early lane changes, rather than relying on merging at the lane blockage

Rating: 8a - 3. 20 - 3. 8b - 3. 6 - 2 or 3. 16 - 2

4.1.5.5. <u>Concepts #9 & 14</u>

Concept Summary:

- Common: infrastructure support, platoon, mixed classes
- Difference: 9 - continuous barriers. 14 - gaps in barriers

Maneuvers:

- longitudinal
  - capacity can be 2 - 3 times of current, depending on spacings
- lane-changing
  - coordinated
  - identification of communication parties could be a problem
  - establishing a dedicated channel could be a problem
- merging
  - lack of infrastructure "assistance" at merging points could make merging very inefficient, especially for one-lane AHS
  - inefficiency could be much more serious than its free-agent counterpart
  - actually, safety could be a problem

Flow Optimization:

- system control optimization available, including platoon sizing

Interface:

- difference in throughput mainly because of interface

Others:

- incident management flow control is available, but should not use merging function, unless absolutely necessary; should use early lane changes, whenever possible

Rating: 9 - 4. 14 - 3-4

4.1.5.6. <u>Concepts #12a, 12b, 10</u>

Concept Summary:

- Common: infrastructure managed, free-agent,
- Difference: 12a - continuous barriers, mixed classes. 12b - continuous barriers, no class mixing. 10 - gaps in barriers, mixed classes

Maneuvers:

- longitudinal
  - lane capacity can be twice the current for #12a and 10
  - lane capacity can be even higher for #12b (no class mixing)
- lane-changing
  - fully coordinated
- merging
  - fully coordinated

Flow Optimization:

- full system optimization

Interface:

- continuous barriers allow higher speed differential

Others:

- full incident management flow control

Rating: 12a - 3. 12b - 3. 10 - 3

4.1.5.7. <u>Concepts #15</u>

Concept Summary:

Infrastructure managed, free-agent, full mixing with manual, transition lane, mixed classes

Maneuvers:

- longitudinal
  - spacing must be set conservatively due to the presence of manually driven vehicles in the same lane
- lane-changing

  - no coordination possible between automated vehicles and manually driven vehicles
- merging
  - no coordination possible between automated vehicles and manually driven vehicles

Flow Optimization:

- system flow control virtually ineffective due to the presence of unequipped vehicles

Others:

- incident management flow control ineffective due to the presence of unequipped vehicles
- lack of coordination at merging points worsens the impact of incidents

Rating: 15 - 2

4.1.5.8. Concepts #19, 13, 11

Concept Summary:

- Common: infrastructure managed, platoon,
- Difference: 19 - continuous barriers, mixed classes. 13 - continuous barriers, no class mixing. 11 - gaps in barriers, mixed classes

Maneuvers:

- longitudinal
  - capacity can be 2 - 3 times the current for #19 and #11
  - capacity can be 3 - 4 times the current for #13
- lane-changing
  - fully coordinated
- merging
  - fully coordinated

Flow Optimization:

- fully system optimization

Interface:

- physical barriers allow higher speed differential

Others:

- complete incident management flow control

Rating: 19 - 4 13 - 4-5 11 - 3-4

4.1.5.9. Concepts #3, 3a

Concept Summary:

- Common: Slot, continuous barriers, no class-mixing
- Difference: #3 - infrastructure controlled. #3a - infrastructure managed (variable slot length)

Maneuvers:

- longitudinal
  - capacity depends on technology and can vary
- lane-changing
  - efficient due to full infrastructure control
- merging
  - efficient due to full infrastructure control

Flow Optimization:

- full system flow optimization

Others:

- full incident management flow control, if the infrastructure control system is fully operational
- the whole system is down if the infrastructure control system fails

Rating: #3 - 2 or 3, depending on technology. #3a - 2 or 3, depending on technology

4.1.5.10. Concepts #2,2a

Concept Summary:

Slot, Infrastructure control, free-agent, continuous barriers, mixed classes

Similar to #3, except that this concept involves slots of variable length

Similar to #3a, except that this concept involves infrastructure control

Rating: 1 or 2, depending on technology

4.1.6 Reconcepting and Downselect Suggestions/Inclinations

The throughput team reached much consensus regarding reconcepting and downselect suggestions, which is documented in the first subsection. Although the team could not reach a unanimous consensus on a number of issues, it identified the majority views on these issues, which are labeled as "inclinations" and documented in the second subsection. Some Inclinations are stated as such because the rationale was not primarily about throughput, which was the jurisdiction of the Team.

4.1.6.1. Reconcepting and Early Loser Suggestions from the Throughput Team:

On Mixing Of AHS And Non-AHS Vehicles:

(1) "Full Mixing" of AHS and non-AHS vehicles in a lane is not considered as AHS but something short of AHS. (This solution was motivated in part by applications of automation technologies to rural areas.) Therefore, it should be treated separately from the current concept development effort, which focuses on the target AHS (i.e. the end state of AHS).

On Distribution Of Intelligence:

(2) Create a new distribution called "Infrastructure Assisted". The Infrastructured Assisted solution provides more functionality than the Supported in that communication from the infrastructure to INDIVIDUAL vehicle or platoon and vice versa is allowed at merging locations, e.g. on-ramps, highway-to-highway interchanges and other merging locations.

(3) Eliminate Autonomous Concepts as target mature AHS concepts. (Although some variations of them could be good intermediate steps toward mature AHS.)

(4) Eliminate Infrastructure Controlled concepts. (This suggestion is made in the absence of a clear understanding of the Virginia Tech concept.)

On Obstacle Detection And Avoidance

(5) Leave Obstacle Detection and Avoidance in for further analysis. There does not exist sufficient evidence regarding the viability of the automated solutions. Treat this concept characteristic as an attribute that needs to be explored for each selected concept, instead of as a concept discriminator.

4.1.6.2. Some Throughput Team's *Inclinations* Regrading Early Loser etc.

On Mixing Of AHS And Non-AHS Vehicles

(6) Eliminate Concept 17, which supports platooning with virtual barriers, for primarily safety (and also throughput) reasons.

(7) Eliminate Concept 15, at least the version described in the Concept Description Document, for reason of attribute incompatibility. The current Concept description calls for Infrastructure Managed distribution of intelligence while allowing Full Mixing of automated vehicles and manual vehicles in a lane.

(The two Inclinations above were actually team consensus but were not provided as Suggestions because the rationale was not primarily about throughput, which was the jurisdiction of the Team.)

On Entry/Exit

(8) An inclination is to eliminate Entry/Exit attribute as a concept discriminator. However, realizing the fact that some concepts, e.g. the autonomous ones and a solicited concept involving mechanical linkage between two longitudinally adjacent vehicles) do not require special entry/exit facilities, the team thought that Entry/Exit should remain as a concept discriminator, at least until those concepts have been ruled out. Those concepts that do require either dedicated on-off ramps or transition lane but differ only in this concept characteristic can be combined for the following reason. Dedicated on- and off-ramps are a necessity for locations with heavy entry/exit demand. Without them, congestion on the manual portion will limit access to and egress from AHS lanes. A transition lane is needed for light-demand areas. Entry/exit configuration is likely to be site-specific, depending on the availability of land, demand volume, construction cost, etc. At this point, the solution set should perhaps be changed from the current two solutions (i.e. dedicated and transition lane) to a different set of two solutions (i.e. "dedicated/transition lane", and none).

On Mixing Of AHS And Non-AHS Vehicles

(9) Entry/Exit solutions are closely related to the attribute "Mixing of AHS vehicles with Non-AHS vehicles", particularly the solutions "Continuous Barriers", "Barriers with Gaps" and "Virtual Barriers". Consequently, it is better to use Physical Barriers (continuous for a long segment or with gaps) and Virtual Barriers (continuous for a long segment or with gaps) as two solutions for this concept discriminator.

On Mixing Of Vehicle Classes

(10) Another inclination is to eliminate "NO MIXING" of vehicle classes [throughout the AHS; not even transitory mixing] as a solution and hence eliminate the whole concept characteristic as a concept discriminator. However, some team members disagreed with this.

To support non-mixing of vehicle classes throughout the AHS would require a dedicated on-/off-ramp for each vehicle class at each interchange that entry/exit of the class of vehicle is to be supported. A set of 8 highway-to-highway connector ramps is required for each class of vehicles at each of such interchange. The structures are likely to be very complex and costly. Also, in a configuration where there is only one truck lane, blockage of the truck lane after an incident implies the blockage of all truck traffic until the clearance of the blockage. In addition, the current mix of vehicle classes on the highway shows a low truck and bus percentage, which casts doubt on the desirability of dedicating lanes to specific vehicles classes thoughout the AHS. (Local authorities will have the option of dedicating lanes to specific vehicle classes.) Some member questions the "requirement" of supporting trucks on AHS and believe it may be dropped in the future after evidence against it accumulates. If it is indeed dropped, much effort will be wasted if the Consortium concentrates exclusively on the Mixed solution.

4.2 SYSTEM SAFETY

The material provided in this section briefly summarizes the results of the safety concept evaluation team meeting held at the Richmond Field Station of UC Berkeley September 7 and 8, 1995. This meeting was called to allow the safety team to compare individual evaluations of the concepts for the AHS. Attendees at the meeting included P. Goddard (Hughes), R. Hettwer (Hughes), E. Page (Bechtel), L. Valavani (Volpe), J. Castro (CALTRANS), B. Michael (PATH), and S. Shladover (PATH). The meeting was successful in providing a clear consensus on several of the concept dimensions and on those concept dimensions which could not be resolved and would need to be carried forward into the next round of concept development (C2).

4.2.1 Baseline AHS System

For the purposes of evaluating the various concepts and concept dimensions, the team used a baseline of a mature AHS system. This was taken to mean that in at least some areas, the AHS would be multi-lane - having several adjacent automated lanes of traffic at one time. The approach of evaluating the effectiveness of a concept or concept dimension based on a mature AHS, operating under worst case conditions, was taken to ensure that concepts which did not have adequate growth potential would be penalized. For some of the concept dimensions, the difference between single lane and multi-lane AHS operation is of major consequence for safety.

4.2.2 Evaluation Approach

The evaluation approach used by the team during the meeting consisted of evaluation of the concept dimensions based on a combination of evaluation metrics provided by Bret Michael and some of the safety MOEs which had previously been developed. The specific evaluation measures the team used included:

1. Emergency and failure handling capability - This capability was considered to be the ability of the concept dimension to aid in handling or preventing rogue vehicles, including aberrant behavior caused by sudden failure of vehicle or infrastructure equipment. Sudden, safety critical

failures of vehicles and/or the appearance of obstacles in very dense urban traffic in multi-lane AHS applications was given particular scrutiny.

2. Inclement weather - Did the concept dimension assist in inclement weather capability, hinder it, or was it indifferent?
3. Media event potential - Does the concept dimension have a potential for causing multi-vehicle crashes? These crashes were felt to have an impact on the acceptance of the safety of the AHS out of proportion to their rate of occurrence.
4. Complexity - How testable and verifiable was the system approach?
5. Coordination required - How much inter-vehicle and wayside-vehicle communications were required under both normal and emergency situations?
6. Data/Sensor fusion potential - How complex was the data from the sensors and the processing of that data needed to support system operation under normal and emergency operation?
7. Maintenance deferral problem potential - How subject was the approach to safety problems caused by maintenance deferral by either the vehicle owner or the roadway operator?
8. Average collision rate - How well was the concept or dimension expected to perform with respect to the average number of collisions?
9. Average collision speed and severity - How well did the concept or dimension perform with respect to average severity of any collisions?
10. Average number of vehicles per collision - What was the expected impact of the concept or dimension on the number of vehicles per accident? This was separate from the media event size multi-vehicle collisions.
11. Robustness - How well did the concept or concept dimension appear to handle failures in any part of the system? Could it reasonably be expected to survive multiple failures without compromising safety?

Each of the evaluation measures was evaluated qualitatively, not quantitatively. The team did not consider the design detail currently available able to support detailed measurements of any of these measures. Also, the team decided that measurement of each individual concept against these measures was without merit. Instead, the concept dimensions which underlie the concepts were evaluated. This resulted in a set of safety team evaluations which clearly indicate the team's recommendations and those areas where further work will be needed before the team can make a decision regarding the concept dimension. The needed work tended to be additional studies which need to be completed and documented so the team can compare the results with the concept dimensions.

4.2.3 Concept Dimension Evaluation Results

This section provides a brief overview of the results of the team's evaluation of theconcept dimensions. Some of the major issues are presented where appropriate. However, most of the results are provided without detailed backup based on the conversations between team members during the meeting.

4.2.3.1 Entry/Exit

Two options are available for this dimension; dedicated entry and exit ramps or transition lanes. All members of the team agreed that dedicated entry and exit ramps are preferred for their ability to control rogue vehicles, allow controlled and more thorough check-in of vehicles if needed, and prevent gore point problems associated with impalement and/or rejection of entering vehicles in transition lanes due to local traffic surges. All of these are potential issues in very dense urban traffic during peak traffic hours. Overall, entry/exit was not considered a major discriminator between possible approaches. All team members felt that this was probably allowable as a roadway operator's decision. On a scale of one to five (five highest), entry/exit was considered to be of level one importance. The team recommends that entry/exit be considered an implementation issue, best -solved by local roadway operators and should not be used as a concept discriminator. The AHS should be designed to support both approaches.

4.2.3.2 Mixing of AHS and non-AHS traffic in the same lane

Separate automated lanes with barriers between the automated lanes and the non-automated lanes were considered safest by the team. Mixing of AHS and non-AHS traffic may be possible without major safety impact in a few, limited cases, in single, barriered lanes. However, in multi-lane implementations, mixing of automated and non-automated traffic creates a major compromise in system safety. The team rated this dimension a three (of five) in importance. One of the major issues with barriers for single lane concepts that the team felt deserved mention was the potential for blockage of the lane, due to jamming between the barriers of a vehicle in a collision. This could lead to a multi-vehicle collision when the first vehicle (e.g. articulated truck) suddenly blocks the lane. Vehicles are not generally expected to maintain 'brick wall' stopping distances during automated travel.

4.2.3.3 Mixing of vehicle classes

The safety team concluded that mixing of vehicle classes during active use of the roadway would compromise safety. Allowing different classes to use the automated roadway during different times would be acceptable if the roadway is checked for damage and debris after heavy vehicles have been allowed use of the roadway. The team considered this dimension to have an importance ranking of three on a scale of one to five (five highest).

4.2.3.4 Obstacle avoidance

The safety team was unable to provide a definitive recommendation with respect to obstacle detection and avoidance approaches. Some members of the team believe that any manual involvement in obstacle avoidance is unsafe, other members strongly disagree believing that driver takeover may be safer than automated avoidance in some, low traffic conditions. Neither side of the ensuing discussion was able to cite any significant studies to support their beliefs. Thus, both manual and automatic obstacle detection and avoidance approaches need to be included in the C2 concept development. The current concepts include only one concept, 1A, with manual detection and avoidance. This indicates a strong predilection to discard manual obstacle detection and avoidance on the part of the concept developers. The team recommends that manual detection and avoidance not be discarded from consideration until definitive study of the possible options and their impact can be performed. In some cases, manual intervention may have the potential to be safer than automatic avoidance. Combined manual and automatic detection and avoidance techniques may have potential and should also be explored. This dimension was considered to have an importance ranking of 3 to 4.

4.2.3.5 Separation policy

Traditional slot concepts, being based on infrastructure control were considered unsafe by the safety team. This is primarily a robustness issue. After discussion, the team was unable to realistically distinguish between platoon and free agent concepts. A free agent equates well to a one vehicle platoon. The team consensus was that the AHS will have to be designed to allow both free agent and platoon concepts to be implemented. There is some preliminary evidence from precursor studies and from studies conducted at PATH that platoons may be safer at some traffic densities due to low inter-vehicle collision speeds within platoons. However, these studies make a number of simplifying assumptions, chiefly that all colliding vehicles remain in the same attitude during the collision (all rear end collisions, single lane or single file), that may invalidate the studies. Detailed simulation and analysis is needed, including detailed simulation of multiple automated lanes and the post initial collision vehicle vectoring, which is common in real world collisions. Both platoon and free agent separation policies need to be studied further during the C2 activity. The team recommended that slot concepts be dropped from further consideration. This dimension was considered to have an importance ranking of 4 to 5.

4.2.3.6 Distribution of intelligence.

The safety team consensus was that all infrastructure control concepts were too prone to catastrophic failure due to common cause or common mode failures. Major multi-vehicle collisions were considered to be too likely when failure occurred for infrastructure controlled options to deserve further consideration. The safety team considered the other four possible distribution of intelligence options to be, more correctly, layers in a well developed AHS system instead of separate concepts. The AHS must support operation as an infrastructure managed system. It must also support operation, albeit possibly at a lower throughput, as an infrastructure supported, as a cooperative, and as a autonomous (driver alertness is an issue here) system. The team felt that the difference in operation should be dependent on the infrastructure equipment which has been installed and on whether or not it is operational at a given time. The team found that the concept that should be explored is how to provide the needed layering of functionality to allow the AHS to respond to differences in local installations and to failures with appropriate spacing and speeds so that safety is not compromised. The different options, which are currently being cited, were not seen by the safety team as appropriate concept discriminators. The options with lesser infrastructure support seemed to be more appropriate for lower capability 'modes' of operation, to be appropriate for areas that do not need to support high throughput, or possibly to provide an evolutionary path to an infrastructure managed design. An infrastructure managed design with its ability to maintain visibility over a significant roadway area, and to recommend or command emergency response of vehicles when unexpected events occur, was considered to allow the maximum safety achievable without undue vulnerability to common mode or common cause failures. Concepts that did not allow centralized emergency coordination of vehicle responses would need to maintain greater spacing and hence lower throughput to achieve operational safety equivalent to an infrastructure managed approach. This dimension was considered to have an importance ranking of 5.

4.2.4 Current Conclusions

The safety team concluded that the concepts as currently developed cannot serve as adequate safety discriminators for the concept selection currently in process. Safety evaluation of the individual dimensions was possible for some of the dimensions. Other dimensions will require further, more detailed study during the next concept selection phase (C2). The distribution of intelligence, with the exception of infrastructure controlled, was found by the team to be less a concept than an appropriate layering of functionality, all of which needs detailed exploration as the program progresses.

4.2.5 Safety Ratings

For the overall evaluation exercise (Section 4.6 below), it was necessary to generate numbers that captured the consortium's best guess as to a safety rating for the various concept. These were generated as follows.

The overall evaluation team reviewed the safety team report, and based on that report, assigned preliminary safety evaluation ratings to each concept. These numbers were given to the safety team for review. After some revision, they were used in the overall evaluation.

4.2.5.1. Safety Numbers

The concepts were rated by giving each characteristic a safety rating on 0-10, and each dimension a rating on how much it influences safety. These were the numbers reviewed with the safety team. They are discussed in Appendix C.

4.2.5.2. Final Safety Rating Results

Each Concept was given an overall safety score by a weighted adding of the safety rating of each of its characteristics. This was normalized to a range of 0 to 100%, with higher scores being better. The safety ratings that resulted from this process were. The safety scores are graphed below.

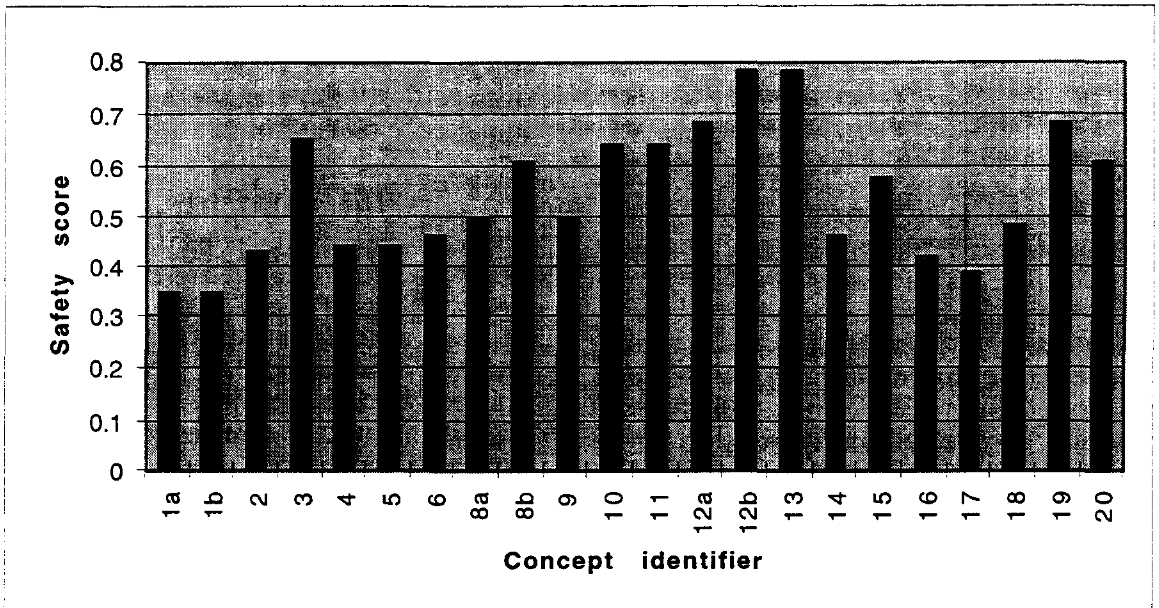

Figure 4.2.4-1. Overall Concept Safety Rating

4.3 COST EVALUATION

4.3.1 Introduction

This section concentrates on ranking the Concepts with regard to cost, from a purely qualitative perspective. The process requires quantitative judgments for comparison purposes only, but no functional cost estimates have been performed in this evaluation. The 22 Concepts have been considered as "end-state," with no accommodations for an evolutionary path. An average degree of complexity was also assumed for each Concept in an attempt to accommodate the various vehicle types and settings (rural, urban, and suburban) that currently exist.

The initial step in this evaluation process was to identify the potential cost contributors and define the key cost elements. Cost is attributable to a variety of factors, but it was imperative that the number of discriminators be limited to perform an effective assessment. The following list identifies these "key" cost elements.

1. Infrastructure and Support Capital Costs–Civil/Structural
2. Infrastructure and Support Capital Costs–Systems and Instrumentation
3. Vehicle-Based Capital Costs–Instrumentation
4. Operations and Maintenance

Cost Element 1 encompasses the costs associated with building or modifying the functional portion of the highway to meet the AHS service requirements. This includes the paved surface, plus entry or exit ramps and any elevated portions of the freeway. Cost Element 2 accounts for the cost of building the infrastructure network. This could involve the construction of a central control facility, as well as any remote communication stations. Cost Element 3 represents the vehicle costs attributed to AHS functions only. This cost element does not attempt to account for the total vehicle cost, but concentrates on those costs added purely to support AHS. Cost Element 4 accounts for the operation and maintenance expenses for the infrastructure and the vehicles.

These key cost elements attempt to encompass most of the cost issues required to construct and operate a transportation facility of this nature. Given the developmental stage of the AHS program, a variety of cost issues were not considered in this evaluation. These issues apply generically to the AHS program and, for the most part, are not Concept dependent. Specifically, the following cost issues were not considered in this evaluation, but must be reviewed at a later stage of development to determine their impact on AHS:

1. Drivers Education
2. Insurance and Liability
3. Technological Developments
4. Operation Inefficiencies

With the cost elements and general assumptions defined, the next step of the evaluation was to clarify the cost sources associated with each cost element. This allowed a scoring system to be developed to identify those Concepts that had the potential for maximum cost in each cost element. Because the dimensional characteristics define each of the 22 Internal Concepts at a high level, pursuing the relative costs on an individual Concept basis was impractical. A more practical manner of addressing the cost issue was to isolate possible costs that relate to each dimensional characteristic.

For each cost element, the assumption was that two or three of the Dimensions envelop most of the related costs. As the applicable Dimensions were reviewed, scores were assigned to each dimensional characteristic to designate the potential for high cost versus low cost. A score of *10* for a specific dimensional option represented the potential for maximum cost, while *0* represented no cost impact. Weighting each Dimension acknowledged the fact that, for a particular cost element, one Dimension may affect cost more significantly than another. The weighting was designed so that scores of *10* for each applicable Dimension resulted in a combined score of *100* for that particular cost element. Thus, a Concept with a score of *100* for a given cost element represents the maximum possible cost associated with that cost element.

The Concept composite ranking was determined by assigning relative weights to each of the four cost elements and summing these weighted values. The weights for each cost element were assigned on a percentage basis and reflect the relative contribution of each cost element toward the maximum cost possible for a given Concept. Marketability was a consideration when assigning a weight to Cost Element 3, since this element represents cost incurred directly by the consumer. The assumption was that the automotive market would not tolerate an extremely high cost associated with the AHS features, whereas the other capital cost elements could absorb a potentially higher cost, since funding would originate with state and federal governments, as well as private enterprises.

The 22 initial candidate concepts were ranked from high to low after calculating a composite score for each concept. This ranking reflected the data compiled for each cost element, but sensitivity analyses were performed to test for consistencies and to identify any reasonable conclusions.

4.3.2 Cost Element Summary

A relative scoring table, concept scoring matrix, and cost element rating graph have been prepared for each of the four cost elements. These results are presented in Appendix D and summarized below. The scoring table identifies the Dimensions that have been considered to encompass the cost for each cost element, plus the associated weighting. This table also assigns the relative scoring for the dimensional options and provides the assumptions and rationale for these values. The scoring matrix displays the scores and calculates an element rating for each Concept. The rating graph displays as a bar graph the results of rating each Concept.

The relative scoring tables reflect the range of costs associated with each of the applicable Dimensions. Given the high level at which the Concepts are currently defined, the manner of incorporating each of these dimensional options into AHS is unspecified.

To maintain consistency throughout the evaluation, the relative scores were based on the highest practical cost for each of the options. The term "practical" has been included in this description to emphasize the fact that informed judgments were applied when scoring the Concepts and restraint has been applied when contemplating a worst-case cost scenario. The assumptions and rationale portion of the tables attempt to outline the extent to which the subteam considered the dimensional development. As the Concepts become more clearly defined, these scores and assumptions should be reviewed and adjusted accordingly.

A review of Cost Element 1 offers a prime example of the range of possibilities that exists for each option. A dedicated AHS facility with continuous barriers has been assigned a score of *10* based on the maximum level of complexity. However, this aspect of the system can be instituted several different ways, as dramatized in Appendix D.

The values applied in the scoring tables reflect potential cost and, as noted, should be reevaluated as the Concepts become more clearly defined. The preceding example is intended to identify alternatives for one specific dimensional option, as well as acknowledge the range of alternatives that exist for other dimensional options.

4.3.2.1. Cost Element 1

Cost element 1 addresses the costs associated with building or modifying the physical portion of the highway. Two Dimensions were considered to envelop the costs associated with this element. The Dimension entitled "AHS and Non-AHS Mixing" identifies the requirements for interconnecting an AHS freeway with a non-AHS freeway. This Dimension was regarded as the major civil/structural cost element due to direct association with the physical infrastructure, and is weighted accordingly. The Dimension entitled "Class Mixing" outlines the necessity for class-specific lanes on the AHS freeway. This Dimension was considered to affect selective portions of the infrastructure only and, as a result, was weighted much lower.

4.3.2.2. Cost Element 2

Cost Element 2 addresses the cost of instituting the systems and instrumentation network necessary to control the AHS environment. Three Dimensions were considered to envelop this cost element. The Dimension entitled "Distribution of Intelligence" identifies the level of participation the infrastructure has in controlling the operation of the AHS facility. This Dimension outlines the basic system functions of the infrastructure and, as a result, was weighted heavily. The Dimensions entitled "Obstacle Detection" and "Separation Policy" were considered to define specific parameters that enhance the system. These Dimensions were weighted lower, since the impact on the system cost depends entirely on the role of the infrastructure. The complexity required to adequately detect roadway obstacles warranted a slightly heavier weighting between these two Dimensions.

4.3.2.3. Cost Element 3

Cost element 3 addresses the cost of adding AHS-related sensors and intelligence to a vehicle. Two Dimensions were considered to envelop this cost element. The Dimension entitled "Obstacle Detection" specifies the most sophisticated sensor requirements on an AHS vehicle. This was weighted heavily due to the wide field of view required on-board the vehicle to adequately detect obstacles, plus the extensive coordination required to support automated evasive action. The Dimension entitled "Distribution of Intelligence" defines a much broader range of sensor requirements, but none as complicated as avoiding and detecting obstacles; thus the lower weighting.

4.3.2.4. Cost Element 4

Cost element 4 addresses the relative costs attributed to infrastructure and vehicle O&M. By definition, these costs depend on the first three cost elements; therefore, three Dimensions were considered to envelop this cost element. The most dominant Dimension from each of Cost Elements 1, 2, and 3 was assumed to represent the O&M for that cost element. The dimensional scoring mirrors that applied to the Dimension in the previous ratings, for each respective cost element. The O&M for the infrastructure system was weighted the heaviest to reflect the relatively short service-life of an electronic-based system and the extensive network of personnel required to prevent extended down times. The O&M for the physical infrastructure was weighted marginal to reflect the resources required for snow removal and other maintenance tasks along the extensive highway system. The O&M of the vehicle was weighted low, since the AHS-specific maintenance required for the vehicle will be minimal.

4.3.3 Composite Cost Ranking

The relative weighting table, Table 4.3-I, identifies the weights applied in the composite analysis to each of the four cost elements. This table summarizes the make-up of the composite analysis and outlines the rationale used to determine these weightings. Cost Elements 1 and 2 have been considered equally heavy when calculating the composite ranking. As described in the introduction, this evaluation considered potential cost with an emphasis on practical applications. Therefore, most of the potential cost was assumed to be linked to the assembly of the infrastructure. Structural capital costs will be required at the beginning of the operation cycle, while the system capital costs will be cyclical and will hinge on the instrumentation service life. If a present value analysis were to be performed on these costs, the assumption would be that these costs would be fairly equal and encompass most of the AHS costs included in this evaluation. Cost Elements 3 and 4 have also been considered equally in this composite ranking. The AHS-specific vehicle costs have been weighted lower than the infrastructure costs as a result of marketability considerations. These costs, for the most part, must be passed directly to the vehicle consumers and will become a sensitive issue when determining retail prices. Government subsidies may play a role, but competitive marketing will be an incentive to minimize these costs. The large volume of vehicles expected to use the AHS roadways constitutes a sizable cost, but the cost of the AHS-related options alone were considered to be less than either component of the infrastructure. When considered on an annualized basis, the O&M for a typical existing freeway is less costly than the capital expenses. Certain components of the AHS O&M are unpredictable, but a similar relationship was assumed in this evaluation.

The concept ranking matrix, Table 4.3-II, summarizes the cost element ratings and calculates the Concept composite ranking. Figure 4.3-1 displays the results of this ranking in bar graph format. The resulting values have been sorted from high to low and presented in Table 4.3-III to allow easier comparison of the Concepts. These scores are ratings and do not relate directly to dollars. Higher scores indicate more expensive.

Table 4.3.3-I. Composite Ranking–All Cost Elements (Impact Proportioned by Relative Weighting)

Weight	Cost Element	Assumptions and Rationale
30%	*Cost Element No. 1* Infrastructure Capital Costs – Civil/Structural	• High cost of inserting/modifying existing well-developed infrastructure • Long useful life of physical infrastructure
30%	*Cost Element No. 2* Infrastructure Capital Costs – Systems and Instrumentation	• Relatively short service life for infrastructure instrumentation • Need to upgrade/update systems and equipment frequently to utilize advancing technology
20%	*Cost Element No. 3* Vehicle-Based Capital Costs	• Relatively short service life to utilize advancing technology • Limited to increased cost associated only with AHS "options" • Lower outlay required when comparing the contribution of each capital-based cost element towards the maximum possible cost
20%	*Cost Element No. 4* Operations and Maintenance	• High levels of maintenance standards for roadway instrumentation to assure reliable operation • Relatively high operating costs of infrastructure-assisted system • AHS vehicle maintenance costs will not be significantly higher than for non-AHS vehicle

Table 4.3.3-II. Summary of Cost Element Rating and Calculation of Concept Composite Reading

	Cost Element Percentage				Total
	0.30	0.30	0.20	0.20	1.00
Concept No.	Cost Element No. 1 Rating (Infrastructure & Support Capital Costs, Civil/Structural)	Cost Element No. 2 Rating (Infrastructure & support Capital Costs, Systems & Instrumentation)	Cost Element No. 3 Rating (Vehicle-Based Instrumentation Capital Costs)	Cost Element No. 4 Rating (Operations and Maintenance Costs)	Composite Ranking
1a	8	7	9	9	8
1b	8	7	100	19	28
2	80	90	38	95	78
3a	100	79	79	82	86
4	40	7	88	31	38
5	40	7	88	31	38
6	40	28	79	49	46
8a	80	28	79	64	61
8b	100	28	79	64	67
9	80	38	79	64	64
10	40	59	79	67	59
11	40	69	79	67	62
12a	80	59	79	82	74
12b	100	59	79	82	80
13	100	69	79	49	49
14	40	38	79	49	49
15	8	59	79	55	47
16	32	28	79	46	43
17	32	7	88	28	35
18	80	7	60	42	47
19	80	59	51	78	68
20	100	28	51	60	61
HIGH	100	90	100	95	86
AVERAGE	59	39	73	57	55
STANDARD DEVIATION	33	27	20	23	20
MEDIAN	60	33	79	62	60
LOW	8	7	9	9	8

Table 4.3.3-III. Composite Ranking (Sorted From Highest to Lowest Cost)

Max of Composite Ranking	
Concept No.	Total
3a	86
13	83
12b	80
2	78
12a	74
19	68
8b	67
9	64
11	62
8a	61
20	61
10	59
14	49
15	47
18	47
6	46
16	43
5	38
4	38
17	35
1b	28
1a	8

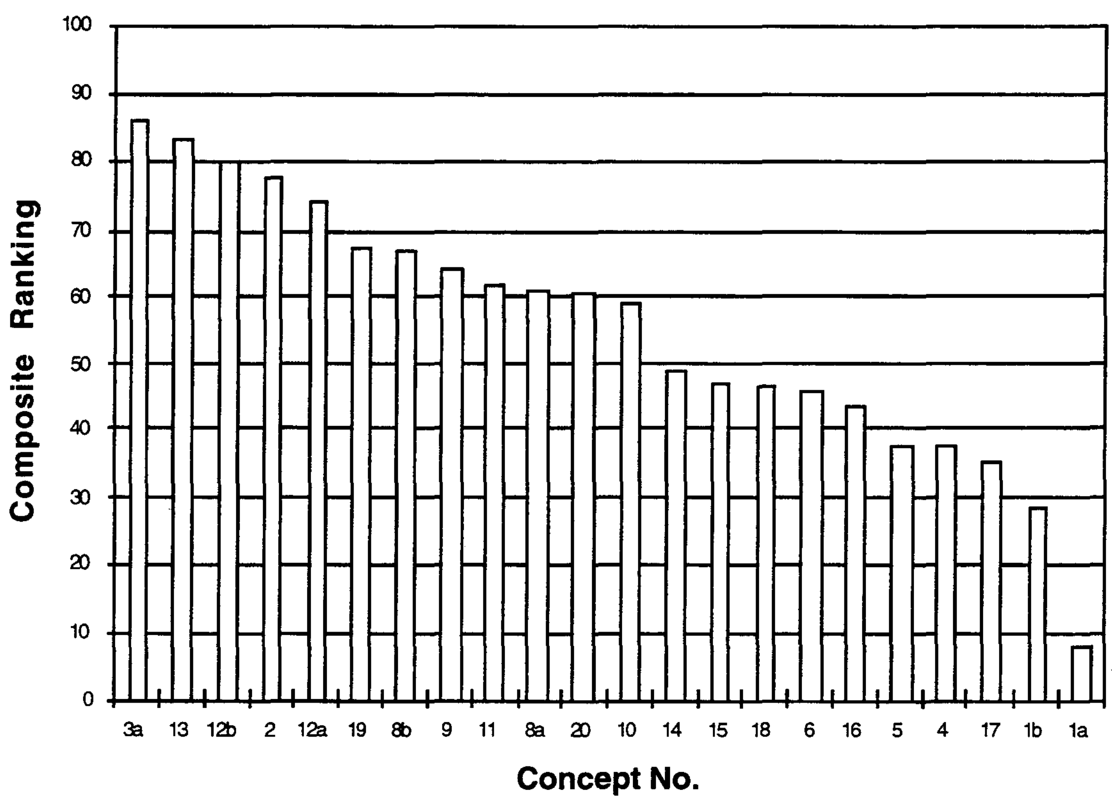

Figure 4.3.3-1. Composite Ranking (Highest to Lowest)

4.3.4 Sensitivity Analyses

The sensitivity analyses were considered essential in determining the consistency of the evaluation results. The weights appliedwhen rating each of the cost elements, as well as when performing the composite ranking, were the focus of these analyses. Various composite percentages were applied to recalculate the rankings and these results were compared with the original data. A similar comparison was made with each of the four cost elements. The goal of these analyses was to identify common results that would support a reasonable conclusion.

The ranking of individual Concepts from high to low with respect to cost was never intended to identify the single most-expensive Concept. It is impossible to accurately perform this task given the current high level of the Concepts. Instead, grouping the Concepts into high-, medium-, and low-cost groups would be possible if the results were consistent throughout thesesensitivity analyses. This grouping could then be used to identify the AHS characteristics with the highest potential cost and possibly to support a cost-benefit analysis.

The first step in determining sensitivity involved modifying the percentages that were applied in the composite ranking. This process could be used to determine if one cost element is able to control the results. The specific results are in Appendix D.

Independently modifying the applied weights from each cost element formed the basis of the next step of the analysis. Adjusting the composite percentages did not significantly affect the results; therefore, the original percentages were considered to be acceptable or, as a minimum, representative. Changing the internal weights of a cost element without modifying any other parameters isolated the direct impact of this change and more clearly defined the significance of each cost element in the composite ranking. This also generated more data to support the creation of cost-groups and help define their alignments.

4.3.5 Cost Conclusions

The original phase of this evaluation process attempted to rank the Concepts from high to low with regard to cost. While this effort was completed, it is not clear that the ranking alone is actually a useful tool. The second phase of this evaluation explored the weights applied in the composite ranking itself, as well as the internal weights applied to the cost elements. The additional data generated in this exercise verified that consistencies existed in the evaluation. Reviewing this data showed that cost groupings could be created to identify those Concepts consistently occurring at either the high or the low end of the cost scale. Three groupings were created as a result of this effort. The sensitivity data showed that seven Concepts consistently occur at the high end of the composite ranking, regardless of how the weights are modified. It also showed that six Concepts consistently appear at the low end of the composite ranking. The remaining nine Concepts fluctuate in their relative positions, but are uniformly found in the middle portion of the ranking. The following list, as displayed in Table 4.3.5-I, identifies the groupings, plus the common attributes shared in each group.

- *Group A: Toward the high end of the composite ranking scale*–Characterized by a fully dedicated AHS facility with considerable infrastructure support (Concepts 2, 3a, 8b, 12a, 12b, 13, and 19)
- *Group B: Mid-range of the composite ranking scale*–Characterized by dedicated AHS lanes with moderate infrastructure support (Concepts 6, 8a, 9, 10, 11, 14, 15, 18, and 20)
- *Group C: Toward the low end of the composite ranking scale*–Characterized by slightly modified existing roadway and an emphasis on vehicle-based intelligence (Concepts 1a, 1b, 4, 5, 16, and 17)

Table 4.3.5-I. AHS Internal System Concepts (Concept Groups)

Candidate Concept Identifiers	1a	1b	[illegible]	[illegible]	4	5	6	8a	[illegible]	9	10	11	[illegible]	[illegible]	[illegible]	14	15	16	17	18	[illegible]	20
Distribution of Intelligence																						
Autonomous	X	X																				
Cooperative					X	X													X	X		
Infrastructure Supported							X	X		X						X		X				X
Infrastructure Managed											X	X					X					
Infrastructure Control																						
Separation Policy																						
Free Agent	X	X			X		X	X			X						X	X		X		X
Platooning						X				X		X				X			X			
Slot																						
Mixing AHS & Non-AHS Vehicles in Same Lane																						
Dedicated lanes with continuous physical barriers								X		X										X		X
Dedicated lanes with some gaps in the physical barriers					X	X	X				X	X				X						
Dedicated lanes with virtual barriers																		X	X			
Full Mixing	X	X															X					
Mixing Vehicle Classes in Same Lane																						
Mixed	X	X			X	X	X	X		X	X	X				X	X	X	X	X		
Not Mixed																						X
Entry/Exit																						
Dedicated								X		X										X		X
Transition	X	X			X	X	X				X	X				X	X	X	X			
Obstacle																						
Manual sensing and avoidance of obstacles	X																					
Automatic sensing, stop or manually avoid																				X		X
Automatic sensing and automatic avoidance maneuver if possible		X			X	X	X	X		X	X	X				X	X	X	X			

Group "A" - High   Group "B" - Mid-Range   Group "C" - Low

These groupings highlight the cost issues associated with reshaping this country's highway network. It seems to indicate that costs could be controlled by making use of the existing resources. However, a cost-benefit analysis must be completed to adequately interpret these conclusions.

4.4 FLEXIBILITY/DEPLOYABILITY CONCEPT EVALUATION

This section summarizes the process and findings of the "Flexibility/Deployability" subgroup of the Automated Highway System Work Breakdown Structure C1 task, *Develop Initial Suite of Concepts,* one of five concept evaluations performed for the C1 task. The task was initiated 25 July 1995 and essentially concluded with the presentation at the Systems Requirements Review #1 on 22 September. The findings were summarized in a presentation at the AHS Workshop #2, 20 October.

4.4.1 Summary

The evaluation of the 23 concepts for Flexibility/Deployability was beneficial from five perspectives:

1) Assessment of the concept dimensions to the Flexibility/ Deployability concerns,
2) Observation of design peculiar attributes to enhance Flexibility/ Deployability,
3) Identification of requirement deficiencies,
4) Development and training in the use of decision analysis tools, and
5) Team building.

In regard to item 1), Assessment of the concept dimensions to the Flexibility/ Deployability concerns:

The findings are tabulated as follows:

In regard to item 2), Observation of design peculiar attributes to enhance Flexibility and Deployability: Much of the discussion of design peculiar attributes was contingent upon application specific opportunities. These and other design centered issues will be addressed in the continuing concept development phases of the program.

In regard to item 3), Identification of requirement deficiencies: The Objectives and Characteristics document has since been improved to eliminate some contentious statements, and requirements development is part of the spiral development process.

In regard to item 4), Development and training in the use of decision analysis tools: Many of the Consortium members learned what is planned to be a frequently applied decision analysis process.

In regard to item 5), Team building: The consortium is composed of people from different corporate, government and academic environments. This task helped to form better relationships within the consortium–professional and inter-personal.

4.4.2 The Objective

The Flexibility/Deployability subgroup, referred to henceforth simply as the Flexibility group, was challenged to assess the relationship between concept dimensions and eleven (11) of the AHS System Objectives and Characteristics (SOC) [Automated Highway System Objectives and Characteristics 2nd Draft; May 22, 1995.]. Figure 4.4.2-1 lists the SOC topics designated as "flexibility issues"--as compared to the other four evaluation groups: Throughput, Safety, Cost and Social Acceptability.The Concept Dimensions were created by the Concept development (C1) team and are defined in section 2 of the C1 Report. Twenty three concepts were developed to support this analysis and are defined in section 3 of the C1 Report.

4.4.3 The Process

The Flexibility group applied a structured decision analysis method. The process assured the findings are defensible and supported by the whole team. The process steps are defined as follows and described in the following paragraphs:

- Review Objectives and Characteristics for Discriminating Criteria

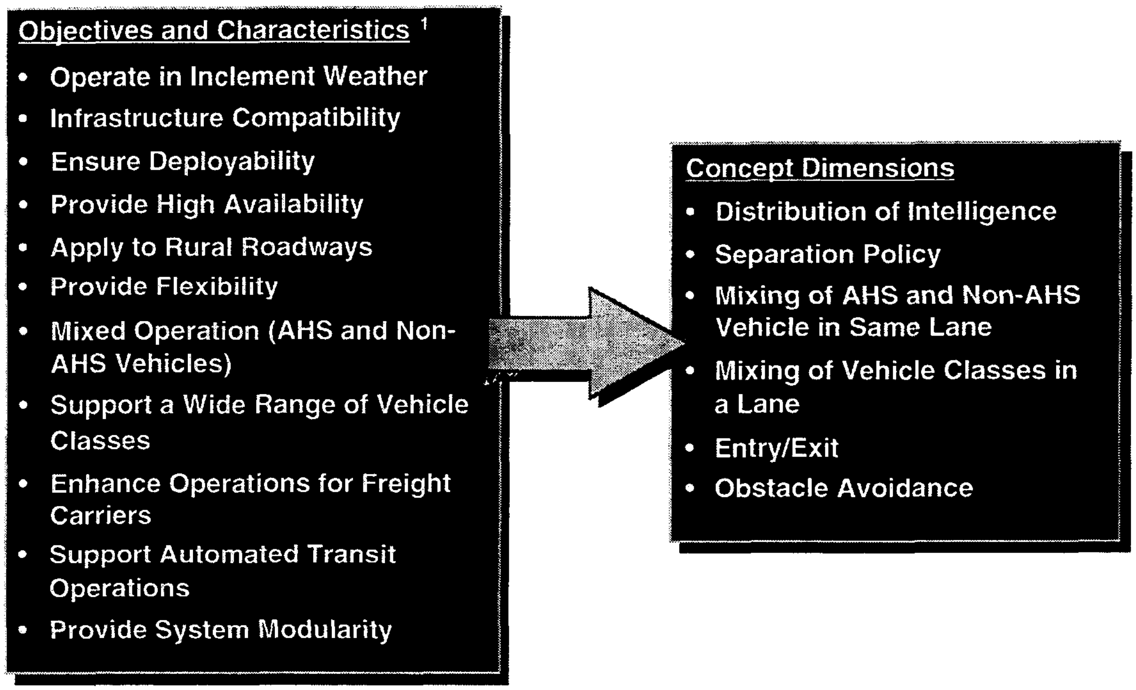

Figure 4.4.2-1 Flexibility Evaluation Objective

- Develop Criteria Definitions and Scoring Symbols
- Score Each Concept Based on Criteria, Completing the "Flexibility Assessment Table"
- Process and Analyze the Data
- Report Findings

4.4.3.1. Review Objectives and Characteristics for Discriminating Criteria

The "flexibility" paragraphs of the SOC document were scrutinized for salient discriminators. Specifically, the following sections (SOC page numbers in parentheses) prescribe the evaluation boundaries:

- Inclement Weather (pg. 23)
- Infrastructure Compatibility (pg. 26)
- Phased-in Implementation of Technology (pg. 27)
- Public Acceptance (pg. 27)
- High Availability--System Malfunction (pg. 28)
- Emergency Vehicles (pg. 28)
- Rural Roadways (pgs. 28 and 31)
- Support a Wide Range of Vehicle Classes (pg. 31)
- Enhance Operations for Freight Carriers (pg. 32)
- Enhance Operations for Transit Operations (pg. 32)
- Provide System Modularity (pg. 33)

4.4.3.2. Develop Criteria Definitions and Scoring Symbols

A coarse evaluation methodology to perform relative qualitative comparisons was ascribed to this task. To achieve robustness, symbols were selected as a scoring proxy in lieu of absolute values. The evaluation criterion were decomposed into five relative categories and specific definitions for each criteria were documented. One of the eleven criteria and discriminating evaluation definitions is shown below as an example. The complete set of criteria is provided in Appendix E.

Infrastructure Compatibility

(&) This concept requires extensive modifications to the infrastructure, e.g. creation of new travel lanes or entry/exit lanes.

(#) This concept requires some modifications to the infrastructure, e.g. installation of communication and control equipment.

(-) This concept requires minimal modifications to the infrastructure, e.g. lane markers, magnetic nails or tape.
(0) This concept requires no modifications to the infrastructure.

Two other scores, "+" and "x", are also used in some criteria to indicate better than current.

4.4.3.3. Score Each Concept Based on Criteria, Completing the "Flexibility Assessment Table"

To facilitate the collection and manipulation of the data, a "Flexibility Assessment Table" was created. Each team member performed an assessment of each of the 23 concepts, based on the criteria discussed in section 2.2. A representation of the Table is shown in Figure 4.4.3-1.

	Inclement Weather	Infrastructure Compatibility	Public Acceptence	Phase-in Technology	High Availability - Malfunction	Emergency Vehicles	Mixed Type with non AHS	Vehicle Classes	Freight Carriers	Transit Operations
01a										
01b										
02										
03										
03a										
20										

Figure 4.4.3-1 Flexibility Assessment Table

4.4.3.4. Process and Analyze the Data

Numerical values were assigned to replace each of the symbols. The scale spanned 15 points from negative nine (-9) to positive six (+6). A summation for each of the concepts was performed and the original 22 concepts were then ranked--from 1 to 22--for each of the evaluators.

> Note: A concept was created at meeting August 23rd, resulting in a total of 23 concepts. The evaluation process was repeated to incorporate the additional concept.

A cumulative ranking was prepared and the results were examined by the Flexibility group. Data entry errors were corrected. This analysis was shown to be insensitive to single and multiple scoring changes.

Each of the criteria were considered to be of equal importance for the initial evaluation. A weighted evaluation, whereby proportional factors were assigned based on a survey of the Program Manager's Council, was also performed. This is a fairly coarse analysis and the findings were not affected by the assignment of the weighting factors.

A spreadsheet program (Microsoft Excel) was utilized to facilitate the data manipulation. Appendix E provides the converted data sheets, summary tables and graphs.

4.4.3.5. Report Findings

The methodology and findings of this process were presented and discussed at a C1 Concept Team meeting August 20th and also at the AHS SRR #1 September 21st. The findings were combined into the team report presented at the AHS Workshop #2, October 20th. The success of the process was dependent upon providing an objective, structured approach and assuring team validation of the methodology and the results.

4.4.4 The Team

Team membership of the Flexibility group included representatives from many of the AHS core participants. Jerry Sobetski performed the role of group leader.

Personnel	Organization
Michelle Bayouth	Carnegie Mellon
Albert Chen	Delco
Tom McKendree	Hughes
Bret Michael	PATH
Steve Schuster	Hughes
Asfand Yar Siddiqui	Caltrans
Jerry Sobetski	Lockheed Martin

The group membership was intentionally broad, presuming the task would be best accomplished by "systems thinking" persons representing dissimilar points of view. The size of the group proved to permit discussion of diverse opinions--and yet allow completion of approximately 80% of the task within one month.

4.4.5 The Results

4.4.5.1. Analysis

The scoring results are shown in Table 4.4.5-I and Figure 4.4.5-1. The conclusions drawn from the data and team discussion follows:

a) The scoring results were reviewed for reasonableness and predictability. The data provided what the team felt were expected results; there were no surprises.
b) Two outliers were identified. The common trait of the two concepts was *infrastructure control* distribution of intelligence.
c) The group sought out concept dimensions common to the best ranked concepts. The two best scored concepts were based on a *vehicle autonomous* distribution of intelligence. Other dimensions common to the favorably scored concepts are: *free agent* separation policy, *full mixing*, *dedicated lanes with virtual barriers*, *mixed vehicle classes* within a lane, and *transition lanes* for entry exit.
d) At the opposite end of the spectrum, in addition to *infrastructure control* distribution of intelligence, *dedicated lanes*, *dedicated entry/exit*, and *not mixed vehicle classes* were identified as poor architecture solutions for deployment and flexibility.
e) Two simple sensitivity analyses were performed. As mentioned earlier, the relative scoring was not affected by changing some of the individual scores. Also, weighting of the criteria (based on a survey of the PMC) did little more than change the relative position of some concepts by a couple of places.

4.4.5.2. Process Critique

The interpretation of the System Objectives and Characteristics document, and specifically how this analysis process linked the rural highway environment to the mixed traffic scenario was challenged. The mixing of AHS and non-AHS equipped vehicles is a significant flexibility and deployment issue; however, this issue is not unique to the rural highway environment. Therefore, the evaluation was performed correctly--providing for the scoring of the concepts relative to their ability to accommodate mixing of types of vehicles. The implicationanticipated as concept development matures. For many of the concept development team members, this was their first experience with this form of decision analysis methodology. This task was valuable not only for the findings relative to the concept dimensions, but also as education and team building.

A note of caution. This is a coarse analysis intended to identify relative pros and cons of the concept dimensions. The evaluation team performed this analysis for an unspecified application. Specific design solutions and geographic application sites analysis could cause challenge of these findings. Also, the fidelity of the analysis does not support specific critique of any one concept versus another.

Table 4.4.5-I. Concepts in Rank Order from Most to Least Flexible/Deployable

Candidate Concept Identifiers	**1b**	**1a**	**15**	**16**	**17**	**11**	**12a**	**12b**	**10**	**4**	**18**	**8a**	**9**	**8b**	**13**	**5**	**6**	**19**	**14**	**20**	**3a**	**3**	**2**
Distribution of Intelligence																							
Autonomous	X	X																					
Cooperative					X					X	X					X							
Infrastructure Supported				X								X	X	X			X		X	X			
Infrastructure Managed			X			X	X	X	X						X			X			X		
Infrastructure Control																						X	X
Separation Policy																							
Free Agent	X	X	X	X			X	X	X	X	X	X		X			X			X			X
Platooning					X	X							X		X	X		X	X				
Slot																					X	X	
Mixing AHS & Non-AHS Vehicles in Same Lane																							
Dedicated lanes with continuous physical barriers							X	X			X	X	X	X	X			X		X	X	X	X
Dedicated lanes with some gaps in the physical barriers						X			X	X						X	X		X				
Dedicated lanes with virtual barriers				X	X																		
Full Mixing	X	X	X																				
Mixing Vehicle Classes in Same Lane																							
Mixed	X	X	X	X	X	X	X		X	X	X	X	X			X	X	X	X				X
Not Mixed								X						X	X					X	X	X	
Entry/Exit																							
Dedicated							X	X			X	X	X	X	X			X		X	X		X
Transition	X	X	X	X	X	X			X	X						X	X		X				
Obstacle																							
Manual sensing and avoidance of obstacles		X																					
Automatic sensing, stop or manually avoid											X							X		X			
Automatic sensing and automatic avoidance maneuver if possible	X		X	X	X	X	X	X	X	X		X	X	X	X	X	X		X		X		X
RANK	4.1	5.6	7.0	7.3	7.7	8.8	8.8	10.3	10.7	11.2	11.2	11.3	11.8	12.0	12.5	13.3	13.7	13.8	14.5	14.8	16.8	21.3	21.6

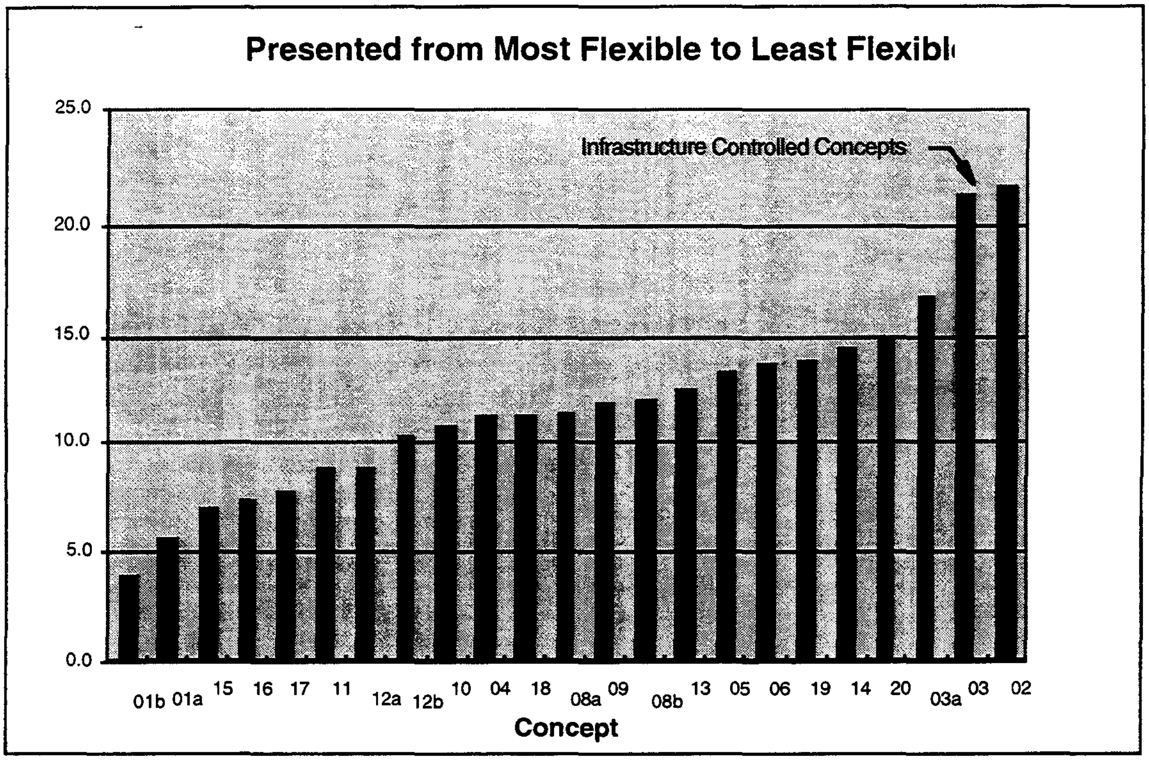

Figure 4.4.5-1. Rank order of concepts for Flexibility/Deployability

4.4.5.3. Flexibility and Deployment Findings

The findings of the evaluation are summarized in Table 4.4.5-II and Table 4.4.5-III.

Table 4.4.5-II. Observations relative to the Objectives and Characteristics

Objectives and Characteristics	Observations
Operate in Inclement Weather	⇒ Technology Dependent ⇒ Not Well Supported by Autonomous Architecture (assuming no vehicle supported communications)
Infrastructure Compatibility	⇒ Movable Physical Barriers Preferred
Ensure Deployability	⇒ Emergency Vehicle Support Facilitated by Communication to AHS Traffic
Provide High Availability	⇒ Availability is a Function of Reliability
Support a Wide Range of Vehicle Classes	⇒ Possible for All Architectures
Enhance Operations for Freight Carriers	⇒ Consider Priority Use, Not Just Access
Support Automated Transit Operations	⇒ Consider Priority Use, Not Just Access
Provide System Modularity	⇒ Possible for All Architectures

Table 4.4.5-III. Findings: Concept dimensions vs. Flexibility/Deployability

Architecture	Favored Dimension	Indifferent to the Flexibility Evaluation	Discouraged Dimension
Distribution of Intelligence	Autonomous	Cooperative Infrastructure Supported Infrastructure Managed	Infrastructure Control
Separation Policy	Free Agent	Platooning Slot	
Mixing of AHS and Non-AHS Vehicles in Same Lane	Dedicated Lanes with Virtual Barriers Full Mixing		Dedicated Lanes with Continuous Physical Barriers Dedicated Lanes with some Gaps in the Physical Barriers
Mixing of Vehicle Classes In a Lane	Mixed		Not mixed
Entry / Exit	Transition		Dedicated

4.5 Acceptability

This section of the C1 Final Report consists of that portion of the evaluation of the twenty-two original consortium-generated concepts relative to the overall category of acceptability issues.

4.5.1 Introduction

This report documents the work performed within the Acceptability component of the overall Concept Development Task of WBS C1. It covers the work performed since the Technical Interchange Meeting (TIM) in Denver the last week of July 1995. The work that is documented in this report consists of the following areas:

- Formation of the Acceptability Team
- Development of the set of evaluation criteria
- Methodology for performing the evaluations
- Methodology for derivation of the aggregated concept evaluation results
- Depiction of the overall concept rankings based on the Acceptability Team's analysis
- Discussion of the findings, including interpretation, conclusions, and recommendations

4.5.2 Formation Of Team

The Acceptability Team was assigned the task of considering a particular subset of the AHS performance objectives and characteristics contained within *Automated Highway System (AHS) System Objectives and Characteristics 2nd Draft (May 22, 1995)*. These issues were related to the social, user, and political acceptability of AHS and was generally referred to as the acceptability issues. The formation of the Acceptability Team was a very easy and natural task since built within the framework of the AHS Consortium's overall program is the Societal and Institutional (S&I) group that is looking at numerous related issues. The other advantage of having the Acceptability team be comprised of Societal & Institutional group staff, is that the people making up the S&I group are well distributed among the consortium organizational core members, though not all core organizational members, however, they truly reflect the views of the core organizations from an S&I perspective. The Acceptability Team was comprised of the following people:

- Mark Miller (California PATH), Team Leader
- Janie Blanchard (Bechtel)
- Matt Hanson (Caltrans)
- Avraham Horowitz (GM)
- Haris Koutsopoulos (CMU)
- Alan Lubliner (PB)
- Edith Page (Bechtel)
- Habib Shamskhou (PB)

4.5.3 Evaluation Criteria

The final list of evaluation criteria was formed from an iterative process based on input from the entire C1 Team at the in-progress concept evaluation team meeting held at PATH in August as well as subsequent meetings among a subset of the Acceptability Team. There was a very substantial list of potential criteria that was pared down to reach this final list (See next section on Section 4.5.4 OMITTED CRITERIA). Suggestions made at the August meeting were, for the most part, incorporated into the decision-making process to develop the final list with some final modifications, however, made by the Acceptability Team. The final list consisted of the following twelve criteria, grouped into four major categories:

<u>MOBILITY/ACCESS</u>

- Trip Time Predictability
- Trip Time
- Accessibility
- Intermodal Transportation Operations

<u>USER ISSUES</u>

- Adaptability/Training
- Driver Participation (level of engagement in non-driving activities)
- Driver Participation (level of engagement, ability to monitor the goings-on of the system and ability to communicate with the system)

<u>ENVIRONMENT</u>

- Vehicle Emissions
- Fuel Consumption

- Travel - Demand Management/ Transportation Systems Management Policies (TDM/TSM)

OTHER

- Ease of Construction and Maintenance
- Ease of Traffic Operations

The original set of eight attributes for the Acceptability category from the Objectives and Characteristics document is as follows:

1. Enhance mobility
2. More convenient & comfortable traveling
3. Reduce environmental impact
4. Easy to use
5. Facilitate intermodal & multimodal transport
6. Disengage driver from driving
7. Support TDM policies
8. Support sustainable transportation policies

The set of criteria used in the evaluation is as follows:

A. Trip time predictability
B. Trip time
C. Accessibility
D. Intermodal
E. Adaptability/training
F. Driver participation (I) [driver disengagement]
G. Driver participation (II) [ability to communicate with system]
H. Vehicle emissions
I. Fuel consumption
J. TDM/TSM
K. Ease of construction & maintenance
L. Ease of traffic operations

An exact and complete correspondence between these two sets cannot be made since the Acceptability team modified the list in their review of the original 8 attributes in conjunction with suggestions made by the C1 team at the August meeting.

The correspondence is given in Table 4.5.3-I.

Table 4.5.3-I. Correspondence between original set of attributes and final evaluation criteria selected.

ORIGINAL SET OF ATTRIBUTES\ FINAL EVALUATION CRITERIA	
1.	A. and B.
2. & 4.	E.
3.	H. & I.
5.	D,
6.	F. and G.
7.	J.
8.	No correspondence as team felt this was a non-discriminator among the concepts at least in their present form
	Criteria C., K., & L. have no counterparts in the original list of eight as these criteria were added by the team, and original criteria #8 was not used in the evaluation.

4.5.4 Omitted Criteria

Numerous topics were brought up for consideration during both the August meeting and subsequent discussions within the Acceptability Team regarding potential evaluation criteria. These issues, which are listed below, were felt to be significant yet were omitted from further consideration for the evaluation because (1) there was likely to be insufficient information with which to evaluate the concepts relative to such issues, (2) such criteria were really not concept discriminators, considering the current stage in the concept development, that is, their very high level of description, even at a qualitative assessment, (3) such criteria were already addressed in other criteria, or (4) such criteria were already addressed by other teams.

Even with the twelve criteria that the team eventually selected there was some doubt as to whether or not they were concept discriminators. This suspicion was proved out, as several team members chose for several of the criteria the "U" score.j The Acceptability category was especially prone to this occurrence as at least some of its topic areas were less quantitative than the throughput, cost, and safety categories. The omitted criteria are listed below. These issues are important, and as the concepts get substantially more developed, may more easily submit to investigation.

- Ride smoothness
- Acoustic noise
- Visual impact
- Electromagnetic fields
- Driving characteristics (local increases in emissions)
- Incentives for efficient use of available resources (sustainable transportation policies): modal vehicles
- Incentives for efficient use of available resources (sustainable transportation policies): infrastructure
- Community goals (neighborhood growth/development and infrastructure construction)
- Land use patterns
- Market demands (different user needs [commercial, transit, private], price, rollout plan)
- Progressive phased deployment
- Equity
- Privacy
- Sustainable transportation policies

4.5.5 Evaluation Criteria And Ranking Levels

Appendix F lists each of the twelve evaluation criteria accompanied by the complete set of gradation levels and descriptions. Where possible, the middle ranking level designated by "0" was associated with a neutral or no impact grade. This was not, however, feasible for all twelve criteria (See for example, the following criteria and associated description for their "0" grade: Intermodal, Adaptability/Training, Driver Participation (I), Driver Participation (II), and TDM/TSM).

4.5.5.1. <u>Mobility/Access</u>

- Trip time predictability
- Trip time
- Accessibility
- Intermodal

4.5.5.2. <u>User Issues</u>

- Adaptability/training
- Driver Participation (I) (Disengaged if desired)
- Driver Participation (II) (Engaged if desired)

4.5.5.3. <u>Environment</u>

- Vehicle Emissions
- Fuel Consumption
- Transportation Demand, Management (TDM)/Transportation, System Management (TSM) Policies

4.5.5.4. <u>Other</u>

- Ease of construction & maintenance
- Ease of traffic operations

4.5.6 Methodology For Performance Of The Evaluation

The process of evaluating the concepts was by nature a very qualitative endeavor, based on best professional judgment as well as any research results known to each team member in his or her knowledge base of information. Of course, each team member had the full set of write-ups for each concept to aid them in the evaluation. These write-ups, however, did not always prove to be the best source of information to execute the evaluation, because of the variability in the write-ups, from writing style, depth of knowledge of each concept developer, and level of detail contained within each document. An additional method sometimes used to assist in the evaluation was to concentrate on the six dimensions (distribution of intelligence, separation policy, mixing of AHS and non-AHS vehicles in same lane, mixing of vehicle classes in same lane, entry/exit, and obstacle detection/avoidance) and investigate the dimension(s) which was(were) the true determinant(s) of the impacts of each of the concepts relative to each of the evaluation criteria.

4.5.7 Methodology For Derivation Of Results

For each of the twelve evaluation criteria, each team member had a choice of the following five ranking levels or grades from which to choose: "++", "+", "0", "-", "--", and "U". Obviously, the "++" represented the most attractive score while "--" represented the least attractive score. The "U" score was used to allow the team members to express their inability to assign a grade, however qualitative, for any of the twelve criteria. The fact that the team members were not forced to make a selection was done because it was thought that the criteria within the Acceptability category might more readily associate itself with some uncertainty. Even the criteria that were eventually chosen from a substantially larger set of potential evaluation criteria, a lot of which were thought to be either non-concept discriminators or insufficient information about them, would be shown to require evaluators to answer with "U". The category labeled "U" generally stated that "unable to determine x due to lack of sufficient information". It was felt that such a category to capture the uncertainty sentiment was important to include in the evaluation.

A numerical score was assigned for each of the five grading options for each criteria, i.e. for "++", "+", "0", "-", and "--" as 4, 2, 0, -2, and -4, respectively. The raw data from the individual team members was first aggregated by giving equal weight to each team member who actually made a selection for each concept and evaluation criteria. As a result of having the choice to select this "U" option, not all 7 team members "voted" for each concept/evaluation criteria pair. The summary score used for each cell of the Acceptability assessment matrix (Table 4.5.7-I) was an average or normalized score for each cell, i.e. the total score for that cell divided by the number of team members who actually selected a score, and not "U". It was important to factor out the differences in the number of scorers, otherwise, a concept could be penalized simply because not every one voted for one of the 5 scores. The aggregated Acceptability assessment matrix consisted of twenty-two columns (concepts) and twelve rows (criteria).

Of the 264 cells in the 12 x 22 assessment matrix, approximately 16% of them contained raw scores (excluding the "U" vote) that had major differences among them, i.e. a spread of either three or four gradation levels. The team was unable to meet either in person or via a conference call to reconcile the differences. It was possible, however, to discuss with some individual team members some of the major differences where their vote was the outlier to better understand where the major differences arose from, whether it was a difference in assumptions, in their knowledge/information base or in their best professional judgment.

There were two areas where variability was allowed due to uncertainty. The first area was whether to keep or omit one of the evaluation criteria, namely, Driver participation (II). Four of the seven team members voted "U", and thus any representation of the results including that criteria would necessarily represent only a minority view. Instead of eliminating this criteria from further consideration, it was suggested by the team to include both cases in the sensitivity analyses to investigate the impact of this criteria. The second area was in the set of weights assigned to the twelve (or as just indicated, in some cases eleven) criteria. The default set of weights was equal weight for all criteria. Opinion from team members was solicited on different sets of weights to test out to perform sensitivity analyses to address the uncertainty in knowing which set of weights to use. Different sets of weights were used in conjunction with the original set of evaluation criteria as well the slightly modified set of criteria (Driver participation (II) omitted).

The following sets of weights were used in the sensitivity analyses run:

1. Default set of weights: equal weights among the criteria
2. Trip time predictability, Accessibility, Vehicle emissions, Ease of construction & maintenance had equal weight and three times the weight of all other criteria, which were weighed equally among themselves.
3. Vehicle emissions, Fuel consumption, Ease of construction & maintenance, and Ease of traffic operations had equal weight and three times the weight of all other criteria, which were weighed equally among themselves.

TABLE 4.5.7-I. ACCEPTABILITY ASSESSMENT

EVALUATION CRITERIA:	1a	1b	2	3a	4	5	6	8a	8b	9	10
MOBILITY/ACCESS:											
Trip time predictability	0.8	0.8	1.86	2.67	2.14	2.29	2.43	1.86	2	2.57	2.43
Trip time	0	0.4	0.83	1	1	1.33	1.5	1.83	2.33	3	1.5
Accessibility	1	1.33	0.8	0.8	0	-0.67	0.8	0.8	0.4	0.33	0.4
Intermodal	-0.2	0.2	1	0.33	0.33	0	1	1.67	0.33	1.33	1
USER ISSUES:											
Adaptibility/training	1.67	1.67	0.67	0	0.67	-0.67	0.67	1	1	0	0.33
Driver participation (I)	-2.29	1	3.33	3.33	3.33	3	3	3.67	3.33	3.33	3
Driver participation (II)	4	0.67	-1.33	-0.67	0	-1.33	-1.33	-0.67	0.67	-0.5	1.5
ENVIRONMENT:											
Vehicle emissions	1.2	1.67	2.71	2.33	1.57	2.57	1.86	2.14	2.29	2.86	1.86
Fuel consumption	1.2	1.2	2.83	2.4	2.4	3	2.6	2.17	2.33	3.33	2.6
TDM/TSM policies	-2	-2	0.5	0	-1.5	-1.5	-0.25	0.25	-0.25	0.25	0.5
OTHER:											
Ease of construction & maint.	0	-0.29	-3.14	-3.14	-1.43	-1.43	-2	-2.57	-2.29	-2.57	-2.43
Ease of traffic operations	0.29	0.86	-0.29	0.29	-0.33	0	0.57	0.57	0.29	0.29	0.57

EVALUATION CRITERIA:	11	12a	12b	13	14	15	16	17	18	19	20
MOBILITY/ACCESS:											
Trip time predictability	2.43	1.86	2.57	2.29	2.57	1.2	1.86	2	1.29	1.57	1.71
Trip time	1.57	1.5	2.67	3	2	1.6	1.83	2	0.83	2.17	1.5
Accessibility	0	0.8	0.8	0.8	0.33	0.8	0.8	0	0	0	0.4
Intermodal	1	1.33	0.33	0.33	1	1	1	0.33	0	1	-0.33

TABLE 4.5.7-I. ACCEPTABILITY ASSESSMENT (CONTINUED)

EVALUATION CRITERIA:	CONCEPT # 11	12a	12b	13	14	15	16	17	18	19	20
USER ISSUES:											
Adaptibility/training	0	1	0.67	-0.33	0	0.8	1	0	0	-1.33	-0.33
Driver participation (I)	3.33	3.67	3.33	3	3	2.67	3.33	2.67	0	0.57	0.57
Driver participation (II)	1	1	0.5	0.5	-1	0.67	0.67	2.67	2	0	0.67
ENVIRONMENT:											
Vehicle emissions	2.71	2.14	2.29	3.14	2.71	2.4	1.86	2.57	2	2.43	1.86
Fuel consumption	3.17	2.17	2.33	3.33	3.17	2.4	2.6	3	2	3.17	1.83
TDM/TSM policies	0	0.5	0.5	1	0.25	1	0.75	-0.5	-1	1	-0.25
OTHER:											
Ease of construction & maint.	-2.71	-2.71	-3.29	-2.71	-2.29	-1.5	-0.67	-0.67	-1.71	-3.29	-2.57
Ease of traffic operations	0.29	0	0	0.29	0.29	-0.33	0.33	-0.33	-0.29	0	0.29

Each of these sets of weights were used with and without the inclusion of the Driver Participation (II) criteria.

4.5.8 Evaluation Results

The results of the evaluation are depicted in the Figures 4.5.8-1. Similar figures in the appendices, which depict all the alternative sensitivity analyses, are ordered both by concept number as well as by evaluation score. The former method readily shows results corresponding to the original ordering of the concepts which were clustered by certain of the six dimensions. The latter method of illustrating the results clearly indicates where changes in scores occur as well as extent of such changes, i.e. steepness of changes in heights of bars corresponding to each concept score:

Labels used in the above figures are described as follows:

Driver Participation (II)	DP (II)
Trip time predictability	TTP
Accessibility	A
Vehicle emissions	VE
Ease of construction & maintenance	ECM
Fuel consumption	FC
Ease of traffic operations	ETO

4.5.9 Findings: Interpretation, Conclusions, And Recommendations

Even though numerical scores were assigned and calculations were made from which a single summary score was derived for each of the twenty-two concepts, the objective was not to pick out the top six concepts. There was definite clustering of concepts in the top tier of concept scores from which it would be inappropriate to say much about the absolute top six scores. It would be important to make statements about such clustering. It is, however, relatively easy in some cases to confidently say, "eliminate concepts X, Y, and Z". The general objective is to recognize features or dimensions that the more successful

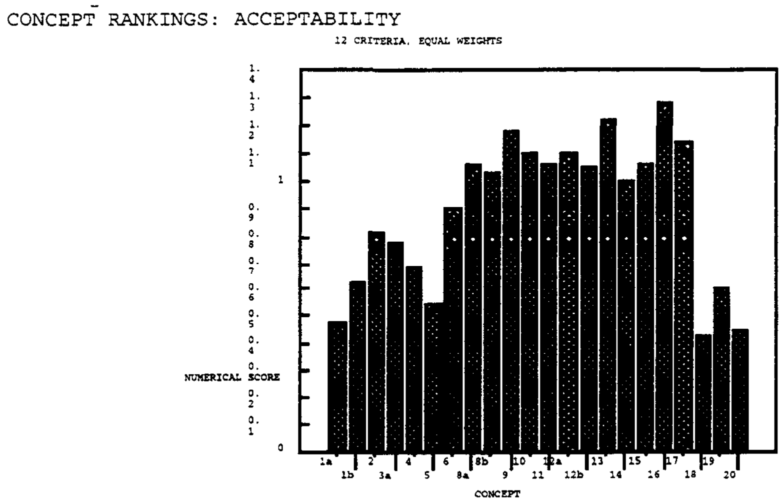

Figure 4.5.8-I. Acceptability Evaluation Results

concepts, relative to this evaluation, have in common. There may, for example, be multiple tiers or levels in the concept rankings, and, of course, differences among the concept scores within the same tier are too close to be able to say that such differences were statistically significant. Moreover, there is insufficient data to make such claims.

Raw data indicated a high level of clustering around the three middle range grading levels (+,0,-) for almost all criteria (exception: Driver Participation (I)). Approximately 16% of the assessment matrix cells of disaggregate raw data contained scores (excluding "U" vote) with major differences, i.e. a spread of three or four gradation levels. Some criteria were sometimes difficult to evaluate either because such criteria were not deemed by the evaluator to be a concept discriminator or there was insufficient information, especially Driver Participation (II) and TDM/TSM. Generally, though not without exception, concepts 6-17 scored higher then either 1-5 or 18-20 across sensitivity analyses with and without the inclusion of Driver Participation (II). The following three conclusions may confidently be made about the findings of this analysis:

- automated obstacle detection *and* avoidance is *very* important
- some form of infrastructure involvement is important (support or manage)
- platoons generally looked on positively, not exclusively though

These three findings remained fairly consistent even allowing for the sensitivity analyses, not exclusively though or without exception, (See the two sets of figures 1, 5, and 9 [all 12 criteria] and 3, 7, and 11 [Driver participation (II) thrown out]). The one notable consistency throughout the evaluation analysis is that automated obstacle detection and avoidance is very important and so confidently it may be said that concepts 18 through 20 should be deleted from further consideration, or rather, the dimension of manual control of obstacle avoidance should be deleted from further consideration.

It is suggested that variation should be maintained in following original dimensions: separation policy, mixing of AHS/non-AHS, mixing of vehicle classes, entry/exit.

4.6 COMPOSITE SCORING

An attempt was made to combine the various evaluations into an overall evaluation. The process illustrated to the participants how difficult it is to combine multiple, often conflicting, attributes into a single, overall rating, without making badly mistaken implicit assumptions.

4.6.1 Developing the Composite Weightings

As expected when alternatives are evaluated from different viewpoints, the ratings of the five teams varied considerably. For example, the minimal alternatives (such as 1a) were given good ratings in cost and flexibility, but low in safety and throughput. The Program Management Council agreed that a resolution of these differences requires relative weighting of the various factors. To this end, the results of the five evaluation teams were turned into numerical ratings. In many cases, the team gave multiple ratings, which were combined using weighting factors provided by the teams themselves. The throughput team assigned a range of ratings, so both high and low are shown. The following Table 4.6.1-I summarizes those ratings. Except for cost, higher is better. Since these are ratings and not actual measures the values are not linear, e.g., a score of 20 is not necessarily twice as good as a score of 10.

Table 4.6.1-I. Evaluation Ratings of the Candidate Concepts

Concept Number	Safety Composite	Cost Composite	Thruput Low	Thruput High	Flexibility	Acceptability
1a	70	8.10	1	2	16.00	0.44
1b	70	28.30	1	2	15.40	0.70
2	85	78.60	1	2	-11.40	0.79
3a	129	85.90	2	3	1.50	0.75
4	87	37.30	2	3	10.10	0.66
5	87	40.30	3	3	7.90	0.70
6	92	45.40	2	3	5.60	0.93
8a	100	61.00	3	3	7.60	0.96
8b	121	67.00	3	3	7.90	0.92
9	100	64.00	4	4	7.90	1.14
10	127	58.30	3	3	8.40	0.94
11	127	61.30	3	4	10.90	0.96
12a	135	73.90	3	3	10.40	0.90
12b	156	79.90	3	3	9.40	0.89
13	156	82.90	4	5	7.90	1.15
14	92	48.40	3	4	4.40	1.03
15	115	46.90	2	2	10.50	0.97
16	83	42.40	2	2	11.40	1.21
17	78	37.30	2	3	11.60	1.07
18	95	46.90	3	3	8.60	0.39
19	135	67.90	4	4	4.90	0.55
20	121	61.00	3	3	3.90	0.41

Each of these ratings was based on an independent scoring scheme, and so direct comparisons are not possible. The levels of the scores vary by one or two orders of magnitude. Hence the next step was to normalize them, with 0 being the lowest achievable score and 1 being the highest. A single throughput score came from averaging high and low. Again, except for cost, high is good. The results of the normalization are shown below in Table 4.6.1-II.

There was a two-stage process to determine the proper weightings. In both cases the Expert Choice tool was used to merge the inputs of the Program Managers, Council. In the first round, the members were asked to rate the relative importance of each of the 24 Objectives and Characteristics from the stakeholders' viewpoint. This was done in the form of a questionnaire generated by the tool, which asked whether each criterion was equally important or moderately, strongly, very strongly or extremely more important than each of the others. Expert Choice then applied the widely used Analytical Hierarchy Process to compute weightings from these responses and identify areas of inconsistencies within the answers for each individual and across the group. The inconsistency levels were found to be acceptable for this high-level analysis. These weightings were used within some of the evaluation areas to weight the various issue areas to produce the single value in the table above. Flexibility in particular did this, since that area addresses a very large number of criteria. The next stage repeated the process with the five evaluation areas. Again, the inconsistency levels were acceptable. The resulting weights are:

- Throughput 24%
- Safety 25%

Table 4.6.1-II. Normalized Evaluation rating

Concept Number	Safety Score	Cost Score	Thruput Score	Flexibility Score	Acceptability Score
1a	35%	8%	13%	77%	56%
1b	35%	28%	13%	79%	59%
2	43%	79%	13%	46%	60%
3a	65%	86%	38%	65%	59%
4	44%	37%	38%	76%	58%
5	44%	40%	50%	72%	59%
6	46%	45%	38%	68%	62%
8a	50%	61%	50%	72%	62%
8b	61%	67%	50%	73%	61%
9	50%	64%	75%	74%	64%
10	64%	58%	50%	72%	62%
11	64%	61%	63%	77%	62%
12a	68%	74%	50%	77%	61%
12b	78%	80%	50%	74%	61%
13	78%	83%	88%	73%	64%
14	46%	48%	63%	67%	63%
15	58%	47%	25%	77%	62%
16	42%	42%	25%	76%	65%
17	39%	37%	38%	75%	63%
18	48%	47%	50%	75%	55%
19	68%	68%	75%	70%	57%
20	61%	61%	50%	67%	55%

- Cost - 22%
- Flexibility 13%
- Acceptability 16%

The following Figure 4.6.1-1 shows the results of using the weightings to merge the five evaluations. The one that was the best, number 13, is the very high end approach, with platoons, infrastructure management, dedicated lanes, and even segregation by classes. In other words, everything possible that might increase performance has been included, and this is rated the best even when cost is taken into account. On the other end is the infrastructure controlled solution, which is cumbersome, inflexible and expensive. Considerably better, but still low, is the modified slotting concept, 3a. In between, the more powerful solutions rated high, while more rudimentary solutions were low, even considering cost and flexibility. In general, those concepts with the most layers of control, especially when coupled with physical controls such as barriers, scored best.

However, no concept was excellent across the board. They all scored less than 70%, which means that they all have some drawbacks. This indicates that there are trade-offs in these selections, and a deeper analysis might change the relative ratings. On the other hand, the results were only somewhat sensitive to the weightings selected within the range of values that the PMC members generatedThe AHS goals of supporting flexibility and deployability suggests another way of looking at these results, and that is to look for a range of price-performance options. The above results might suggest that Concept 13 is the best solution everywhere, when it is clearly over-kill in areas that do not have major congestion problems. A rural area, for example, may have sparse traffic on long roads, which would suggest a simple system with minimal additional infrastructure, possibly even autonomous.

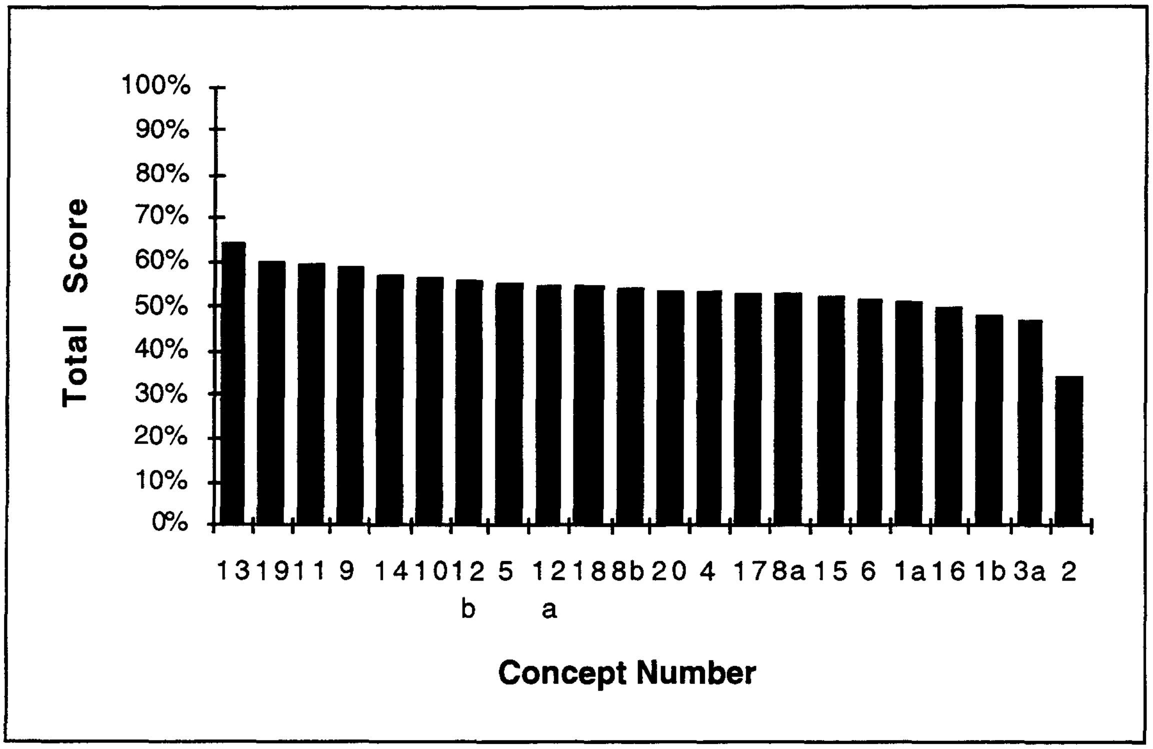

Figure 4.6.1-1. Overall Ratings of the Condidate Concepts

Figure 4.6.1-2 below plots performance against price. The cost score on the horizontal axis is directly based on the cost ratings discussed in Section 4.3. Recall that this is a relative rating, not an actual cost, and so is not necessarily linear. The vertical axis is a weighting to the four scores other than cost, and then normalizing the answer. Thus the points on the top edge of the group of pointsprice range by choosing those that are merit score, computed by applying the are rated better than those directly below them, which are of comparable cost. This allows the selection of the best choice within any at the upper edge of the envelope. Now the autonomous choice looks good as a low-cost option, since its merit score is not much less than others that cost considerably more. But slots and infrastructure control are clearly overpriced for their performance. Analysis of the specific points on this graph also showed that Infrastructure Managed is more cost-effective in general then Infrastructure Supported concepts, especially in high end designs.

The following Figures 4.6.1-3 through 4.6.1-8 indicate the impact of the various concept characteristics on cost and performance. These charts were based on previous weightings roughly estimated from the weightings for the objectives and characteristics, so the positions of the points do not match the previous figure exactly. Here the merit score is the horizontal axis and cost is vertical, so the best choices lie on the lower edge.

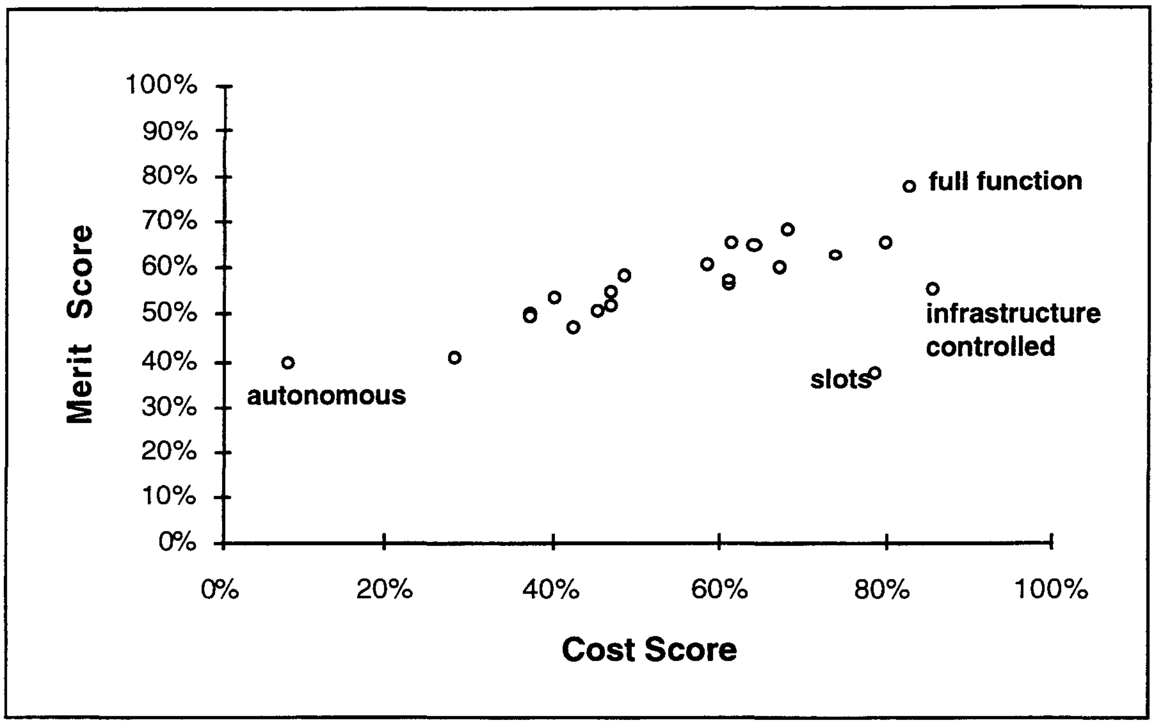

Figure 4.6.1-2. Comparison of Overall Performance vs. Cost for the Candidate Concepts

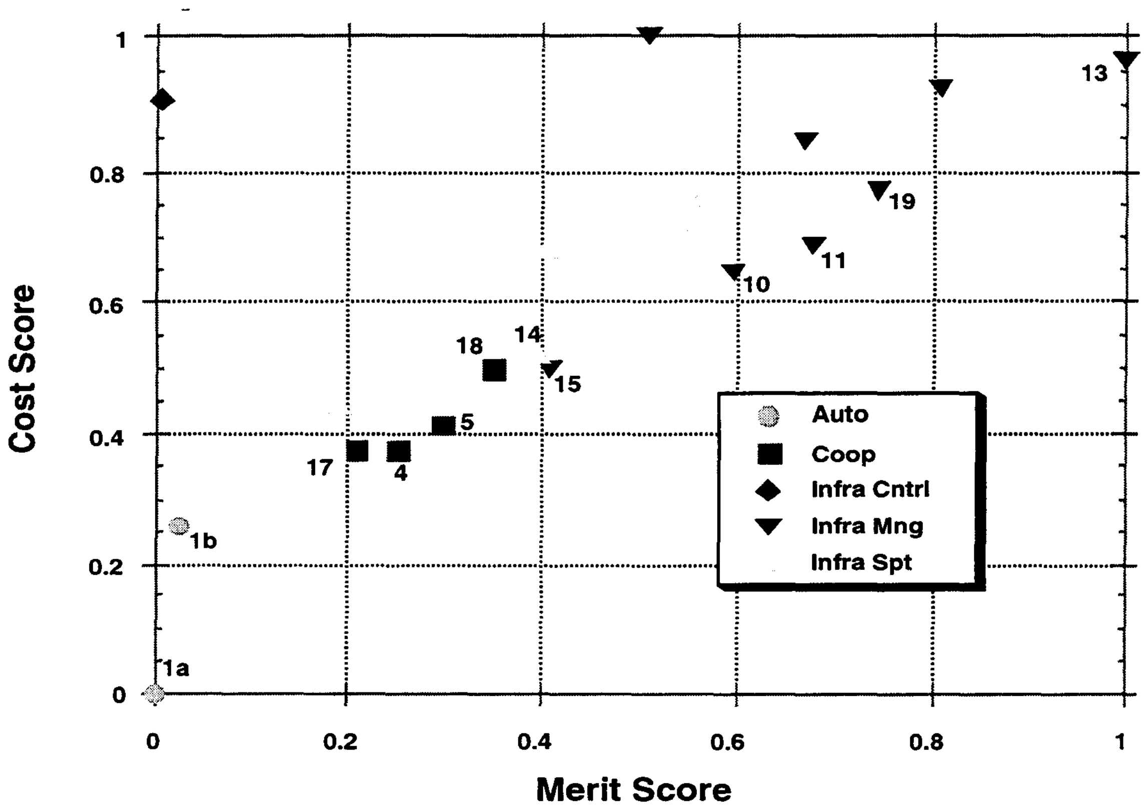

Figure 4.6.1-3. Cost and Performance Per Allocation of Intellgence

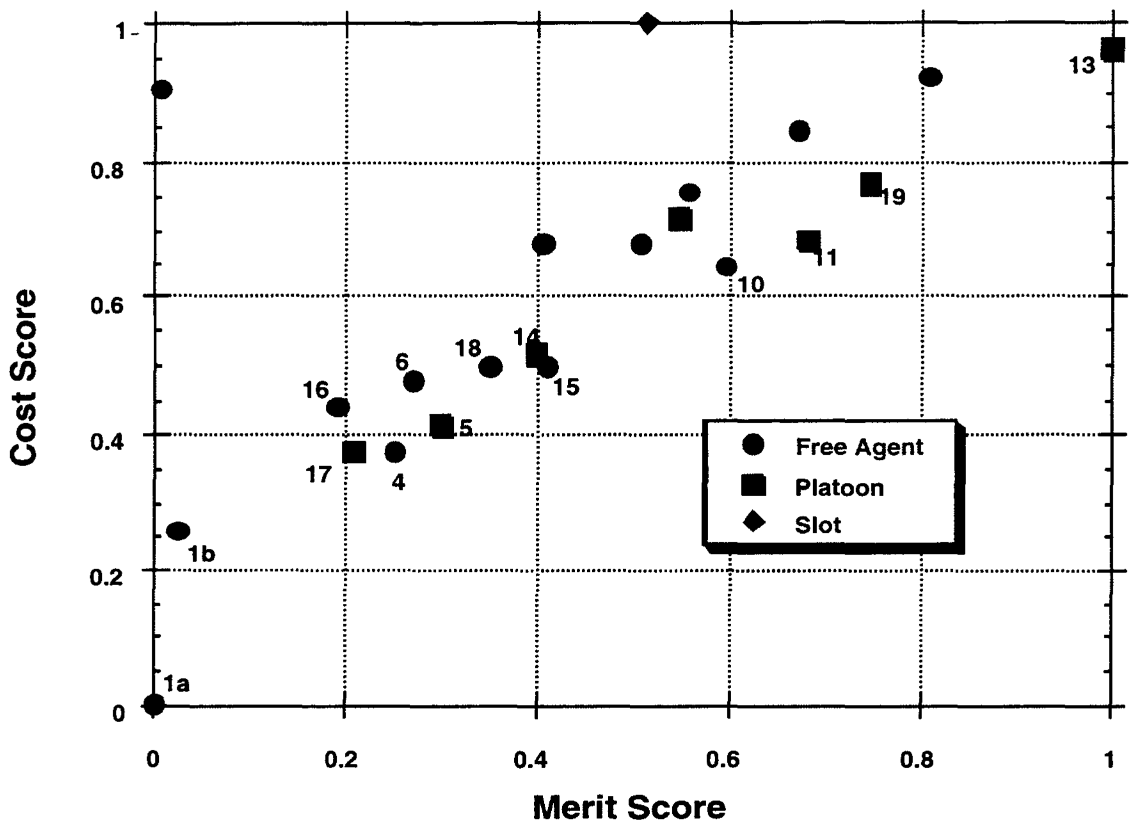

Figure 4.6.1-4. Cost and Performance Per Separation Policy

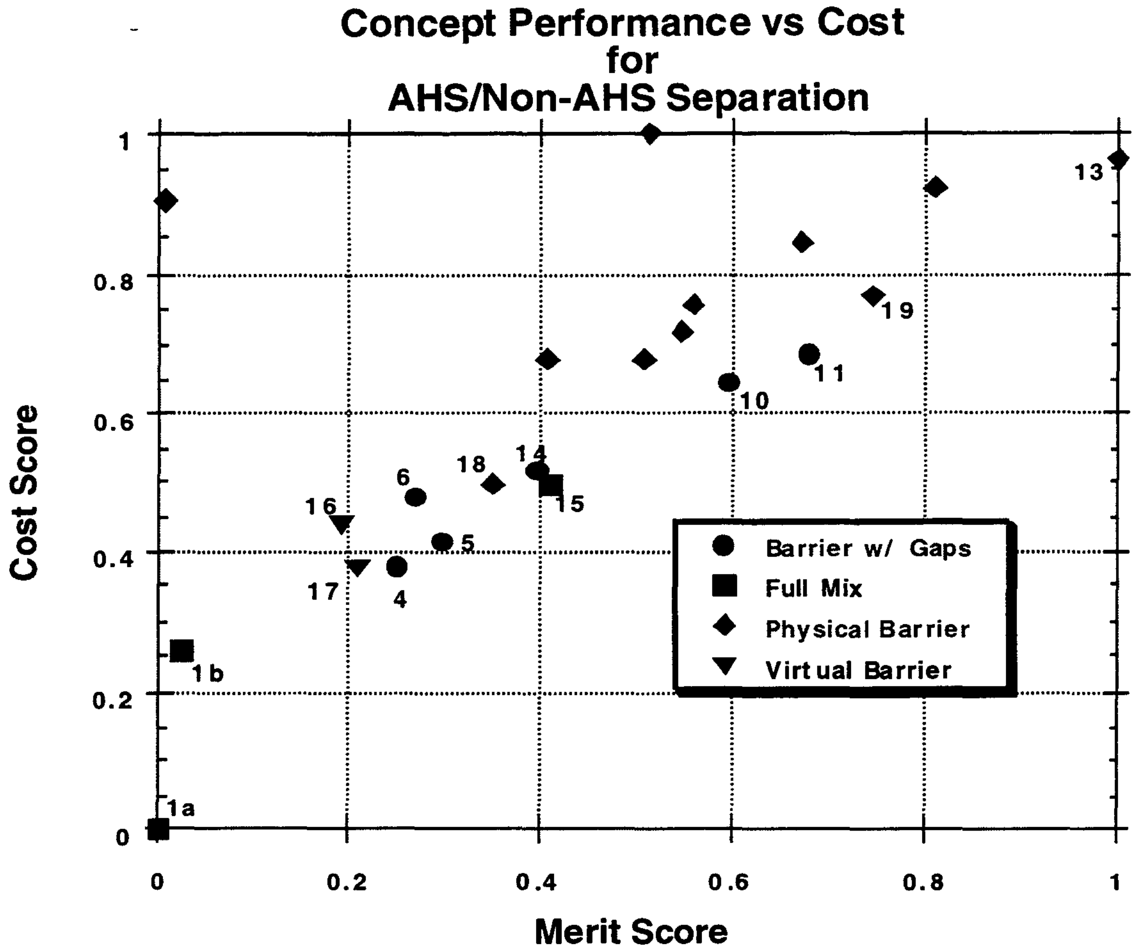

Figure 4.6.1-5. Cost and Performance per Mixed Traffic Approach

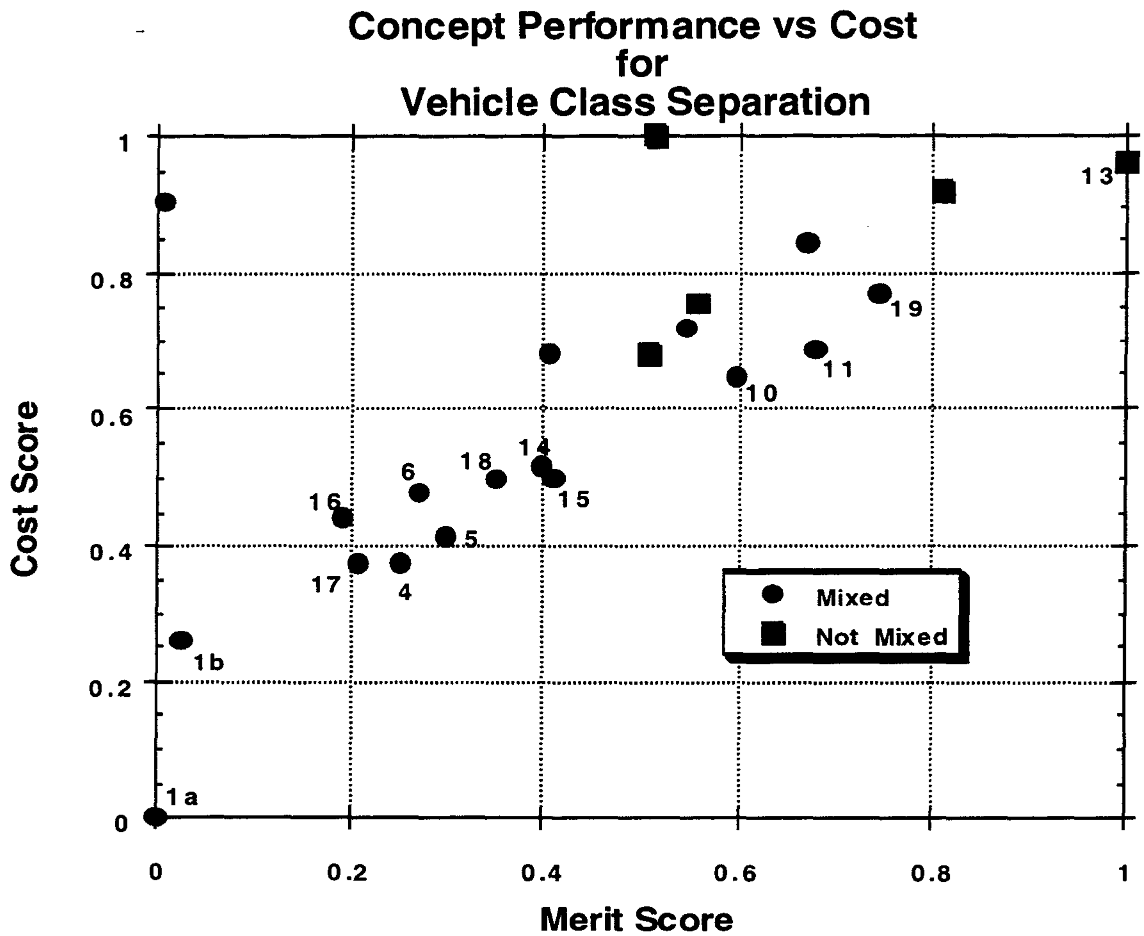

Figure 4.6.1-6. Cost and Performance Per Class Mixing Approach

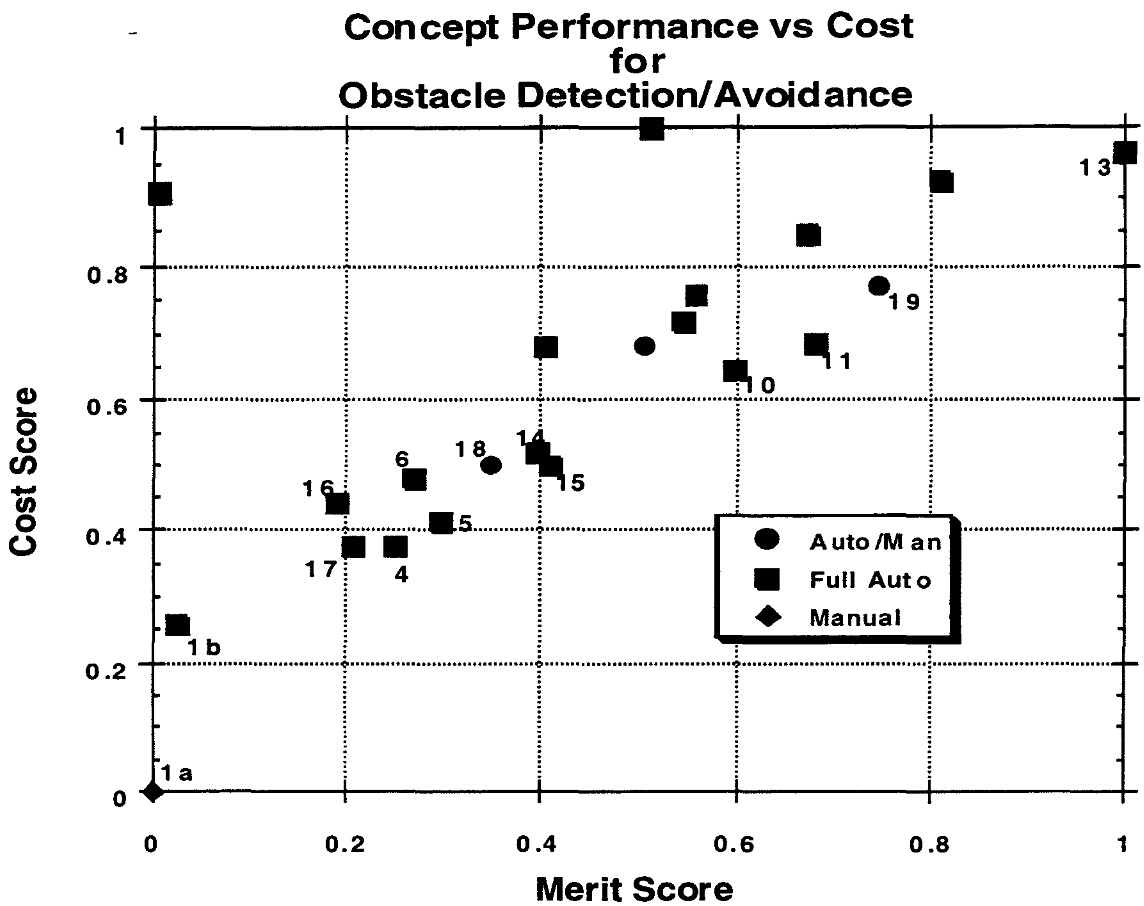

Figure 4.6.1-7. Cost and Performance Per Obstacle Detection and Avoidance Approach

This analysis needs to be caveated. Strong statements at this point about many of the dimensional choices must not be made, since the ratings are qualitative and non-linear. There is a temptation in this type of situation to compute cost-benefit ratios, but with this rating data the result would be meaningless.

The major conclusion of this analysis is that there is a range of reasonable price-performance options between the simple lane and headway keeping concept and the concept that pushes control and throughput to the maximum. This suggests building families of related concepts by choosing good options within each price range and developing a smooth deployment path through these options. An example is shown below. The growth path starts at the left witha low-cost low-performance option. As you move to the right, further capability isadded, allowing the system to grow progressively to whatever level is appropriate for the local needs and budget.

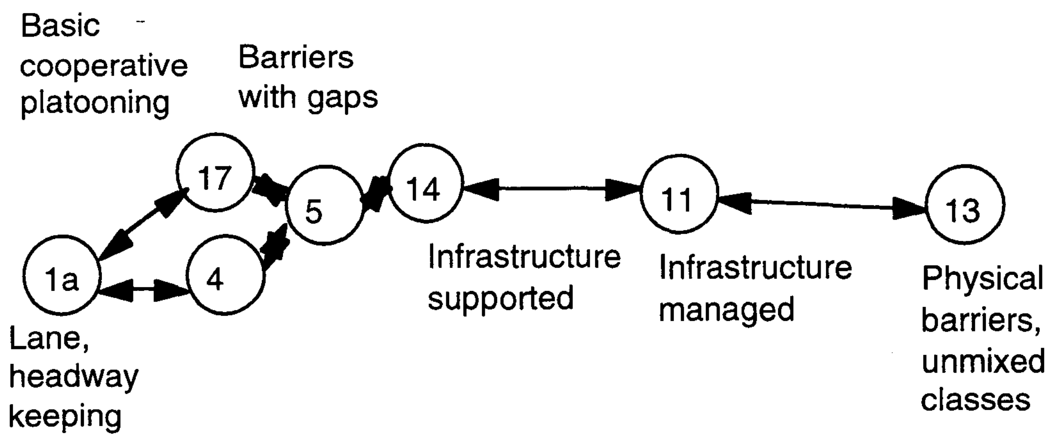

Figure 4.6.1-8. An Example Growth Path of Options with Good Performance for Price