17.5.5 Detection of Hazards

Detection of hazards is performed by both the vehicle and infrastructure. The vehicle and infrastructure fuse sensor data, with the objective of distinguishing between hazards (e.g., rogue vehicle or roadway obstacle) and non-hazards (e.g., shallow puddle of water or newspaper blowing across or along the roadway).

17.5.6 Maneuver Planning

Vehicles within a platoon communicate with each other in order to prepare for a maneuver. When two or more platoons are involved in a maneuver, inter-vehicle communication takes plan for coordination purposes. The infrastructure provides aggregate vehicle and roadway information, which the vehicles utilize in planning maneuvers.

17.5.7 Maneuver Execution

Maneuver execution is performed by vehicles, according to the maneuver plans developed by platoons.

17.5.8 Transition from Automatic to Manual Control

Same as for transition from manual to automatic control, only in reverse order.

17.5.9 Check-Out

Same as for check-in, only in reverse order. The infrastructure will provide aggregate information regarding the status of manual highway and arterials at the exit point.

17.5.10 Flow Control

The infrastructure will provide aggregate roadway and vehicle status information. The vehicles receive this information and make local decisions (i.e., decision specific to one or more roadway segments) regarding control actions which will affect local and global flow of traffic. That is, the information provided by the infrastructure is in the form of recommendations rather than commands.

17.5.11 Malfunction Management

The platoons and infrastructure coordinate with each other in managing malfunctions. The infrastructure provides position and other platoon status information to platoons in the vicinity of a faulty vehicle or roadway infrastructure. If the malfunction is within the infrastructure, the management coordination will have to rely on vehicle-to-vehicle communication, planning, and execution. If vehicle-to-vehicle communication fails, then each vehicle within a platoon will perform malfunction management as a free agent.

17.5.12 Handling Emergencies

The infrastructure will provide global commands for stopping or restarting movement on the AHS lanes. Vehicles will provide the infrastructure with their status.

17.6 IMPLEMENTATION

17.6.1 Vehicle

17.6.1.1. <u>Roadway Sensing</u>

Used for lateral and possibly longitudinal control (e.g., if vehicle communication fails, calculate spacing and relative speed from beacon data). Such technology includes all types of indirect road reference systems (by indirect we mean there is no physical link between the sensor and the marker: the signal processor is responsible for determining the distance between the sensor and the sensed marker, e.g., energy sources, reflectors, etc.).

17.6.1.2. <u>Sensing Other Vehicles</u>

Primarily for used in longitudinal control to maintain safe intra- and inter-platoon spacing, and in combined longitudinal and lateral control to coordinate maneuvers.

- Sensors to detect neighboring vehicles in the same lane. Sensors to find distance and relative velocity from preceding vehicle in the same lane is needed. Possible choices are Doppler Radar, Sonar, Two cameras mounted on the vehicle, etc. Sensing of the distance and relative velocity from the vehicle behind may also be needed/used in designing robust control laws and also during emergency situations.

- Sensors to detect neighboring vehicles in adjacent lanes, including the transition lane.

17.6.1.3. Vehicle-to-Vehicle Communication

- *Control*: Infrared communication (e.g., on-off keying with clock encoding). However, the size and spacing of vehicles, radius of roadway curvature, height and reflectance of barriers, and so on will affect the effectiveness, in terms of line-of-sight constraints, of infrared communication devices.
- *Maneuver*: Pulse (i.e., frequency hopping spread spectrum) or WaveLAN (i.e., direct sequence spread spectrum) radio systems, along with the use of a mobile Internet protocol. FCC allocation of the frequencies for AHS is an unresolved issue.
- *Advisory/Navigation*: Advisory and navigation information can be transmitted within and between platoons in a daisy-chain manner. Packet loss and delay of advisory and navigation information are non-critical. However, channel access is random in source, destination, and time, and communication distances are very long.

17.6.1.4. Vehicle-to-Infrastructure Communication

- Control: Broadcast communication medium. Cellular-based technologies are not a viable option since there will be more vehicles per 6 mi radius (effective range of cellular communication devices) than there are cellular channels to allocate. The infrastructure shall broadcast positional information and each vehicle must provide an acknowledgment. The infrastructure provides the central coordination function. The technical questions to be answered are how to provide for positional information and acknowledgments.
- *Maneuver*: Broadcast communication medium, for the same reason as described above. The same issues also apply here.
- *Advisory/Navigation*: Broadcast communication medium, for the same reason described above. The same issues also apply here.

17.6.1.5. Vehicle Identification Tag

One or more vehicle identification tags can be used for activities such as check-in, toll collection, and maneuver coordination.

17.6.2 Infrastructure

17.6.2.1. Low Level Modifications

- *Lateral Position Sensing*: Indirect road reference system (e.g., energy source, reflectors, etc.). Specific examples of this type of technology are acoustic resonance reflectors and magnets.
- *Barriers*: Barriers between the automated lanes and manual lanes; gaps in barriers for egress and ingress.
- *Transition Lanes*: Transition lanes.
- *Macroscopic Traffic Condition*: } Infrastructure-based sensors to collect traffic flow data (e.g., loop detectors).
- *Microscopic and Traffic Condition*: Infrastructure-based sensors to collect system performance data and determine the movements of individual vehicles.
- *Roadway Impediment Sensing:* Infrastructure-based sensors for detecting stationary or moving obstacles on the highway.

17.6.2.2. Intermediate-level modifications

- Short-range roadside transmitters shall provide information to vehicles. The communication will be in terms of radio broadcast. Approximately one every 1.6-3.2 km.

- Roadside controllers that get the flow data from roadside flow sensors as well as flow data from a few sections down the road to generate commands/information to be passed on to vehicles
- A communication network between different sectional controllers.
- A communication network between TMC and each sectional controller.

There last two communication networks do need high bandwidth as the frequency of updates received from TMC will be of the order of 10s of minutes whereas the frequency of update of information to vehicles will be of the order of 1-2 minutes.

17.6.2.3. High Level Infrastructure modification

Network level TMC controller and two way communication between each sectional controller and the network controller.

17.6.3 Rural Highway

One possibility is to neither provide platooning nor transportation management center (TMC) services for routing.

17.6.4 Urban Highway

As described in Section 17.3.

17.6.5 Deployment

The minimum deployable system consists of the following:

- one or more dedicated automated lanes some gaps in the inter-lane barriers
- at least one transition lane for use in entry exit, with the transition lane length proportional to the design speed and size of the length of the barrier gaps such that vehicles can safely enter and exit through the gaps
- check-in and check-out facilities at each entry and exit point, respectively
- full automation of vehicles
- partial automation of the infrastructure, including command, control, and communication capabilities

The degree to which command, control, and communication functions are shifted to the roadway infrastructure will have an impact on the cost to develop, manufacture, and deploy automate vehicles. Too little or over reliance on infrastructure support can result in high-priced automated vehicles; for example, at either extreme, the complexity of the in-vehicle automation systems can be high and thus, costly to design, manufacture, and maintain.

There are some disincentives to deploying an this concept AHS. The more prominent disincentives are as follows:

- cost and complexity of automated systems which allow vehicles to precisely execute maneuvers through gaps in barriers
- public perception of risks associated with shared transition lanes
- cost and complexity of transition-lane-based check-in and check-out technology and ability of the system to deter rogue vehicles from entering the automated highway

The incentives of such an architecture are as follows:

- depending on the infrastructure design, in some cases it may be possible to upgrade the roadway infrastructure, especially in terms of communication, but less so for the physical roadway (e.g., resizing entry and exit ramps)
- it is possible to use existing manual lanes as transition lanes

17.7 GENERAL ISSUES AND CONSIDERATIONS

17.7.1 Failure modes

As the intelligence is distributed between roadside and vehicle, the two types of control systems can back up each other. Different types of sensors and communication devices are used on the vehicle and the roadside to gather information of the world as well as for coordination. These systems can be used to back up other subsystems in case of a failure. Most of the vehicle failures—in sensors, communication devices, and so on—will have a localized effect. Infrastructure failures will only result in reduced throughput and will not be safety critical. As the driver will not be able to drive in a platooned environment, the control should not be passed to the human driver while the vehicle is on AHS.

17.7.2 Sensing Weather Conditions

Adverse weather conditions (e.g., limited visibility, snow, ice, etc.) will be sensed by the on-board vehicle sensors and then communicated to the infrastructure. They may also be sensed by roadside sensors placed at specific locations on the roadside for that purpose. The infrastructure communicates this information to the upstream traffic. The infrastructure may also advice the vehicles to slow down.

17.7.3 Vehicle Functionality

Typical users will travel at the speed limit (typically in the range of 65-70 mph. Although one can design a system to operate at a higher speed such as 80-85 MPH. Beyond certain speed, the gain in throughput will be offset by the large inter-platoon spacing required for safety and the cost of associated sensors). Due to infrastructure support functions, highway speeds are fully tailorable.

The vehicles equipped to drive in this AHS will be able to perform feet-off driving using Adaptive Cruise Control (ACC) capabilities on the conventional roads. They can also use most of the ATIS information for route selection.

17.7.4 Throughput and Safety

The *platooning* feature of this concept will most contribute to increasing traffic. In fact, platooning allows one to realize maximum achievable increase in capacity. Infrastructure support is also critical in optimizing the traffic flow.

Entry/exit via transition lane will create serious problems during heavy traffic. This option requires the traffic entering AHS to weave through manual lanes before reaching the transition lane thereby reducing manual highway throughput. On the other hand, traffic exiting AHS, has to enter the fast manual lane creating problem with respect to safety as well as capacity.

The safety of the overall system will be increased compared to current system because of automated obstacle detection and avoidance and due to distributed intelligence between infrastructure and vehicle.

17.7.5 Cost

As vehicles and infrastructure both have sensors, controllers and communication systems, regular maintenance of vehicles and infrastructure will be required.

18. CONCEPT 15: INFRASTRUCTURE MANAGED FULL MIXING

18.1 OVERVIEW

This concept represents a full mixture of AHS and non-AHS vehicles operating on the same infrastructure that will be managed mainly by the infrastructure on the existing roadway. This concept considers a mixture of both AHS and non-AHS vehicles classes on existing infrastructure and each AHS vehicle considered to be a free agent and individually will be controlled and managed.

The transition of AHS vehicles status from manual to automatic and back to manual at the entry and exit locations will take place in a transition lane (this is further discussed in the operation section).

Obstacles on the roadway are automatically detected by AHS vehicles and/or the infrastructure (based on their location) and are managed by the infrastructure to automatically execute the proper maneuver to avoid them.

In this concept obstacles are automatically sensed by the AHS vehicles and infrastructure can be upgraded to be used by both existing non-automated vehicles and AHS vehicles. By doing so, there will not be a need for dedicated AHS right-of-way until all the vehicles are AHS equipped. While in evolutionary path toward full automation, the potential capacity of the existing facilities equipped with the AHS can be maximized. Finally, the system will reach its maximum capacity when all the vehicles on the system are fully automated.

This concept offer an opportunity of transition from existing infrastructure management system currently in operation to future upgraded version to manage the AHS vehicles.

18.2 SELECTED ALTERNATIVE DIMENSIONAL DESCRIPTION

18.2.1 Distribution of Intelligence—Infrastructure Managed

The choice of infrastructure management system is desirable since the existing freeway systems are such and the addition of AHS system only could complement that.

The infrastructure managed system can be utilized to operate as mixed traffic (AHS and non-AHS vehicles operating simultaneously) or as a non-AHS system when needed (during off-peak hours in those locations that operation of AHS is not economically feasible).

18.2.2 Separation Policy—Free Agent

In this option each AHS vehicle is considered as a separate entity and a platoon will be composed of many entities following each other in a minimum allowable gap (function of vehicles speed and maximum or desirable deceleration rates).

This option seems to be superior over the platooning option since there could be other non-AHS vehicles included within the platoon that the system does not have any control over their movements. Also, even though the system does not control non-AHS vehicles, it can always sense each individual vehicle's location and speed and based on that make proper adjustment to manage the AHS vehicles.

18.2.3 Mixing of AHS and non-AHS Vehicles in Same Lane—Full Mixing

This option will allow the local operators to maximize the wage of their existing infrastructure with the lease amount of

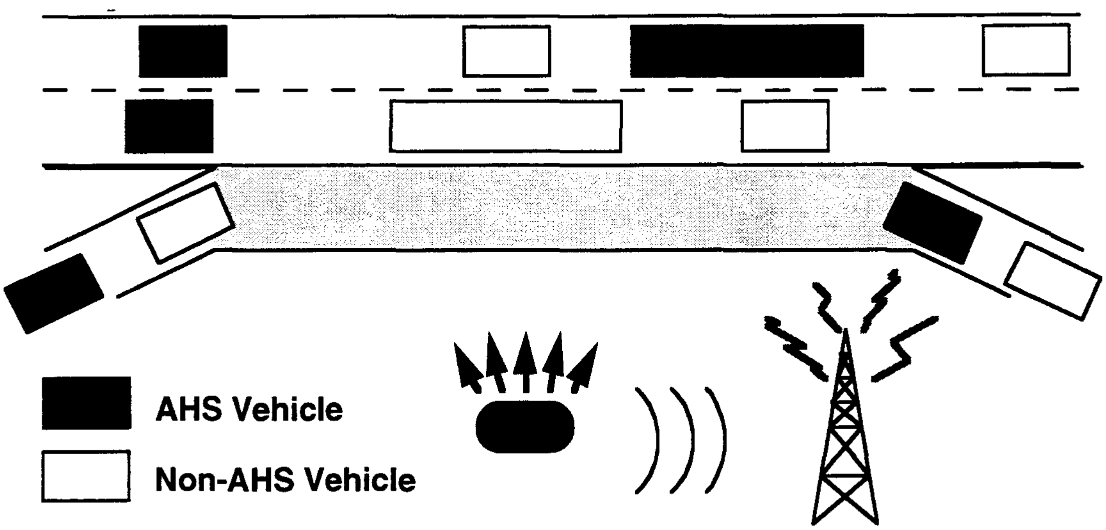

Figure H.18-1.

modifications needed. Also, in the event of system malfunctions or during off-peak hours where operating AHS is not economically feasible, this option will allow the local authorities to operate the system as non-AHS.

18.2.4 Mixing of Vehicle Classes in a Lane—Mixed

In this concept, different classes of AHS and non-AHS vehicles are operating together on the same roadway. Managing the operation of this mixture of vehicles will not be as easy as it would be with all AHS vehicles, since, in addition to variety of different vehicles' functions (such as acceleration and deceleration rates), lack of control over the non-AHS vehicles plays an important role in designing the system.

In this option, local authorities can provide some types of limitation on the use of left lane by non-AHS vehicles (such as only be used for passing maneuver when it is feasible).

18.2.5 Entry/Exit—Transition

In this option, the existing entry and exit will be shared by the AHS vehicles. This will take place on a transitional basis where AHS and non-AHS vehicles enter and exit the system from the same locations. The possible locations for drivers to request the change of status from manual to automated operation or vice versa (transitional area) are:

1) Along the roadway section
2) Along the entrance and exit ramps
3) Along the acceleration and deceleration lanes provided for entrance and exit ramps.

18.2.6 Obstacle Sensing and Avoidance—Automatic Sensing & Automatic Avoidance Maneuver

In this option, obstacle are detected by either infrastructure or AHS vehicles' sensors (where it will be reported to the infrastructure). AHS vehicles are given the proper direction to follow to avoid the obstacle and the information is routed to the Traffic Operation Center (TOC) where through the use of Intelligent Transport System (ITS) features non-AHS vehicles can also be informed of the location of the obstacle. At this time, TOC will further analyze and make the proper decision on the needed actions to be taken to remove the obstacle.

18.3 OPERATIONAL CONCEPT

The operation of this concept is more complex than other concepts since two separate entities (AHS and non-AHS vehicles) must be managed together.

The operation of this concept can be conducted in three levels of command, control, and communication.

At vehicle level, individual AHS vehicles can sense where they are relative to other surrounding vehicles. This level relies on computer software and hardware technologies.

Local infrastructure is where the bulk of traffic operation and management will take place. Its majority of functions will concern sending, receiving and interpreting signals. This level of operation acts as a funnel through which commands travel from the TOC to individual vehicles and through which status and feedback are sent back to TOC from each vehicle. Also, at this level, data from the local infrastructure, infrastructure to vehicle, and infrastructure to infrastructure communication technologies.

The TOC must know in aggregate the traffic status in real time. It receives aggregate data from local controllers, analyze the data and then provide appropriate command. The type of technology needed at this level will be mainly information/computing and communication technologies. Also, a high order of intelligence will be required at this level as the system needs to make complex decisions concerning traffic operations and incident management.

18.4 SYSTEM DIAGRAM

The system diagram showing data flows and sensing between vehicles and infrastructure is shown below:

18.5 FUNCTIONAL ALLOCATION

18.5.1 Check-In

The request to change the status to automated will be transmitted from the vehicle to the infrastructure. Next the infrastructure will check the AHS capabilities after approving the status, local controller will admit the vehicle as an AHS and will change its status. Next, the vehicle's parameters needed to be controlled (i.e., maximum deceleration and acceleration rate) are tagged along to the vehicle in order to be able to automatically control its movements.

18.5.2 Transition from Manual to Automatic Control

Transition will be controlled by the infrastructure are few possibilities as of where the transition could take place. Three of which are listed below:

1) If the metering of entrance to the roadway is of interest, then, the status of vehicle will be checked prior to entering to the roadway. Next, based on the availability of gaps and unused capacity of roadway (and other factors such as level of air and noise pollution and environmental conditions) vehicles will be queued and in turn enter the roadway.
2) If the metering is not a concern, the AHS vehicle can operate manually and enter the roadway. Next while traveling, the request to change the status could be checked by the infrastructure (such as local controllers) and if feasible the status will be changes.
3) The acceleration lane can be used as a transitional lane to grant the automated status to approved AHS vehicles.

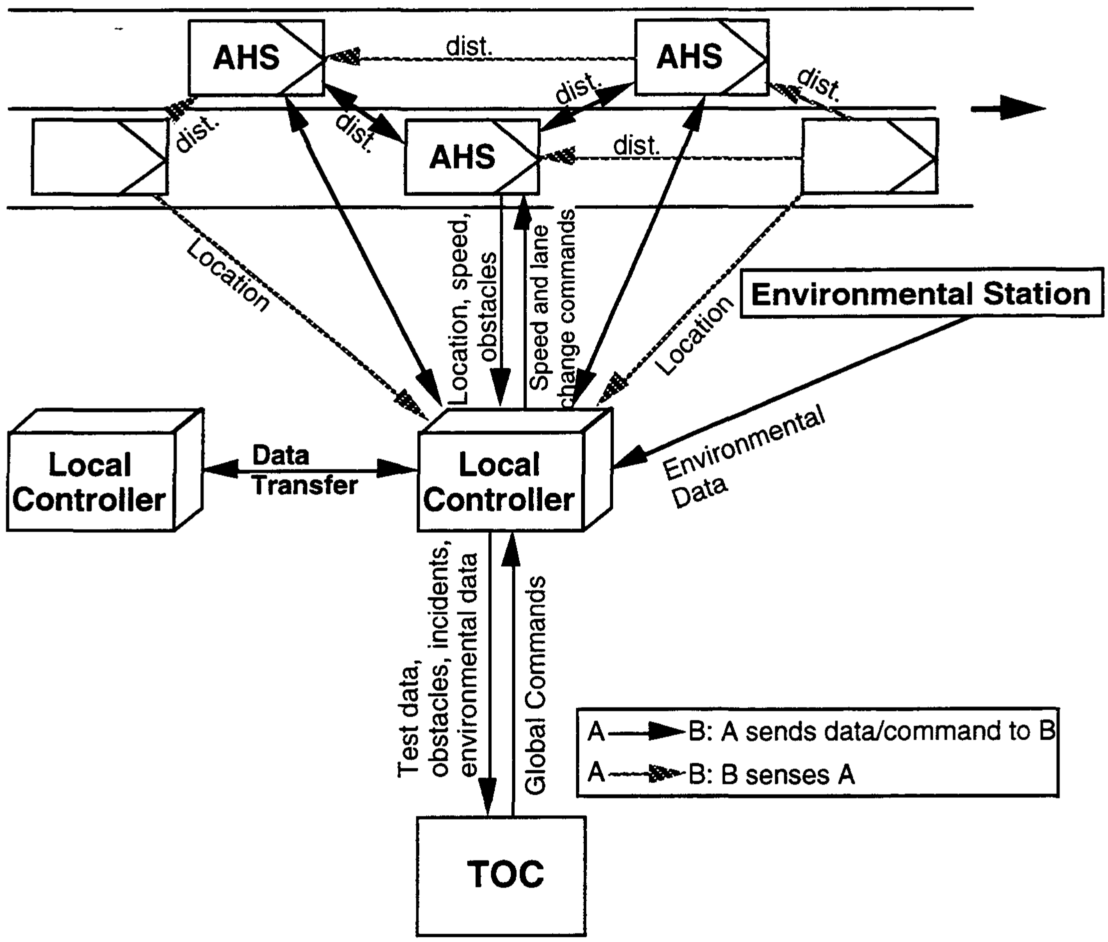

Figure H.18-2.

18.5.3 Automated Driving

18.5.3.1. Sensing of Roadway, Vehicles, and Obstructions

Sensing of roadway, vehicles, and obstructions while driving will be conducted by the AHS vehicles. Infrastructure will be capable of sensing the obstructions and providing the automated vehicles and the TOC with the needed information. Infrastructure can also sense the location of all types and classes of vehicles on the roadway in order to make proper decisions.

18.5.3.2. Lane and Headway Keeping

Lane and Headway keeping are conducted by the AHS vehicles equipped with longitudinal and lateral sensors. The TOC will determine the allowable speed and spacing between vehicles and the command funnel through the local controller and transmitted to AHS vehicles. Infrastructure will only govern the allowable speed and spacing between vehicles.

18.5.3.3. Detection of Hazards

Hazards are located by vehicles and the infrastructure. If an AHS becomes disable, automatically, its location and status will be reported to the local controller and the TOC and the proper respond maneuvers to be executed will be send to the AHS and non-AHS vehicles will be informed via other means (such as in-vehicle computer). If the disable vehicle is a non-AHS vehicle, the infrastructure and/or AHS vehicles will be able to detect and report the condition to each other and TOC. Other hazards can be detected by both AHS vehicles and the infrastructure.

18.5.3.4. Maneuver Planning

The local controller will be the one allowing the vehicle to make the needed maneuver any time during the automated driving. If the AHS vehicle detects a hazard, it can only notify the local controller and take the proper action to stop, the lane changing maneuver will only take place when the local controller decides there is sufficient gap to do so.

18.5.3.5. Maneuver Execution

After the needed maneuver is scheduled by the infrastructure, the execution of it will be conducted by the AHS vehicle following the proper command from the local controller.

18.5.4 Transition from Automatic to Manual Control

As the AHS vehicle reaches the destination, the infrastructure will check to make sure the driver is ready to accept the manual control of the vehicle. In the event of possible response, at the proper transition place the control of vehicle will be granted to the driver and the status of the AHS vehicle will be changed to manual. The infrastructure will update the database and send the needed data to the TOC. There are few possibilities as of where the transition could take place. Three of which are listed below:

1) On the off-ramp where if the driver did not verify its readiness it could be routed to the storage area.
2) Any location along the roadway where driver can request and be granted.
3) Along the deceleration ramp to the exit entrance.

18.5.5 Check-out

As the AHS vehicle goes through the change of status and returns to its manual mode, the infrastructure will update its database and the vehicle no longer will be controlled by the system.

18.5.6 Control of Traffic Flow

This will be conducted by the local controllers where they follow the global decisions set by the TOC (refer to the section 18.5.7). Traffic data such as; number of vehicles within the system, portion of the automated vehicles, unused capacity of the system, level of air and noise pollution, weather conditions, occurrence of incidents, will be collected and transmitted to the TOC where proper global parameters will be determined and communicated back to local controller for execution.

18.5.7 Global Decisions

The ability of TOC to adjust global parameters dynamically will allow the effect of specific changes in the system to be evaluated and the optimized performance of the system to be achieved. Global parameters include items such as headway, system speeds, access metering rates and overall volume on the system. Small changes in one or combinations can be evaluated and used in the further refinement of the overall system and development of guidelines for future expansion of the system.

TOC can set control parameters by regulating the traffic ingress to optimize system service levels. It can also process environmental data to determine how many users can be on the system to keep the level of pollution under control and respectively, change the metering rates.

18.5.8 Status Monitoring

The AHS should be monitored for system performance. Monitoring allows the TOC the ability to lay a proactive role in the success of the system. The quicker the system can recognize and respond to problems, the better the system user can be served. The TOC and local controllers will provide continuous evaluation of all devices in the system, reports of the status, and related information about maintenance and construction.

18.5.9 Vehicle Malfunction Management

Vehicle malfunction management will be conducted by both the AHS vehicles and the infrastructure. If a vehicle is malfunctioning, it will report its status to the local controller and request exit or assistance. If the vehicle is not capable of exiting the system or its malfunction will effect the performance of other vehicles, the infrastructure will inform other vehicles of the existence of an obstacle ahead and provide them with proper action to take.

18.5.10 Incident Management (Handling of Emergency)

The automatic deployment of the incident management will become of vital importance in the area of handling public safety and liability concern. Incident management includes incident detection verification and response procedures.

Early remote detection and verification of an incident can be conducted by AHS vehicles and the infrastructure. The automated incident response management will be conducted by the TOC. These responses can include speed regulation, alternate route assignments, and advisory signs in addition to informing proper authorities to take the needed actions to remove the incident as early as possible.

18.6 GENERAL ISSUES AND CONSIDERATIONS

Although one of the major advantages of this concept is that it flows with the existing traffic patterns and does not cause major disruption to the existing infrastructure and current traffic demand, still, it needs to deal with the non-AHS vehicles. As a result, issues such as safety, societal and institutional impacts, and traffic non-AHS vehicles should be of concern.

The existing traffic operation is impacted by mixture of different classes of vehicles on the same infrastructure (i.e., impact of heavy vehicles on passenger vehicles operation). Introduction of a new generation of AHS vehicles along with its own classes will magnify this problem and needs to be further analyzed.

Management of non-AHS vehicles may be required for a safe and efficient system. Therefore, the management task of this concept could be horrendous.

Currently, multi-jurisdictional interactions are among important issues that need to be resolved. Coordinating of TOCs and multi-jurisdictional interaction of the AHS will only magnify the problem and the proper solution needs to be identified.

Since non-AHS vehicles operate on the same infrastructure as AHS vehicles, the control of traffic operation will be some how limited and types of malfunctions and incidents unpredictable.

Since one of the advantages of this concept is the economical feasibility of it, this concept should be given appropriate consideration and its viability issues should be further investigated.

Since the operating speed of AHS vehicles may require to follow the general flow of traffic (namely, non-AHS vehicles' speed), this may be considered as a deficiency of the system.

Even though, during the inclement weather conditions, infrastructure can properly manage the AHS vehicles in the system by using the input from weather monitoring stations, the lack of capabilities of non-AHS vehicles will reduce the efficiency of the system.

Each possibility of the location for transition of the status of AHS vehicles from automated to manual and manual to automated will carry along its own issues which needs to be further studied.

The possibility of this concept to follow an evolutionary path needs to be further analyzed and the fact that it could be the most feasible and economical solution to the AHS needs to be further investigated.

19. CONCEPT 16: FREE AGENT ON MIXED-CLASS DEDICATED LANES WITH VIRTUAL BARRIERS

19.1 OVERVIEW

This concept features the operation of mixed-class Automatically Controlled Vehicles (ACVs) as free agents (i.e. ACVs following each other at safe distances) and using one or more dedicated AHS lane that are separated from the manually driven lane or lanes by a virtual barrier (i.e. pavement markings, magnetic tapes along-side of the AHS lane, etc.). The highway infrastructure will be equipped to support the operation of the ACVs through the provision of non-vehicle specific information such as speed, merge demerge instructions, lane availability, etc.

This concept offers a deployable AHS system that satisfies the general objectives of the National AHS Program and that is :

- Compatible with the existing national freeway system
- Amenable to being deployed in transitional stages with minor disruption to existing freeway operation.
- Upgradeable to higher levels of technological sophistication.
- Relatively low cost of public expenditure for ultimate deployment.
- Deployable in urban as well as rural environment.

The primary advantage of this concept is the combination of low cost and ease of deployment.

19.2 SELECTED ALTERNATIVE FROM EACH DIMENSION

19.2.1 Free Agent in a Mixed Vehicle-Class Environment

The combination of free agent operation with mixing various classes of vehicles in one dedicated AHS lane would limit the practical throughput of the AHS lane and thus, its efficient operation. Available options would include:

- dedicating more than one lane to AHS operation. Such an option would only be practical in urban applications. It would allow slower moving vehicles to operate on one lane with faster moving vehicles on the other.
- restricting the operation of slow vehicles to off-peak hours only.
- using the transition lane as a passing lane in case of a one dedicated-AHS-lane operation.

19.2.2 Distribution of Intelligence: Infrastructure Supported

This dimension assumes that acceleration, deceleration and possibly maneuver data concerning adjacent vehicles in a local area is available to the single vehicle coordination unit. The infrastructure supported dimension provides infrastructure monitoring of global events such as traffic flow and incidents. The infrastructure communicates pertinent information to vehicles within its local zone. Data is expected to include general parameters such as assigned travel speed, headway, or roadway geometry.

Vehicle control loop commands are generated by the vehicle. The vehicle control loop can use local zone information generated by the infrastructure to improve maneuver planning. Individual vehicles are not responsible for roadway condition or environment sensing, allowing vehicle sensors to focus on obstacle detection and headway measurement. The reduced responsibility in terms of vehicle sensors is balanced by an increase in infrastructure instrumentation to support sensing and communications between the vehicle and the infrastructure.

19.2.3 Separation Policy: Free Agent

The separation policy specifies that individual vehicles operate as the coordination unit for AHS maneuvers such as merge and separation to and from the automated lane. The vehicle separation is determined by an infrastructure controller at the zone or regional level and communicated to the vehicles at check-in or enroute. The vehicles maintain their own headway through sensing of adjacent vehicles and generation of acceleration, deceleration, and turning control loop commands. Vehicles may cooperate by sharing speed and acceleration/deceleration data with adjacent vehicles, allowing coordination of non-emergency maneuvers within a local zone.

19.2.4 Transition Lane and Location of the Virtual Barrier

The transition lane will be used by Automatically Equipped Vehicles (AEVs) driven under manual control as well as by Automatically Controlled Vehicles (ACVs) ready to transition to the dedicated AHS lane or lanes. To prevent manually controlled vehicles from encroaching on the transition lane, the virtual barrier may be placed between the transition lane and the manually driven lane or lanes. This location would also be recommended in case the transition lane is used as a by-pass AHS-controlled lane as discussed above.

The transition lane could be continuous alongside the entire length of the AHS-dedicated lane or lanes, or it could be discontinuous allowing its use by manually driven vehicles on non-transition segments. The first option may be applicable to urban applications where interspacing between interchanges are relatively short, while the second option may be appropriate for rural applications where interspacing between interchanges are relatively long.

19.2.5 Obstacle: Automated Sensing and Avoidance Maneuver

Obstacle detection is performed by the vehicle. Vehicle detection of obstacles can be shared cooperatively with adjacent vehicles. Acceleration, deceleration, and maneuver commands are generated by single vehicle units based on internal information and data obtained cooperatively.

19.2.6 Infrastructure Messages

This concept calls for the infrastructure to provide AEVs and ACVs with informational, advisory, cautionary, and other types of messages. Depending on the placement and medium of transmitting these messages, it may be advisable to combine these messages with other messages intended for the manually driven lanes and manually driven vehicles as well.

19.2.7 Check-in Procedure

A vehicle-based intelligence, an infrastructure-based intelligence, or a combination of both would be required to clear AEVs to operate on the AHS facility.

19.3 OPERATIONAL CONCEPT

19.3.1 Check-In

As AEVs approach an AHS facility, they would be checked-in for operability on the AHS System. Check-in options would be vehicle-based, see 3.6 for discussion. The check-in function should be accomplished prior to entering the freeway facility in order to give the driver the opportunity to react to the results without impinging on the normal operation of the freeway. AEVs that pass the check-in testing would use common on-ramps to access the freeway equipped with an AHS operation.

19.3.2 Transition to Automated Control

As the AEV merges into the freeway, it would operate in a completely manual mode maneuvering its way to the transition lane of the AHS system. Once on the transition lane, the AEV would communicate its position to ACVs on the dedicated AHS lane or lanes. While still on the transition lane, the AEV would transition from manual operation to automatic operation. At the proper time, it would merge into the AHS facility and operate as a free agent with other ACV's of various classes of vehicles.

19.3.3 Automated Driving

The ACV's operation on the AHS lane should proceed in a normal fashion communicating with other vehicles for longitudinal and lateral positioning. Some of the alternatives discussed above, if implemented, would use the transition lane as a by-pass lane (to pass a slow-moving vehicle or to avoid an obstacle on the AHS lane). In this case, an infrastructure message may be required to signal the acceptability of such use.

19.3.4 Check-Out and Transition to Manual Operation

The exiting process is initiated by the trip planning function through which the vehicle and the driver are notified that they are approaching the desired exit or the terminus of the AHS system. In this concept, such notification would be vehicle-based and supported by infrastructure messages. Check-out would be processed through vehicle-based instruments that would insure that both the vehicle and the driver are capable of operating in a manual mode. The vehicle would then communicate its intention of exiting the system to adjacent vehicles and proceed to move to the transition lane, still under automatic control. The driver would then assume manual control of the vehicle and maneuver into the manually-driven lanes and to the desired exit ramp.

19.3.5 Communications to Support Maneuver Coordination

Maneuvers such as lane change, entry, and exit will be automated in this concept. The infrastructure supported definition of intelligence distribution assumes cooperative sharing of acceleration, deceleration, turning, and position data between adjacent vehicles. Wireless technologies can be used to implement communications among a group of vehicles. The steady-state message channel is expected to consist of small packets of information. The channel activity is expected to be on the order of one packet per second, and delivery of non-emergency maneuver information is not time-critical. Connectivity among a group of vehicles will require pairs of vehicles to exchange information without requiring them to be directly adjacent to one another. Infrared links require direct line of sight for reliable data transfer. A broadcast RF method of communications may be best suited to the maneuver coordination function, using global addressing to uniquely identify the sources of data.

19.3.6 Communications to Support Check-In and Check-Out Advisories and Traffic Flow Information

The majority of the intelligence in this concept is located within the vehicle. The vehicle could monitor on-board diagnostics prior to entry to the AHS. The vehicle will initiate entry to the AHS if the check-in procedure is successful with no verification from the infrastructure. A similar procedure could be performed prior to exit. The vehicle would initiate a series of self-tests and transfer control to the driver without verification from the infrastructure. Communications between the vehicle and the infrastructure is not supported.

Traffic advisories, route planning, and road conditions are provided by the infrastructure. The infrastructure monitors sensors and generates advisory messages. The messages can be addressed to vehicles in a local zone but are not expected to be addressed to individual vehicles. The method of communications is expected to be broadcast RF. The infrastructure transmitters can be linked along the infrastructure to a central traffic management center using leased lines, fiber optic, or microwave links. These are implementation options and can be tailored to the specific location.

19.4 FUNCTIONAL ALLOCATION

19.4.1 Position Control

The position control function is performed in the vehicle. Free agent spacing will require sensing of adjacent vehicles to maintain headway and land parameters to maintain lateral position. The individual vehicle is also responsible for obstacle detection and avoidance. The position control function receives absolute position and speed data from on-board vehicle sensors. This function receives commands to change position and speed from the maneuver coordination function. The position control function generates throttle, brake, and steering signals and implements longitudinal and lateral changes to maintain headway and lane keeping, and in response to maneuver commands as required.

19.4.2 Maneuver Coordination

The maneuver coordination function is performed in the vehicle. The maneuver coordination function receives zone and regional roadway information from the flow control function, hazard warnings concerning local obstacles from the hazard management function, and malfunction warnings concerning vehicles or operator detected failures from the malfunction management function.

The maneuver coordination function receives acceleration, deceleration, and turning information from adjacent vehicles allowing maneuvers to be planned in terms of local vehicle motion. This function generates commands to change speed or lane position based on information received from the infrastructure regarding current travel conditions and from adjacent vehicles regarding their position and speed.

The maneuver coordination function receives a message from the check-in function when a vehicle is prepared to access the automated lane and control has been transferred from manual to automated. The maneuver coordination function responds by generating speed and lane change commands which allow the vehicle to move into the automated lane.

The maneuver coordination function receives a message from the check-out function when a vehicle is prepared to exit the automated lane. In the case of exit, control is transferred from automated to manual after the vehicle has moved into the transition lane. The maneuver coordination function generates speed and lane change commands which allow the vehicle to move out of the automated lane. Control is transferred to the operator while the vehicle is traveling in the transition lane.

The maneuver coordination function responds to hazard and malfunction warnings by generating commands to change speed or lane position which allow vehicles to mitigate malfunctions or avoid hazards in a safe manner. This function transmits the control signals addressed to the vehicle in the affected slot. The maneuver coordination function provides notification to the operator interface of merge, demerge, or emergency ,maneuvers. Notification to the operator interface will be coordinated with the maneuver to prepare the driver for unexpected changes in vehicle speed or position.

19.4.3 Hazard Management

The hazard management function is performed in the vehicle. The hazard management function detects obstacles and adjacent vehicles using on-board vehicle sensors. The hazard management function generates a hazard warning message when an obstacle or vehicle enters a specified control zone, and it is passed to the maneuver coordination function for appropriate action.

19.4.4 Malfunction Management

The malfunction management function is performed in the vehicle. This function receives vehicle system status information from on-board vehicle diagnostics, and operator input regarding system conditions or hazards. The malfunction management function generates a malfunction warning message which is passed to the maneuver coordination function for appropriate action based on processing of vehicle and operator data. This function provides vehicle or system failure information to the traffic operations center and provides status messages to the operator.

19.4.5 Flow Control

The flow control function is performed in the infrastructure. The flow control function monitors infrastructure sensors at the zone level and provides information regarding roadway conditions and local incidents to the maneuver coordination function. This function monitors traffic flow at the regional level and provides operating information to the maneuver coordination function such as congestion at entry/exit points, travel speed, and lane or route closures.

19.4.6 Operator Interface

The operator interface function is performed in the vehicle. The operator interface receives inputs from the operator concerning entry and exit requests and generates requests to enter and exit the automated lanes for the check-in and check-out functions. This function processes inputs from the operator concerning system operating conditions, including hazards or malfunctions and generates messages to the malfunction management function indicating a detected hazard or malfunction.

The operator interface provides sensory notification to the driver to indicate impending maneuvers based on messages received from the maneuver coordination function. This function also provides status to the operator concerning ongoing vehicle and system operating conditions. The operator interface will generate messages which provide status and instructions regarding entry or exit procedures.

19.4.7 Check-In

The check-in function is performed in the vehicle. This function receives operator requests to enter the automated system and initiates the check-in process. The check-in function processes vehicle condition information received from the malfunction management function concerning the integrity of the automated control subsystems. This function verifies the ability to perform the transition from manual to automated control safely and generates a message to the maneuver coordination function to initiate entry to the automated lane. The transfer of control from manual to automated takes place in the transition lane prior to entry to the automated lane.

Vehicles which fail the check-in process will be denied access to the automated lane. A message will be generated to the operator interface function which indicates the status of the check-in results and notifies the driver that the vehicle will remain in manual control and will not maneuver to the automated lane.

19.4.8 Check-Out

The check-out function is performed in the vehicle. This function receives operator requests to exit the automated system and initiates the check-out process. This function verifies the ability to perform the transition from automated to manual control safely and generates a message to the maneuver coordination function to initiate exit from the automated lane.

The check-out function will generate a message to the operator interface function which will allow the transition of control to occur. The operator interface will pass a message back to the check-out function when the operator has performed the required tasks successfully. The operator will be prompted to resume manual control prior to transfer from automated to manual control.

Vehicles which fail the check-out process will remain in automated control and will be moved to a safe location. A message will be generated to the operator interface function which indicates the status of the check-out results and initiates the process for exiting under automated control.

19.5 IMPLEMENTATION

19.5.1 Infrastructure

19.5.1.1. <u>Rural Highway</u>

This concept would require at least one dedicated AHS lane plus one transition lane that should be dedicated to AHS operations intermittently; e.g. at entrance ramps, at exit ramps, and for automatically-controlled passing maneuvers. The manual operation of the highway would require at least one dedicated manual lane plus the use of the transition lane (at segments not dedicated to AHS operation) for passing slow-moving vehicles. Since most of our rural highways have only two lanes in each direction, the deployment of this AHS concept would necessitate the addition of one lane in each direction.

19.5.1.2. Urban Region

This concept can be deployed in an urban environment without significant modifications or lane additions to many existing urban freeways. Since inter-spacing between interchanges on urban freeways are relatively short, it appears that the transition lane will have to be dedicated to AHS operation. Therefore, a minimum of two lanes would be required for AHS operation. Since a minimum of two lanes would also be necessary for manual operation, the minimum number of lanes required for the deployment of this concept in an urban environment would be four.

Careful analysis will have to be performed of the throughput of AHS-equipped freeways considering the above lane allocation and the constant maneuvering in and out of manually-driven lane to access or egress the AHS system. AHS operation may have to be suspended at freeway to freeway interchanges subject to confirmation by site-specific analysis.

19.5.3 Deployment

The deployment of any AHS system will have to be staged in several transitional phases until there are sufficient number of automatically-equipped vehicles to justify full deployment of the system. This concept is particularly adaptable to such transitional deployment.

19.6 GENERAL ISSUES AND CONSIDERATIONS

Concept Limitations

- Unless more than one dedicated AHS lane is provided, mixed operation on one lane would restrict ACV's to the slowest moving vehicle. One solution would be to restrict use of the AHS system to certain classes of vehicles, permanently or during certain operating periods.
- The absence of physical barriers between AHS lanes (dedicated and transition) and manually-operated lanes would invite manually-driven vehicles to encroach on the AHS lanes particularly during congested periods on the manually-driven lanes. Even during periods of normal operation, the absence of physical barriers between the two systems would cause inconvenience and anxiety to manual drivers.
- Since the entry/exit maneuvering in and out of the AHS system would consume (in some urban locations) one to two miles of driving in a manual/transition mode, automated driving may only make sense for a minimum trip length. This may preclude the use of the system by certain segment of the traveling public.
- It may be necessary to restrict access to and egress from the AHS lane(s) to certain locations along the length of the transition lane. This may preclude the use of certain on and off ramps by AEVs.

20. CONCEPT 17: COOPERATIVE PLATOONING WITH VIRTUAL LANES

20.1 OVERVIEW

This is one of two cooperative concepts with platooning, and the only platooning concept in which the dedicated AHS lanes are not protected by physical barriers. It is therefore a test case both for cooperative platooning, and for platooning without physical isolation of the AHS lane(s). Unusual features of this concept are 1) two-way communication between the vehicle and the roadside (unusual for a cooperative concept); 2) the use of the transition lane like a railroad siding to allow faster-moving traffic to pass slower-moving traffic.

20.2 SELECTED ALTERNATIVE FROM EACH DIMENSION

Distribution of intelligence—cooperative.

Separation policy—platooning. Local options include excluding the right-hand AHS lane from platooning where two or more lanes are available, and setting a maximum platoon size.

AHS/non-AHS mixing—dedicated lanes with virtual barriers.

Mixing of vehicle classes in the same lane—yes. Where two or more AHS lanes are available, heavy vehicles and non-platooning vehicles will be limited to the right-hand lane. Where only one lane is available, local options include restricting the use of AHS by heavy vehicles to specified hours.

Entry/exit—transition lane. Local options include minimum speed and sharing this lane with HOV's.

Obstacle—automatic sensing and automatic avoidance maneuver.

20.3 OPERATIONAL CONCEPT

In this cooperative concept, the vehicle does autonomous lane-keeping and headway maintenance using a suite of on-board sensors which maintains a current picture of objects in a 270 degree sector centered around the vehicle velocity vector (see System Diagram for a sensor coverage map). It performs obstacle detection using its forward-looking sensor, and position determination using its lane-keeping sensors (see Issues for more details). It senses velocity, computes acceleration, and measures range to any vehicles or objects ahead of it or to either side. The vehicle's processor will use on-board sensor inputs to calculate required heading and speed changes. The processor will use position and speed broadcasts by nearby vehicles to identify vehicles in the sensor blind spot, and roadway obstructions. If an obstruction is identified, the vehicle will broadcast a warning to nearby vehicles and the roadside processor.

20.4 SYSTEM DIAGRAM

Platoons will be formed under this concept by vehicles advertising their position and destination to other nearby vehicles or platoons. Vehicles (or lead vehicles of platoons which can accept more vehicles) with compatible destinations will reply with an invitation to link up unless the driver has issued a "no platooning" command. When a vehicle(s) which is part of a platoon approaches its exit, or the driver wishes to leave the platoon, the departing vehicle(s) will notify the lead vehicle, which will issue commands to all platoon vehicles creating a gap before and after the departing vehicle(s). The departing vehicle(s) will then change lanes.

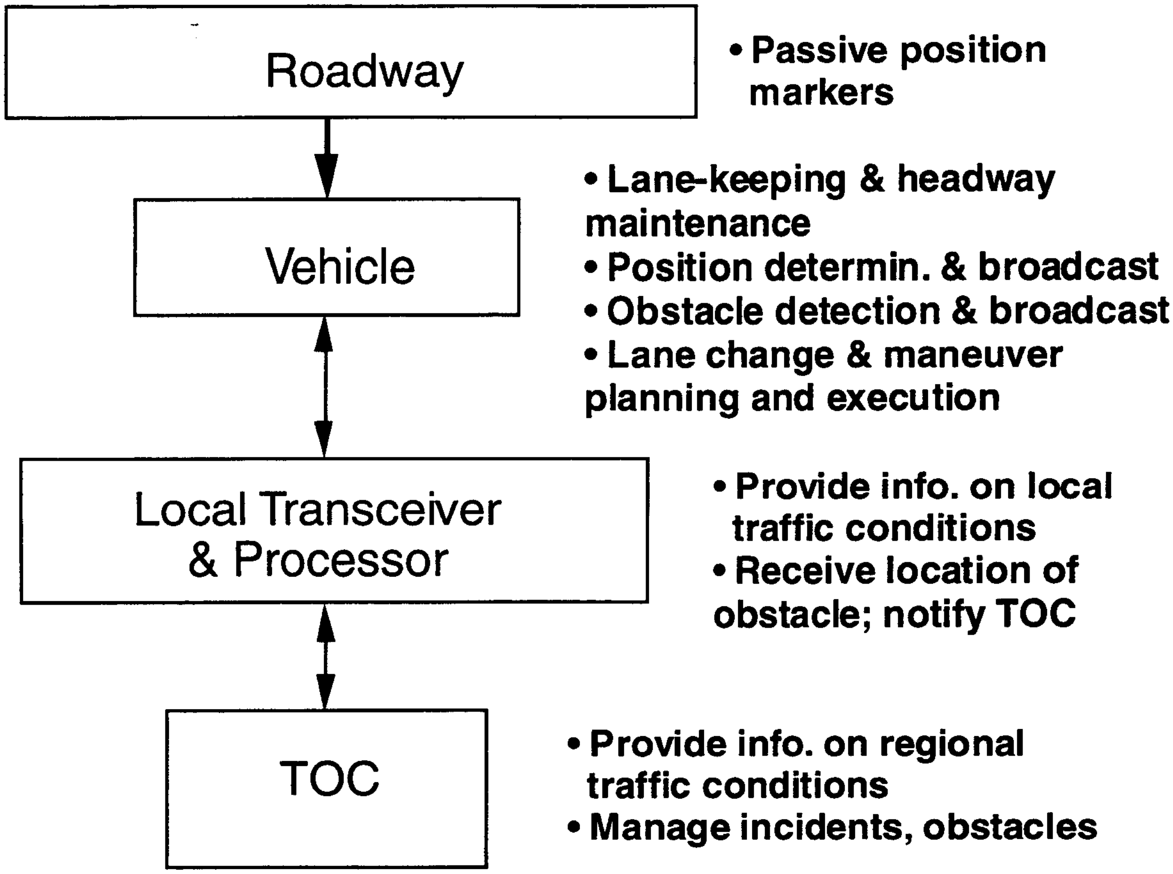

Figure H.20-1.

This is a cooperative concept in which the role of the roadside processor and the TOC is quite limited. The TOC sends regional traffic conditions to the roadside processor which in turn transmits that information to vehicles in the area. The roadside processor monitors traffic density, speed, and environmental conditions using sensors in or on the roadway. It also monitors reports of obstacles and incidents broadcast by vehicles; all this information is forwarded to the TOC.

20.5 FUNCTIONAL ALLOCATION

20.5.1 Check-In

"Check-in" is limited to vehicle self-test of on-board AHS systems.

20.5.2 Transition From Manual To Automatic Control

This is a manual operation performed in motion in the transition lane. Prior self-test of AHS systems is required. The driver throws a switch on the console; visual/auditory confirmation is given if the vehicle processor can take control of the vehicle. Visual/auditory warning is given if the vehicle processor cannot take control. The driver can also select a semi-automated mode for non-AHS roadways. Once in automatic mode, the vehicle will begin broadcasting its availability for platooning and its destination to nearby vehicles.

20.5.3 Sensing of Roadway, Vehicles, And Obstructions

Other vehicles and large obstructions are sensed by the vehicle's forward-looking sensor. If technologically feasible, this will also be used to spot all roadway hazards which can damage the vehicle. If this is not possible, it will be necessary to add one of the following to this concept: 1) a second vehicle-mounted sensor optimized for obstacle detection; 2) use the driver as a spotter for hazards and obstructions which the automatic sensor cannot pick up sufficiently far in advance (see Deployment for more on this). The vehicle processor will compare the range estimates of the forward and side-looking sensors with the broadcast positions of nearby AHS vehicles. Any objects which do not broadcast their position and are detected by the sensors will be assumed to be obstacles unless they are moving within the lines of the transition lane; then they will be assumed to be non-AHS vehicles. Any vehicle detecting an

Concept #17 Data Flows

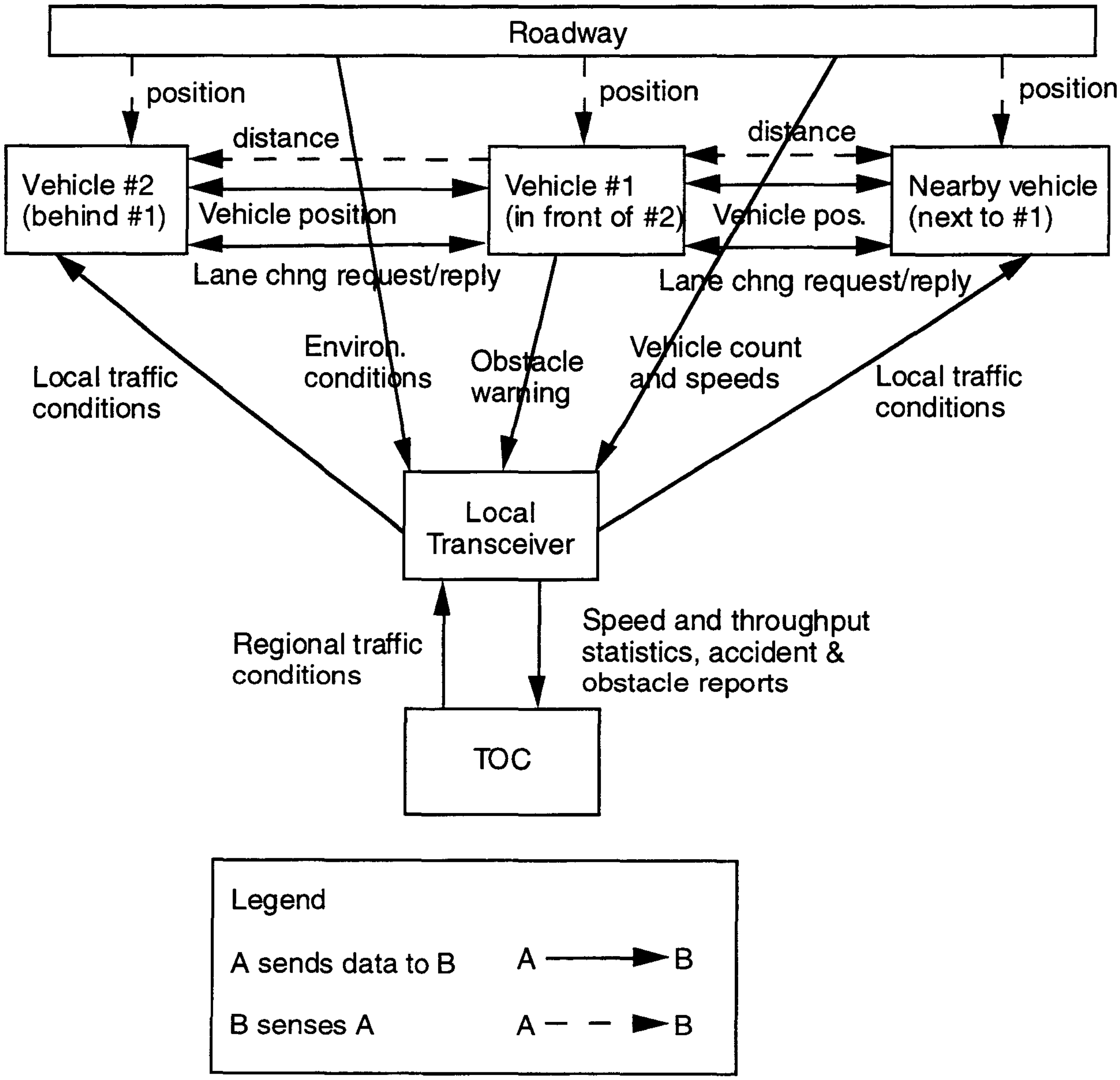

Figure H.20-2.

obstacle will broadcast a warning to nearby vehicles and to the roadside processor, which will forward the report to the TOC. The driver will also have an Alert button, and the ability to enter a limited number of codes for incidents such as request non-emergency communication, report emergency, etc.

20.5.4 Lane and Headway Keeping

Lane-keeping and longitudinal positioning are vehicle-based. Lane-keeping is performed with reflective markers on both sides of the lane which will also be encoded with a sequence number used for positioning (see Issues). These markers may reflect visible light similar to the lane markers used on some interstate highways, or they may be radar reflective. The lane-keeping sensors measure range and can therefore estimate vehicle position relative to the markers. Longitudinal position-keeping is done based on a recommended speed for the region broadcast by the roadside processor, and on inputs from the forward-looking sensor.

20.5.5 Maneuver Planning

The vehicle may make route guidance-based lane change decisions (e.g., lane ends, change lanes for exit or interchange) using in-vehicle routing, or the vehicle may determine the need for an immediate maneuver based on received and sensed vehicle/obstacle positions. Lane change decisions can also be made by the driver, and requested via the user interface. Nearby vehicles will be requested to accelerate/decelerate to make the needed space; if their cooperation is confirmed by return message, the maneuver is executed. Otherwise, an alternative direction is chosen and the process is repeated.

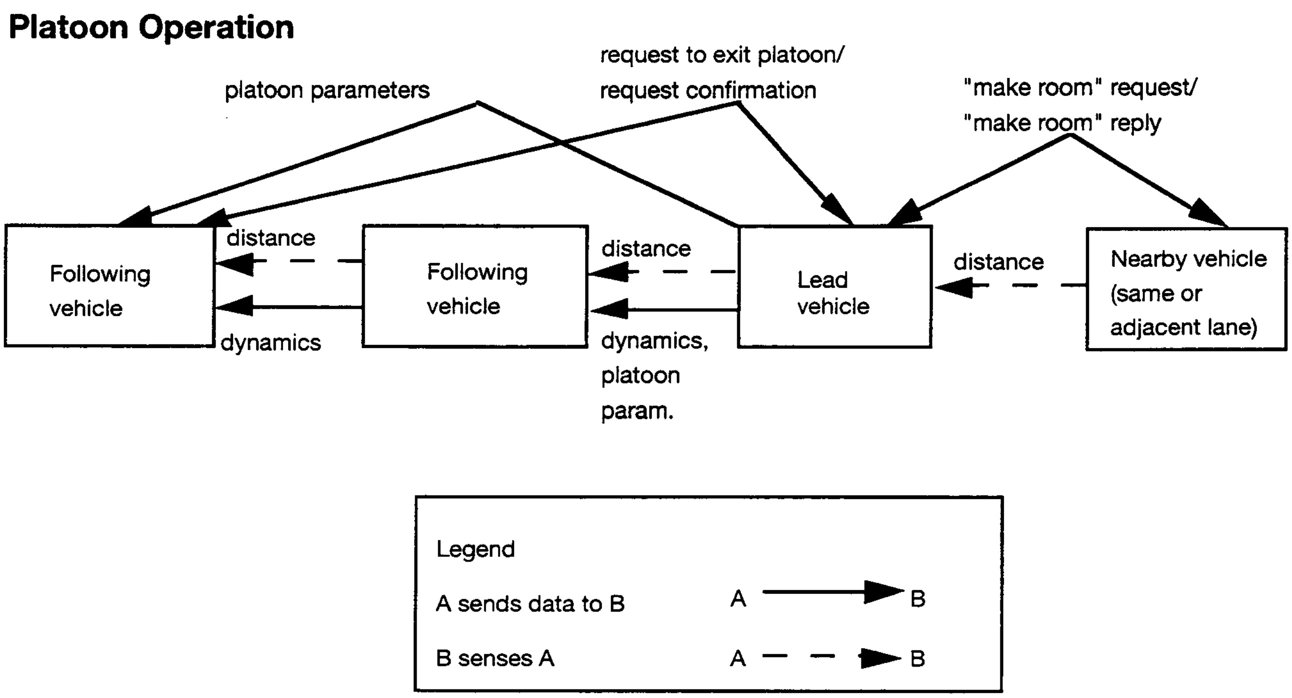

Figure H.20-3.

20.5.6 Maneuver Execution

As maneuver progresses, the vehicle uses its on-board sensors to re-evaluate its relative position and recompute maneuver parameters.

20.5.7 Transition From Automatic To Manual Control

This happens after the vehicle has left the AHS lane(s) under automatic control and is traveling in the transition lane; it can also occur in the case of catastrophic failure of hardware or software. The vehicle signals the driver to resume control, the driver confirms that he is able by pushing a sequence of buttons. If the driver fails to respond correctly within a specified time, he is prompted a second time; if he still does not respond appropriately, the processor brings the vehicle to a stop in the breakdown lane or nearest breakdown area.

20.5.8 Flow Control

In regions where only one lane can be dedicated to AHS, the transition lane can be used like a railroad siding. If faster vehicles are being held up by slower vehicles (e.g., trucks ascending a grade), the faster vehicle can switch to the reflector-equipped transition lane in an attempt to pass without surrendering automatic control of the vehicle. The vehicle will remain under AHS control in the transition lane, and will switch back to the dedicated AHS lane once it has had a chance to pass the slower traffic, or has failed to do so in a certain time interval.

20.5.9 Malfunction Management

The vehicle will have subsystem redundancy for longitudinal position-keeping and lane-keeping. Lane-keeping will be done primarily by sensing reflective markers, and backed up by dead-reckoning. Longitudinal position-keeping will be done primarily by the vehicle-based sensors, backed up by the vehicle's position estimated from lane marker codes, and other vehicles' positions similarly estimated and broadcast.

20.5.10 Handling of Emergencies

If the vehicle's AHS monitoring functions sense hardware or software failures with potentially serious impact, they will broadcast a warning to nearby vehicles, which will respond by increasing spacing and decreasing speed. They will also request the driver to take over manual control, and will bring the vehicle to a halt if he does not (see Transition from automatic to manual control, above).

20.6 IMPLEMENTATION

20.6.1 Vehicle

- Processor
- Short-range vehicle to vehicle communication (2-way)
- Forward-looking sensor for vehicles and obstructions
- Lane-keeping sensors capable of reading encoded position information on specially designed reflectors
- Short-range lateral sensors capable of sensing nearby vehicles

20.6.2 Infrastructure

- Short-range roadside receivers, sufficient density for continuous coverage and accompanying processors
- Traffic Operations Centers at some density
- At least one dedicated AHS lane and one adjacent lane equipped with reflective lane markers compatible with the lane-keeping sensors
- Breakdown lane (or areas) accessible from either the AHS lane or the transition lane. If not continuous, spaced periodically.

20.6.3 Rural Highway

See Flow Control

20.6.4 Deployment

If the lane-keeping sensors can be made compatible with existing rectangular reflectors, then a stepping-stone to implementing this concept could be installation of the on-board vehicle sensors and controllers, but with no capability to plan or execute lane changes, and no modifications to the infrastructure. The vehicle would perform lane-keeping and longitudinal position-keeping under normal circumstances. The driver would have the power to override when he desired, and would be expected to take over under unusual circumstances. Driver monitoring techniques such as the one described in the next paragraph, could be used to periodically check driver alertness.

If a satisfactory hazard detection sensor is not available at the time of initial AHS deployment, the driver can be used as a spotter for hazards and obstructions which the automatic sensor cannot pick up sufficiently far in advance. When the driver pushes an alert button, he can also enter a code (roadway obstruction, fire, medical emergency, etc.). This information, along with the vehicle's position, is broadcast by the vehicle to nearby vehicles and the roadside receiver, which relays the information to the TOC. If the driver pushes a button indicating a possible hazard in his lane, other vehicles near it will begin to slow and increase spacing in preparation for stopping or maneuvering. The driver must volunteer to perform this "spotter" function; reduced tolls represent a possible incentive. Where there are two or more dedicated AHS lanes a speed "bonus" could also be used as an inducement, with vehicles where the driver wants to read or sleep being limited to a lower speed in the right lane(s). Driver alertness and response time could be monitored by periodically projecting an image focused in the distance onto a windshield heads-up-display; the driver must respond by pushing a button within a prescribed time interval; if he fails several times, the vehicle is "demoted" to the lower speed right-hand lane.

20.7 ISSUES

20.7.1 Obstacle Detection Sensor

Obstacle detection could be performed 1) by the vehicle-mounted headway sensor; 2) by a separate vehicle-mounted sensor designed to detect small objects on the roadway; 3) by the headway sensor assisted by the driver (see previous paragraph). This is a technology issue which needs further investigation.

20.7.2 Vehicle Position Determination

This concept proposes that the vehicle calculate its position from a known position when it entered AHS, a count of the number of markers passed since entry, and measured range to the current markers. To do this the lane-keeping sensor must measure both range to the lane markers, and read a three to four bit sequence number encoded on the markers. These markers may reflect visible light similar to the lane markers used on some interstate highways, or they may be radar reflective. They will, however, be spaced at regular intervals, be machine-readable, and encoded with the sequence number of the marker. The vehicle counts markers, and uses the code on the marker as a check in case it misses a few. Where snow falls regularly, the markers will need to be designed or placed so that they are not damaged by snowplows. The feasibility of this position determination method is not critical to this concept, however; other methods can be substituted.

21. CONCEPT 18: COOPERATIVE VEHICLES ON DEDICATED LANES

21.1 OVERVIEW

In this concept, autonomous vehicles utilize inter-vehicular communications for coordinated lane changes and simple platooning of like-vehicle-classes. There is minimal infrastructure intelligence, indicating that traffic flow optimization will not be performed by a global support network. This concept utilizes uni-directional dedicated lanes with physical barriers and dedicated entry and exit ports. Obstacle detection will be performed automatically, however obstacles will either be manually avoided or the vehicle automatically stopped in order to avoid a collision.

21.2 SELECTED ALTERNATIVE FROM EACH DIMENSION

Distribution of Intelligence: Cooperative vehicles (autonomous vehicles with inter-vehicular communication) with minimal infrastructure intelligence Separation Policy: Free agent vehicle. Traffic flow is not optimized by a global support network or organized platoons.

Mixing of Vehicles: AHS vehicles will travel on dedicated lanes with continuous physical barriers.

Mixing of Vehicle Classes: Full mixing of all vehicle classes on the AHS lanes will occur.

Entry/Exit: There will be dedicated entry/exit points onto the AHS lanes.

Obstacle: Automatic sensing of obstacles will lead to manual maneuvering or automated stopping in order to avoid colliding with the obstacle.

Region Specific Options:

1. Each region will need to determine the optimal entry/exit ports onto the AHS lanes in order to maximize throughput and minimize the impact to surrounding streets.
2. Each local region will be responsible for determining which roadways will benefit by installation of an AHS dedicated lane. This may involve simple retrofitting of existing HOV lanes, utilizing existing manual land for AHS use, or the creation of new AHS lanes.
3. Each region will need to determine if AHS dedicated lanes must also be used as HOV lanes.

21.3 OPERATIONAL CONCEPT

21.3.1 Communications

Communications, in this concept, is not limited to "command" information. One aspect of the potential communications architecture is a vehicle beacon which provides steady-state information to surrounding vehicles. This beacon identifies the vehicle as being AHS-equipped and provides a performance indicator for the vehicle. This will allow vehicles to calculate safe stopping distances given the performance of surrounding vehicles. Emergency vehicles will have an additional indicator on the vehicle beacon. When the lights and sirens are used, the beacon will also activate an emergency signal. This information will be used by vehicles in the surrounding area to "make way" for this vehicle. All vehicles will be constantly querying the surrounding vehicles (within a short range) for performance data and will be continually updating the braking profile given the characteristics of surrounding vehicles. This proactive braking calculation will provide a deceleration value that can be used immediately in an emergency situation. Decreased headways will be obtained because of this communications capability. This will result in higher throughputs while continuing to maintain reasonable gap sizes.

21.3.2 Check In

The AHS-equipped vehicle will pull into the dedicated entry point for the AHS. A systems check will be performed by the on-board software to verify that all hardware and software is in proper working order. The AHS computer will have the capability of determining the required fuel loading for the trip and will notify the driver if an earlier exit will have to be taken. The driver will be responsible for ensuring that tire inflation is proper, and that the car is working within the performance measures assigned to that vehicle. This measure of personal responsibility is required for a system without a heavy infrastructure emphasis. Drivers can be discouraged from providing poor maintenance by the use of heavy fines if avoidable breakdowns occur on the AHS lanes. The entry point may require police support to ensure that vehicles that are not AHS-designated do not enter the AHS lanes. This would be necessary due to the fact that infrastructure is minimized in this concept.

Once the vehicle has passed the systems check, the vehicle will assume control. It will be responsible for merging into the AHS lanes and traveling with the flow of traffic. A spacing policy will be required that enables AHS vehicles to merge into the lane without the use of a long transition ramp. At this point, the driver of the vehicle indicates what exit or what approximate distance of travel is desired. This can be achieved through a keypad or voice-based system where the vehicle queries the driver. An on-board, regional-specific database would be required to confirm destination points, and suggestions may be made by the computer for an exit if the number or name is not known by the driver. This will also require that a system be developed to uniquely identify exit numbers throughout the country (for example: PA-79-01A would indicate the Pennsylvania section of I-79, exit 1A). Depending on the amount of available on-board disk space, database loading stations may be required at rest stops along AHS travel routes. This will allow vehicles traveling from one region to another to update the on-board information. This will also minimize infrastructure requirements by updating the database slowly, rather than in real-time.

21.3.3 Normal Operations, Including Obstacle Detection

The vehicle will determine its location on the highway either through vision data or GPS used in conjunction with an on-board database. The vehicle will be able to determine the number of lanes on the freeway and which lane the vehicle is in. The vehicle has 360 degree obstacle detection sensors that detect other vehicles and obstacles. The vehicle will also be capable of detecting the relative velocity of these objects. The on-board logic uses the above information to maneuver the vehicle so that it travels with the flow of the traffic and maintains a safe distance from other vehicles.

A gain in throughput and flowrate is achieved because intelligent vehicles can use shorter headways due to the automated reactions to received information. In the event that the AHS vehicle is closing on an object, the AHS system will signal the driver that a collision may occur. The driver will be required to either manually avoid the object or to indicate to the vehicle that the object is inconsequential. If no action is taken by the driver or if the reaction time would be unacceptable, the vehicle will brake so as to avoid a collision. One of several potential technologies used to detect the relative motion of surrounding objects is Doppler Radar. Sensed information from radar, IR, or vision systems will be integrated with communicated data. These data will feed into the maneuvering and braking algorithms on-board which in turn command the vehicle. Vehicles will have the logic to automatically create a space for a vehicle in another lane that has communicated its intention to merge into its own lane.

The backwards looking sensors will be continually scanning for vehicles which are approaching with a problematic delta v. The vehicle can signal the approaching vehicle by signaling the vehicle via the communications link. If this signaling is unsuccessful due to a hardware failure and a collision is imminent, the AHS vehicle will maneuver out of the lane to avoid a collision.

21.3.4 Check Out

In order to regain manual control, a graceful transition period is required. This will be done outside of the AHS lane in a transition lane that is dedicated to a particular exit. When the transition ramp for the selected exit becomes available, the vehicle will automatically exit. If there are surrounding vehicles in the transition lane, all vehicle headways will be increased for safe manual driving. Transition of control to the driver will be achieved through an alertness test which may involve transition acceleration control first, then braking and maneuvering. If the system has indications that the driver is incapacitated, it will pull into a safe area.

It is important that side-street traffic flow is well coordinated with AHS exiting requirements so that local congestion does not "back up" into the AHS transition lane (and hence, the AHS lane as well). This may require a regional study to ensure that all traffic flow is maximized.

21.3.5 Use of AHS Technology for Rural and Inner-City Driving

Certain features of the AHS system, such as lane-keeping and headway maintenance, can be used independent of other features. This will provide additional safety benefits during inner-city driving as well as rural roadway driving. Partial-use of AHS features will be terminated manually.

21.4 FUNCTIONAL ALLOCATION

In this concept, all intelligence is assigned to the vehicle. No infrastructure changes have been implemented to support AHS. Additional functional allocation information is summarized under "3.0 Operational Concept."

21.5 IMPLEMENTATION

Implementation of intelligence is strictly placed in the vehicle. No infrastructure support will be required.

21.5.1 Vehicle

The following technologies will be examined in order to achieve this concept:

- Forward and backward looking Doppler Radar
- GPS
- Side looking proximity sensors
- Infrared technology
- Vision system technology

Various communications possibilities exist, all of which are to be explored.

21.5.2 Infrastructure

There will be no infrastructure support in this concept other than already existing GPS infrastructure. No TOC will be necessary or available.

21.5.3 Deployment

This system will have tremendous appeal because of the safety advantages, early implementation of technology, and wide applicability of technology. Vehicles can be equipped with AHS technology as soon as it is proven and prior to infrastructure upgrades for dedicated lanes. AHS capability can not only be utilized on freeways but can also be used, at least partially, in the city and on rural roadways. This provides significant and immediate benefit to the consumer.

21.6 GENERAL ISSUES AND CONSIDERATIONS

It was determined that the requirement for manual obstacle avoidance is insupportable technically. Given that the vehicle has autonomous capability, obstacle avoidance is built into the system design and should be fully utilized.

22. CONCEPT 19: INFRASTRUCTURE MANAGED PLATOONS WITH AUTOMATIC SENSING, STOP, AND MANUALLY AVOID

22.1 OVERVIEW

This system implements a highly centralized and controlled system which is managed directly by the infrastructure. Mixed classes of vehicles operate together in dedicated and physically separated lanes. Vehicles operate in platoons for optimal throughput and fuel efficiency, and are allocated a position at the dedicated entry control station.

This concept can provide a highly optimized and efficient system because of its centralized nature. Traffic flow can be optimized although it does require a complex central software system. Growth is very efficient and controlled because all changes can be made at one location irrespective of growth or evolution in vehicle models.

22.2 SELECTED ALTERNATIVE DIMENSIONAL DESCRIPTION

22.2.1 Distribution of Intelligence—Infrastructure Managed

The infrastructure monitors individual vehicles and commands vehicles on an exception basis, including entry and exit. The infrastructure senses obstacles and sends commands to the vehicles; if the vehicle senses an obstacle the infrastructure missed, it requests an emergency stop (to allow the other platooned vehicles to respond simultaneously). Local position keeping is granted to individual vehicles, but there is no communication between vehicles; all platoon level parameters are set by the infrastructure.

22.2.2 Separation Policy—Platooning

Vehicles are required to run in platoons (A single vehicle would still be treated as a platoon). The separation within a platoon is set by the infrastructure as a function of the worst minimum stopping velocity of the vehicles in the platoon. This data is acquired at check-in, is forwarded to consecutive roadside beacons/controllers, and is also maintained by the lead vehicle. All vehicles brake at the same delta velocity upon command of the infrastructure (roadside controllers).

Note there are two other possible separation policies consistent with this option. These are presented here but are not considered in the ensuing discussion:

a) vehicles can maintain their own available delta v and adjust their separation distance as a function of the allocated platoon speed; or
b) the infrastructure controller could develop customized spacings (even smaller) that are a function of each vehicle and the vehicle ahead (for the lead vehicle, the sensing range).

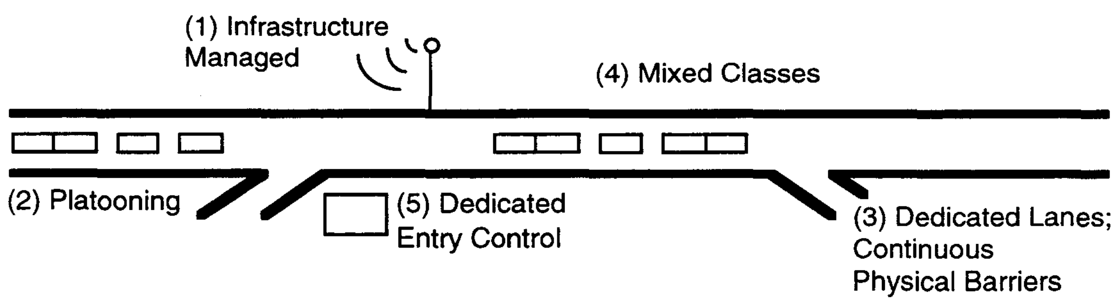

Figure H.22.1-1. System Overview

These variations on the basic alternative can be selected/modified by the local governing agency by simple software modification.

22.2.3 Mixing of AHS and non-AHS Vehicles—Dedicated Lanes with Continuous Physical Barriers

Continuous physical barriers are used with dedicated entry points so that non-AHS vehicles do not operate with AHS vehicles.

22.2.4 Mixing of Vehicle Classes in a Lane—Mixed

Different vehicle classes may be mixed in any platoon arrangement. The infrastructure takes individual vehicle control parameters into account when setting up platoons and platoon operating parameters. The ensuing description (§3 through §7) presumes that platoon spacing and velocity parameters are set as the worst case of the vehicles in the platoon. For example the platoon would maintain common spacing which would be a function of the slowest available negative acceleration (stopping capability) and the desired speed (a function of maximum vehicle acceleration (engine and weight) and hill grades over the highway segment). Each vehicle would maintain this common spacing; thus, platoons would operate at the lowest common denominator of the different classes represented in the platoon.

Note there are two other possible platooning policies consistent with this option wherein the entry station and/or assigning roadside controller sort incoming vehicles into different platoons. These are presented here but are not considered in the ensuing discussion:

a) platoons may be homogeneous with different classes of platoons for each class of vehicle (this reduces control complexity, but also reduces overall throughput); or

b) platoons may be sorted on (throughput affecting) parameters to increase performance at the cost of a slight increase in complexity.

These variations on the basic alternative can be selected/modified by the local governing agency by simple software modification.

22.2.5 Entry/Exit—Dedicated

Entry/exit points are dedicated access points which are located at openings in the continuous physical barrier in conjunction with the AHS check-in function; entry/exit at intermediate points in the roadway is not available.

22.2.6 Obstacle Sensing and Avoidance—Automatic Sensing, and Stop or Manually Avoid

Obstacles are automatically detected by a combination of vehicle and infrastructure. The only allowed response is for the vehicles (platoons) to stop. A human must release the blocked condition, either by driving around or by requesting assistance via the roadside beacon. Two types of response are defined. For infrastructure detected obstacles, the system knows the location and approach vector. Thus, the system can modulate the platoon velocity to bring the platoon to a gradual stop at the correct point. If a (lead) vehicle detects an (unknown) obstacle, it first sends the information to the local roadside beacon which then commands all vehicles to simultaneously come to a stop at a given stopping velocity. Note that if a response is not received by the lead vehicle from the beacon within a specified time, the vehicle can begin braking itself. Subsequent vehicle braking is initiated and controlled by each vehicle's longitudinal controller. The available maximum delta v is a function of the platoon control algorithm and may be less than the available stopping velocity because of platoon stability issues.

22.3 OPERATIONAL CONCEPT

The environment for this concept is highly defined and controlled: the AHS lanes are dedicated and have continuous physical barriers; Check-in is highly controlled at entry points; control of the platoons and vehicle commands are generated by local roadside beacons and is coordinated by a central TOC. Information may also be sent to an overlapping TOC for informational and planning purposes.

Entry into the dedicated lane is controlled at the check-in point. In addition to verifying the readiness of the vehicle, the check-in station gathers vehicle information such as maximum stopping velocity and front sensor range to be used for platoon control. This information is sent to the infrastructure control manager to request insertion into or at the end of a platoon. The infrastructure control manager then grants a request to enter, or form, a platoon. Information maintained on each platoon includes number of vehicles, vehicle IDs, maximum forward sensing range, and worst minimum stopping velocity.

Control of the platoon is governed by the infrastructure. Roadside beacons send commands to the platoon for velocity, etc. based on platoon information, the upcoming highway, upcoming traffic conditions, weather conditions, and infrastructure sensed obstacles. Overall control, governed by a TOC, is aided by the roadside beacons forwarding platoon information to the next beacon.

Control within the platoon is governed by the common set of parameters sent to the vehicles such as velocity. Nominal adjustments (increases/decreases) in speed are commanded and executed by the individual vehicle controllers. In case of the lead vehicle sensing an obstacle, the roadside beacon is alerted which then asserts a defined stopping velocity. Note that one of the parameters that is sent with the platoon is the worst maximum stopping velocity.

Centralized Control and Computing is provided at the Traffic Operations Center (TOC). The communications lines linking the roadside beacons/controller must be highly reliable.

22.4 SYSTEM DIAGRAM

The system block diagram is shown in Figure H.22.4-1. Data rates are defined in §6. Dashed lines indicate sensed information. Solid lines indicate communication links.

Shaded lines indicate the solid physical barriers. The Traffic Operations Center (TOC) provides traffic coordination.

22.5 FUNCTIONAL ALLOCATION

22.5.1 Check-In

Check-in is allocated to the infrastructure at a dedicated entry point. The vehicle state is analyzed to ensure AHS capability, and some dynamic parameters are collected to be passed to the platoon control function. This information would include maximum stopping velocity (=f(weight, tires, brakes)), maximum range and resolution of forward obstacle sensor, and vehicle ID. The check-in station then requests an insertion on to the dedicated lane which may be at the end of an existing platoon, a new platoon, or if in heavy traffic into the middle of a platoon. The request to the roadside controller for entry includes the dynamic information.

22.5.2 Transition from Manual to Automatic Control

Control of transition to automatic driving is allocated to the infrastructure. Once the vehicle is verified to be ready to enter the dedicated AHS lane, the infrastructure controller selects a platoon for the vehicle to join and sends a merge profile to the vehicle. When the vehicle is in the platoon and within a nominal spacing of the forward vehicle, it assumes longitudinal control and maintains its distance given the nominal platoon velocity.

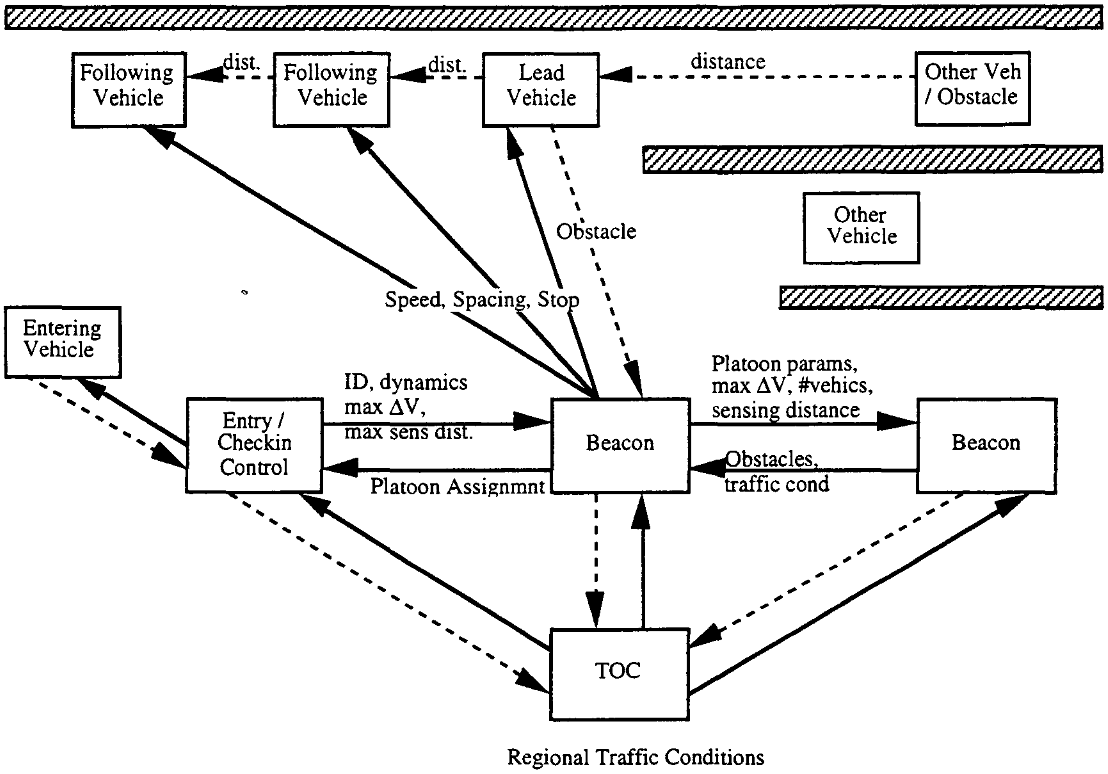

Figure H.22.4-1. System Block Diagram

22.5.3 Automated Driving

22.5.3.1. Sensing of roadway, vehicles, and obstructions

Dynamic sensing of the roadway, vehicles, and obstacles is allocated to the vehicle. Down road obstacles that are sensed by the infrastructure fixed sensors are communicated to the correct roadside beacon which uses the location data to adjust platoon velocities and eventually, at the correct physical coordinates, to come to a simultaneous commanded stop.

22.5.3.2. Lane and headway keeping

Lane and headway keeping are allocated to the individual vehicles. A nominal velocity and spacing is commanded by the roadside beacon; the vehicle then maintains the correct distance by adjusting its velocity around the set point.

22.5.3.3. Detection of hazards

Detection of hazards is allocated to both the vehicle and the infrastructure. The role of the infrastructure is to keep obstacles out of the dedicated lane with continuous physical barriers. If a vehicle becomes disabled its location is transmitted upstream as a local traffic condition. The vehicle sensing role applies only to the lead vehicle of a platoon and is to detect any non-predefined obstacles. Upon identification of the obstacle the vehicle sends a request to the local roadside beacon to request a stop. The command to stop is sent broad band to all vehicles so they may commence braking nearly simultaneously.

22.5.3.4. Maneuver planning

Maneuver planning (both normal and emergency) is allocated to the infrastructure. The only allowed reaction of a vehicle to an obstacle is to stop and this must first be requested to the local roadside controller. The vehicle can begin braking on its own accord if no response is received within a nominal time (~100ms).

22.5.3.5. Maneuver execution

Maneuver execution is allocated to the vehicle.

22.5.4 Transition from Automatic to Manual Control

Transition from automatic to manual control is allocated to a combination of the vehicle and the infrastructure. The vehicle, upon operator request, verifies its readiness to exit to manual control. The vehicle then requests an exit from the AHS lane. The local control system grants the request and also sends any additional instructions necessary to the rest of the platoon.

22.5.5 Check-Out

Checkout functions are allocated to a combination of the vehicle and the infrastructure. The vehicle, upon operator request, verifies its readiness to exit to manual control. The vehicle then requests an exit from the AHS lane. The local control system grants the request and also sends any additional instructions necessary to the rest of the platoon.

22.5.6 Flow Control

Flow control is allocated to the infrastructure. This is divided between the local control beacons and the TOC. Local speed control and platoon forming and braking are under the control of the local beacon. Traffic management is performed at the TOC as a function of inputs supplied by the local controllers.

22.5.7 Malfunction Management

Malfunction management is allocated to a combination of the vehicles and the infrastructure. If a vehicle fails and becomes unable to continue as an AHS capable system, it requests an exit. If the vehicle is unable to reach an exit, the local control beacon notes its location, sends a signal to the TOC, and then forwards the obstacle information upstream to earlier local beacons to give platoons correct instructions on what action to take (such as slowing through incremental speed steps to stop at a particular GPS location).

22.5.8 Handling of Emergencies

Handling of emergencies is the same as Malfunction Management. It is allocated to a combination of the vehicle and infrastructure. If a vehicle fails and becomes unable to continue as an AHS capable system, it requests an exit. If the vehicle is unable to reach an exit, the local control beacon notes its location, sends a signal to the TOC, and then forwards the obstacle information upstream to earlier local beacons to give platoons correct instructions on what action to take (such as slowing through incremental speed steps to stop at a particular GPS location).

22.6 IMPLEMENTATIONS

22.6.1 Vehicle

Below is a coarse comparison of hardware implementation costs compared with other possible concepts. Use of the word ‘same’ implies that this is an independent choice and is not specifically affected by the selection of this particular concept.

Actuators	same
Communication	minimal
Health Monitoring	same
Obstacle Detection	same
CPU	minimal
Lane Keeping	same
Headway Control	same

22.6.2 Infrastructure

Below is a coarse comparison of hardware implementation costs compared with other possible concepts. Use of the word ‘same’ implies that this is an independent choice and is not specifically affected by the selection of this particular concept.

Communication	higher bandwidth
Obstacle Sensors	needed
Check-in	same
Roadside Controllers	greater CPU reqs
TOC	more software

22.6.2.1. Rural highway

Some special considerations for implementing this concept for a rural system are discussed below.

The assumption of continuous physical barriers implies a slightly higher cost for installation of the infrastructure and might restrict access somewhat. However, as the main benefit of this method is increased safety, it may be worthwhile. For instance, it would be a distinct advantage if installed on major interstate trucking routes.

The need for active roadside infrastructure control seems to imply a need for a large number of roadside controllers and communications. However, this issue is easily sidestepped by having the lead vehicle in a platoon carry the pertinent platoon information forward to the next interchange or exit point. This is reasonable since the infrastructure control is only for non-steady-state adjustments which would not occur between activity points.

22.6.2.2. Urban region

Some special considerations for implementing this concept for an urban system are discussed below.

Urban implementations are ideal for this concept. The level of infrastructure required is a perfect match for the required functionality in a complex urban environment. Additional goals and objectives can be met for user incentives as well as real-time throughput and routing adjustments by the TOC and linked roadside controllers.

Multiple lane implementations (when the demand gets high enough) would be simple software modifications. For instance lane switching would require the ability to "open" platoons. However this is the same software needed for vehicle entry. This software would simply be transferred to the roadside controllers, and a request for a lane change would simply be a special case of existing software.

22.6.3 Deployment

The minimum deployable system requires all of the infrastructure and software to be installed up front. This makes the initial funding requirements greater. However, subsequent investments would be minimal. Note that once the first system is up and running, all software is developed (only requires adaptation), and the subsequent infrastructure capitalization costs revert to the same level required for the infrastructure by any other implementation concept

The incentive for people to buy AHS capable vehicles is the low delta cost. This concept would require the fewest components on the vehicle.

Cities and other metropolitan transit authorities should prefer this system because they can use the centralized control to adjust usage policies for their particular region.

22.7 GENERAL ISSUES AND CONSIDERATIONS

Some coarse subjective evaluations relative to the AHS System Goals and Objectives are discussed below. Use of the word 'same' implies that this is an independent choice and is not specifically affected by the selection of this particular concept.

Table H.22.7-I.

Goal/ Objective	Parameter or Alternative	Relative Performance	Notes
Safety	Obstacle Sensing	safer	use of both vehicle and infrastructure is better than one
	Physical Barriers	much safer	
	Unexpected Intrusion	safer	Especially from other nearby vehicles.
Throughput	Platooning	very high	Two additional modes for even more throughput.
	No Non-AHS vehicles	undefined	less vehicles are allowed on but this may increase through put because it enables better platooning
	Traffic Management	very high	Global Optimization is enabled
Cost	Barriers	more	
	Vehicles Electronics	less	minimal cpu required
	Infrastructure Computer & S/W	more	roadside beacons / controllers need more software and elec
	Capitalization	more	Higher up front costs for infrastructure
	Operations	saves money	
Modularity and Growth	Maintenance	easy, centralized	less vehicle maintenance
	Evolution	easy upgrades	upgrades are generally S/W, no vehicle mods needed
	Expansion	no difference	
	Interoperability	no difference	conjunction of regional systems still problematic
Other	Communications Needs	Higher bandwidth; flexible packet routing	No new technology
	User Friendliness		no special attributes

23. CONCEPT 20: AUTOMATED SENSING, STOP AND MANUALLY AVOID WITHOUT CLASS MIXING

23.1 OVERVIEW

This concept was selected to be an AHS concept with as little technical risk as possible. It does not require that the AHS be able to maneuver around all obstacles.

23.2 CONCEPT DIMENSIONS

23.2.1 Infrastructure Supported

Selected as a mainstream option. More infrastructure support may offer more of a challenge and more risk. Less infrastructure support may make the task for vehicles too difficult.

23.2.2 Free Agent

Vehicles maneuver independently, with no effort to form into tight platoons. Vehicles do not communicate with each other, and thus, they must drive allowing extra space as a margin for uncertainty.

23.2.3 Dedicated Lanes With Continuous Physical Barrier

Only AHS vehicles are allowed on the AHS roadway, and this segregation is maintained by physically separating AHS vehicles for the duration of their journey.

A major goal of the physical highway architecture is to minimize hazards and obstacles of all types, as they will severely disrupt traffic flow in this architecture.

A continuous breakdown lane is a necessity. Beyond functioning as a breakdown lane, it provides a space where vehicles can manually be driven around obstacles. On automated highways carrying two classes of traffic in separated lanes, these lanes could share a common breakdown lane between them.

23.2.4 Vehicle Classes Not Mixed in Lanes

Ordinary operations presume that all vehicles in the same lane are of the same class.

As a local option, a highway could allow mixed class vehicles, but in this case all long-stopping-distance vehicles would have to follow using very large headways, under the presumption that they may be following a fast-braking vehicle. Traffic density and total throughput would suffer as a result. Vehicles would be informed during check-in of this exception on such an automated highway.

23.2.5 Dedicated Entry and Exit

Vehicles must pass ordinary check-in to enter an automated roadway.

Note, however, that there is a second kind of entry and exit into AHS operations. When the vehicle comes across an obstacle in the roadway, it stops automated operations and reverts to manual control. This is a check out. Once around the obstacle, the vehicle resumes automated operations. This is a check in. All vehicles must be able to accomplish this simpler level of check-out and check-in at any point on the highway.

23.2.6 Automatic Sensing, Stop, and Manual Avoidance

This is the largest departure from most AHS concepts. When a vehicle comes across a substantial obstacle or hazard, rather than trying to automatically navigate around it, the vehicle stops, notifies the driver, and the driver manually drives the vehicle around the obstacle.

23.3 OPERATIONAL CONCEPT

In steady state, a vehicle is traveling in a lane, maintaining headway using an on-board forward looking sensor, and staying in the lane by relying on passive, machine readable markings in the roadway. If the vehicle comes across an obstacle, it stops and notifies the driver.

23.4 FUNCTIONAL ALLOCATION

23.4.1 Check-In

Performed by the vehicle, in conjunction with the driver and roadway.

The AHS-equipped vehicle will pull into the dedicated entry point for the AHS, and stop. A systems check will be performed by the on-board software to verify that all hardware and software is in proper working order. This will be verified by the infrastructure at the check-in station, using the vehicle communications. The AHS computer will have the capability of determining the required fuel loading for the trip and will notify the driver if an earlier exit will have to be taken. Once the vehicle has passed the systems check, the vehicle will assume control. It will be responsible for merging into the AHS lanes and traveling with the flow of traffic.

23.4.2 Transition from Manual to Automatic Control

Occurs in the vehicles, while they are stopped.

23.4.3 Automated Driving

23.4.3.1. Sensing of roadway, vehicles, and obstructions

Roadway is sensed indirectly, by sensing of standardized, machine-readable markings. Vehicles and large obstructions ahead are sensed using forward looking sensor which measures range and range-rate on large objects. Vehicles are cooperatively marked. Smaller obstacles ahead are sensed using on-board sensors, and if suspicious, lead to stopping the vehicle and being sensed manually by the driver.

23.4.3.2. Lane and headway keeping

Lane keeping is accomplished using machine-readable roadway marking to indicate lanes, and an on-board sensor. The control loop is within the vehicle. Headway keeping is managed using a forward-looking sensor and closing the loop within the vehicle.

23.4.3.3. Detection of hazards

Detection of hazards is handled by individual vehicles, using on-board sensors. Once detected, the vehicle stops and control passes to the manual driver, who is responsible for watching the hazard until it is safely cleared.

23.4.3.4. Maneuver planning (normal or emergency)

A normal lane change is planned by a vehicle.

The emergency maneuver is to come to a stop and transfer control to the manual driver. This is implicitly pre-planned into the control algorithms.

23.4.3.5. Maneuver execution

Accomplished by the vehicles.

In the case of lane changes, the vehicle waits until its proximity sensor indicates that the immediate side it wishes to merge into is clear, and uses the short range LOS communications to inform that it is making a merge. If it receives no objection, then it merges. Vehicles which receive a request to merge are to slow down, and let the vehicle merge in.

23.4.4 Transition from Automatic to Manual Control

Vehicle maneuvers to a stop under automatic control, and is then driven away under manual control.

23.4.5 Check-Out

A vehicle exits the AHS lane by moving through a dedicated transition ramp to an empty space at a check-out station at the desired exit. Communications with the station may tell the vehicle to not take this exit, but the vehicle may request an emergency exit in any case, if it is low on fuel. Once stopped, the vehicle transitions to manual control, and informs the driver, who then drives off.

23.4.6 Flow Control

Flow control is managed by the infrastructure.

23.4.7 Malfunction Management

Vehicle monitors internal state, and takes next exit if possible if it notes a discrepancy. If unable to make the exit, move into the breakdown lane, and make a Mayday call (using ITS).

23.4.8 Handling of emergencies

Standard panic mode for an emergency is to come to a rapid stop, and transition control to manual driver.

23.5 IMPLEMENTATIONS

The following is a notional implementation.

23.5.1. Vehicle

- Forward looking Doppler radar
- Passive marker sensor (may also be forward looking sensor, or side looking sensor)
- Side looking proximity sensors
- GPS
- On-board processor
- Short range, directional, Line of Sight communications

23.5.2 Infrastructure

Passive markers to indicate lanes, AHS traffic rules, other special, static information. Continuous physical barrier, or totally separate roadway, isolating AHS from other traffic.

Widely spaced entry/exit stations. These have spaces to stop for transition to/from automatic control, and simple communications to support check in and check out.

As a local option, traditional traffic control sensors, and TOC control the traffic flow of the AHS

23.5.2.1. Rural highway

Rural highway might use isolated lane, rather than building a continuous barrier.

23.5.2.2. Urban region

Urban region would use continuous, physically isolated lanes, generally on pre-existing highway. Entry and exit stations would be sited where space for large adjacent parking was already available (e.g., airports, shopping malls).

23.5.3 Deployment

Possible first applications: Dedicated transit roadways; Dedicated interstate Trucking roadway; Part of a "shortcut" tollway corridor

23.6 ISSUES

One key issue is "how does the system operate so that a stall in the fast lane does not grow into a massive shutdown of AHS for that vehicle class?"