Precursor Systems Analyses of Automated Highway Systems

RESOURCE MATERIALS

Urban and Rural AHS Comparisons

U.S. Department of Transportation
Federal Highway Administration

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FOREWORD

This report was a product of the Federal Highway Administration's Automated Highway System (AHS) Precursor Systems Analyses (PSA) studies. The AHS Program is part of the larger Department of Transportation (DOT) Intelligent Transportation Systems (ITS) Program and is a multi-year, multi-phase effort to develop the next major upgrade of our nation's vehicle-highway system.

The PSA studies were part of an initial Analysis Phase of the AHS Program and were initiated to identify the high level issues and risks associated with automated highway systems. Fifteen interdisciplinary contractor teams were selected to conduct these studies. The studies were structured around the following 16 activity areas:

> (A) Urban and Rural AHS Comparison, (B) Automated Check-In, (C) Automated Check-Out, (D) Lateral and Longitudinal Control Analysis, (E) Malfunction Management and Analysis, (F) Commercial and Transit AHS Analysis, (G) Comparable Systems Analysis, (H) AHS Roadway Deployment Analysis, (I) Impact of AHS on Surrounding Non-AHS Roadways, (J) AHS Entry/Exit Implementation, (K) AHS Roadway Operational Analysis, (L) Vehicle Operational Analysis, (M) Alternative Propulsion Systems Impact, (N) AHS Safety Issues, (O) Institutional and Societal Aspects, and (P) Preliminary Cost/Benefit Factors Analysis.

To provide diverse perspectives, each of these 16 activity areas was studied by at least three of the contractor teams. Also, two of the contractor teams studied all 16 activity areas to provide a synergistic approach to their analyses. The combination of the individual activity studies and additional study topics resulted in a total of 69 studies. Individual reports, such as this one, have been prepared for each of these studies. In addition, each of the eight contractor teams that studied more than one activity area produced a report that summarized all their findings.

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NOTICE

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Disclaimer

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Executive Summary

The California Polytechnic State University (Cal Poly) was selected by the Federal Highway Administration (FHWA) as part of the Partners for Advanced Transit and Highways (PATH) team in the Precursor Systems Analyses (PSA) of the Automated Highway System Program (AHS) to investigate the urban and rural AHS comparison. The project goal was a "high level" analysis identifying the differences/similarities of issues and risks associated with rural versus urban AHS.

Several potential AHS operating mode alternatives were developed through "representative system configurations" and operating concept variable combinations. Alternatives are mapped in the "Operating Mode Input Matrix" and grouped in four basic stages of development, I_1 through I_4 (ultimate system). System overall performance (for various modes of operation) was assessed. Discussion on the impacts of differences in the evaluation of urban and rural settings follow. Representative System Configuration variables include guideway separation, heavy vehicle handling and intelligence/authority distribution while operating variables include vehicle spacing, speed and demand levels. Theoretical capacity, safety and environmental impact as it applies to air quality are addressed for the operating modes analyzed. Assessments were made by partitioning of the initial questions in subsets of issues. Every group eventually tries to focus its investigation to the differences and similarities between urban and rural AHS deployments as viewed through the prism of the group-specific issues. The subsets studied are the following:

AHS impacts to users.
AHS impacts to society.
AHS and the Transportation Management Centers (TMCs).
AHS and Commercial Vehicle Operations (CVOs).
Design Impacts of CVOs.
AHS and air quality.
AHS and the legal system.
Impacts of vehicle braking capability and potential AHS capacities.

Capacity benefits[1] are expected to be the driving force for AHS deployment in busy sections of urban areas. Substantial gains in infrastructure utilization result from the increased AHS capacity. This is expected to be an area of favorable cost/benefit evaluations. Even older studies [1] with lower target capacities and demands reported AHS in busy urban corridors as a provider of "cost effective highway capacity." Increased AHS capacities, urban travel demand and higher land values are expected to make the cost-benefit results even more convincing. Safety, travel time and comfort benefits are expected to be high in rural areas. Lower travel demand and land values in the rural areas are expected to reduce the benefits from capacity gains through AHS. However, safety benefits due to the reduction of "improper and unsafe driving" caused accidents are expected to be important.

Higher speeds could be pursued in the absence of capacity problems, although this is likely to be at the expense of energy efficiency and air pollution if the internal combustion engine is the primary AHS propulsion, and vehicle designs follow today's principles. After a modest effort of modeling

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[1] Ranging from 5% (early I_1) to 500% (I_4) as shown in section nine of the study

for the Los Angeles regions our team came to a conservative[2] conclusion that tailpipe emissions are likely to be the same before and after AHS (with a constant demand). The savings from a smoother flow were balanced by higher emissions due to higher average speeds[3] . The resulting "total" air quality problem is much more complex than the scope of this study requiring meteorological and other pollutant emitter inputs as well as more accurate descriptions of powertrain activities during AHS operations. The impact of heavy vehicles on the AHS is mixed. On the one hand, it was shown that some savings in operating costs for heavy vehicles can be realized through AHS. On the other hand, capital will be needed for new technologies that will make AHS feasible for heavy vehicles. Additionally as shown in one of the analyses, substantial design and operating constraints[4] will have to be met in order to accommodate heavy vehicles in the AHS. Such design constraints will sometimes be very costly[5] , particularly in the rural areas.

In the area of interactions between AHS and the legal system the investigation concentrated on three major concepts : product liability, negligence and Governmental immunity. Findings show that although problems faced by the AHS look unique and threatening for the survival of the system, there are several legal options that would strengthen its position. However, the basic legal background needs to be set before implementation efforts begin. Another finding was that for changes in the operation of the existing highway system significant legislative efforts were required which can be used as guides for the AHS legal support. Finally the concept of Governmental immunity provides the capability of shielding the system from unreasonable claims, but does so by requiring heavier Governmental involvement in the design and implementation of AHS. In the area of negligence, the AHS is likely to face problems in the cases of infrastructure intensive systems. Both vandalism and/or maintenance activities will be challenging particularly in rural areas. This could be one of the reasons impeding progress of the rural AHS systems beyond stage I_2.

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[2] Specific impacts resulting from the reduction of engine "enrichment" periods were not assessed.
[3] Given present vehicle designs, speeds over 70-80 KPH will usually increase emissions.
[4] Compared to a "light duty" vehicle AHS. Such "heavy vehicle" constraints are also met in a "non AHS" environment but sometimes not as severe in their consequences.
[5] In absolute, cumulative values resulting in low cost effectiveness.

After creating a framework for the evaluation, the group responsible for estimation of the impacts to users concluded in the following findings:

Overall, AHS seems more desirable/acceptable to users for urban trips rather than rural area trips.
The differences are more pronounced in the I_1 and I_3 stages of AHS development.
The highest grades for the urban system, as well as AHS as a whole are achieved during the I_3 stage when trucks are separated. In the case of rural trips stage I_4 gets slightly higher grades than I_3 but still consistently lower than urban trips.
The concepts of both perceived and actual safety were considered important and in need to be addressed early by any implementation effort. In the absence of actual safety statistics, perceived safety becomes even more important. Users will be very sensitive to information about system status and performance. System ridership and market share will depend greatly on user acceptance of the system safety performance.

A delphi type analysis by the team responsible for the evaluation of impacts to society resulted in the following findings:

Overall, the AHS stage I_3 was rated highest.
A very positive impact is expected for the economy particularly at the more advanced stages.
Under the evolution process that the team determined as most likely, AHS deployment was found to have potential problems with equity issues.
Slightly negative scores were also received in the area of technical/financial feasibility.
Positive scores were received for system acceptability.

Additional variables were introduced to analyze form and function of the TMCs. The variables can be grouped as following:

Control activities (vehicle control, inter-vehicle coordination, vehicle management, Traffic Flow Management and incident management).
Location of activity (on-board, at the zone level, and /or regional level control center).

The analysis on the role of the TMCs at the different AHS stages yielded the following findings:

Early stages of the system will be purely vehicle based but zone and regional controllers will assume more responsibility as we move to more advanced stages.
It is likely that urban AHS development will diverge from rural AHS development during stage I_3 with convergence likely in later stages.

The study of the impacts of vehicle braking capabilities on AHS capacities resulted in the following findings:

In highly congested areas (urban situation), and for average tires and pavement conditions, the capacity of the system would benefit by operating at speeds lower than the current highway speed limit.
The maximum capacity speed will become lower for lower quality tires and wet pavement conditions and in the order of 48 kph (30 mph).
Capacity is more sensitive to reaction times for vehicles with good braking capabilities and for

changes in the low part of the reaction time scale.
Some combinations of (good) tire qualities and (usually dry) pavement conditions may not experience capacity degradation at higher speeds. More research and better data on braking are needed in this area since it provides promising results for the future of AHS.
The combination of the above mentioned factors suggests stricter controls in urban areas achieving smaller separations and higher capacities.

After issues and risks for each separate environment were analyzed on an operating mode by operating mode basis, an "overall" comparison of the issues and risks in the two environments was made. This "overall" comparison was intended to detect trends in similarities or differences (in issues and risks) that are mode independent.

Initial contrast and comparison of urban and rural AHS deployment on a mode by mode basis is showing that during the "early" stage of deployment the systems are likely to be identical. During more "advanced" deployment the two environments can still be compatible as long as the evolution towards the "right" side of the operating mode input matrix develops systems that are compatible with their predecessors. Cost effectiveness pressures in the urban environments may require that advances be made quickly towards full automation and segregation from manual traffic. For several rural environments it may <u>never</u> be cost effective to advance to full automation (stages $I_{3\&}I_4$). Most of the AHS benefits in such environments, may materialize as early as I_2, leaving unbalanced costs for any further automation. On the other hand, keeping systems upward compatible may yield design compromises as experience has shown in other comparable systems. Ioannou [2] has already outlined a preliminary conceptual design of such system upgrades to upward compatible modes at the PSA Interim Results Workshop (IRW).

In a compromise solution, it is conceivable that <u>new</u> highway construction projects be designed or redesigned to be AHS compatible. Along those lines, special AHS ready connectors bypassing today's urban network capacity bottlenecks could be designed and given high implementation priority on cost effectiveness grounds. Initially such connectors may be accessible to manual traffic as well. As the AHS ready network materializes and higher AHS ready vehicle market penetration is achieved, manual vehicle accessibility could be restricted on higher efficiency grounds (if applicable/necessary). This "middle ground" solution improving capacity in urban areas (mainly through more infrastructure) while AHS is still in I_2, could preserve coordination between urban/rural deployments and could also ease opposition from manual traffic supporters.

An additional strategy could be to initially market AHS vehicles as probes (detecting and communicating conditions and abnormalities) for the "overall" highway status including local and collector streets. Probing could include (but should not be limited) to speed and congestion information, pavement condition, weather, signal and other traffic device malfunctions etc.

In the "overall" comparison category it was identified that urban AHS are likely to be more attractive/acceptable to users than rural AHS. Concerns were presented for all stages of deployment in the areas of perceived safety and equity. CVOs present a challenge for incorporation in the advanced AHS stages. However, they are an important potentially loyal client and revenue generator. Overall, positive expectations of the AHS deployment impact on the national economy were found to be very high.

On the concept of exclusive urban and/or rural AHS it was identified that there will be pressures in the urban areas to move forward to the more rewarding stages of a separate AHS guideway. If certain urban areas move into these stages while most rural areas will still not be equipped for the initial stages, there is potential, as shown by the TMC analysis, for separation of further developments in rural and urban AHS. One optimistic view expressed in both the TMC group as well as in the impacts to society group, is that eventually unit price reductions and economies of scale will force the system to merge back again towards the mature AHS design. The concept of a separate guideway while AHS market penetration is still low, will also stir up the equity issues, which according to the views presented by the impacts to society group, may be one of the big issues for AHS. The situation will be amplified if the first phases are expensive vehicle based. Under this scenario the AHS will be labeled as a system for privileged users and any further refinements and/or infrastructure investments with public money are likely to be difficult. Extensive public involvement from early AHS design stages will be required in order to reduce these impacts.

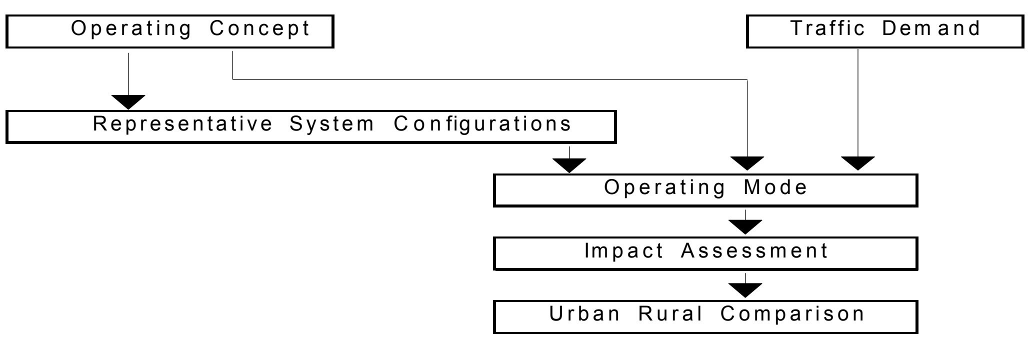
1. PROJECT ANALYTICAL FRAMEWORK(S)

1.1 Background

The concept of AHS has been researched throughout the past forty years by both private industry and Government sponsored programs. Recent technological advances and pressure from the inefficiencies of today's transportation systems have increased the likelihood that AHS will become feasible in the near future. The PSA phase is aimed at laying the groundwork for prototype system development. Coordination with parallel efforts in the area of "Human Factors Design of Automated Highway Systems" and National Highway Traffic Safety Administration (NHTSA) is required. Safety benefits are expected to be substantial in an AHS environment and NHTSA is actively pursuing this area. Lessons learned from other systems (transportation, military etc.) will be compiled to contribute to a more efficient design. Notable AHS baseline [1] assumptions include:

Vehicle compatibility with instrumented and non-instrumented roadway.
Non-instrumented vehicles to be instrumentable on a retrofit basis.[2]
AHS to outperform existing highway system in Safety, Throughput/Capacity, Comfort, and Speed.
AHS to operate under all typical U.S. weather conditions.
AHS control and guidance primary systems to be based on no-contact electronics.[3]

Cal Poly was selected by FHWA as part of the California PATH team to investigate activity area (a) of the AHS PSA focusing on the urban and rural AHS comparison. The present will summarize the methodology to be used by the research team including a research plan and project schedule. The project goal is a "high level" analysis identifying the differences/similarities of issues and risks associated with rural versus urban AHS.



1.2 Methodology

Several potential operating mode alternatives were developed through "representative system configuration" and operating concept variable combinations as shown in the Operating Mode Input Matrix (table 1). Each combination of operating variables, demand combinations and representative configurations results in an operating mode for each setting (urban/rural) evaluated. The darker cells

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[1] According to the PSA Request for Proposals.
[2,3] Assumptions that have been questions in the course of the project.

in the matrix represent modes that have been labeled as "unlikely" according to simple operational or economic considerations. Issues and risks for the AHS deployment under the different remaining alternatives are raised and discussed.

Studies throughout the past decade [2,3,4]show that current institutional and financing practices make the "smart vehicle" (Detachable Electronics Package (DEP)) concept more feasible. This concept of enhanced vehicle intelligence configuration is compatible with the model that has been pursued by PATH[5,6] through the past years. The validation of this idea is revisited to a certain extent in the current study. The enhanced roadway intelligence appears more necessary and possibly cost effective in some cases as we advance towards full automation.
Representative system configurations are specified/described in the following distinguishing characteristics:

1. Alternative guideway configurations (two options: Mixed - Separate).
2. Alternative instrumentation, authority/intelligence distribution:

I_1: Vehicle based system, Autonomous Intelligent Cruise Control (AICC) available control - similar to "autobrake + autogap"), [7] Minor Guideway sensor instrumentation, Guideway provides routing advice and emergency support.

I_2: Same as I_1 plus Guideway passive support for lateral vehicle guidance, advisories on road surface and hazards, possible continuous video monitoring of right of way.

I_3: Same as I_2 plus supporting lane change maneuvers and overall flow coordination at a local and network level, limits to operator/driver intervention capabilities appear, entry-exit responsibility/activities increase, system steady state operation designed for AHS traffic only.

I_4: Same as I_3 plus Platooning[4] , extremely complex and delicate activities in entry/exit,

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[4] Platooning was unofficially defined in the Interim Results Workshop as "very close" spacing, in the order of a few feet, requiring inter-vehicle communications and some form of mechanical, electromagnetic or "other" en-trainment to keep the vehicles in a stable formation. This definition is different from just "closer than today" vehicle spacing which can/will be achieved (safely) through reduction of the system reaction times and standardization of vehicle braking ability. Both have the potential to increase throughput and overall network capacity with platooning creating more dramatic changes but requiring significantly more complex system structure. Initial estimations show that under ideal conditions "close spacing" can achieve throughput of 3,000 to 6,000 vehicles per lane per hour while "platooning" can achieve throughputs approaching 10,000 vehicles per lane per hour. However both alternatives will have only moderate impacts to overall network capacity without special arrangements, substantial AHS market penetration, and modification in the entry/exit facilities. The latter is more critical as the throughput reaches several multiples of today's system lane capacities.

Table 1. Operating mode input matrix.

Operating & Demand Variables ↓ / Representative System Configurations →			Guideway Configuration: G1 (Mixed with Manual)				G2 (Separate Lanes for AHS)			
			Instrumentation Authority/Intelligence Distribution: I1		I2		I3		I4	
Speed	Spacing	Demand	Heavy Vehicle Strategy: M	S	M	S	M	S	M	S
Mod.	Long	D1	1	2	3	4	5	6	7	8
		D2	9	10	11	12	13	14	15	16
		D3	17	18	19	20	21	22	23	24
	Mod.	D1	25	26	27	28	29	30	31	32
		D2	33	34	35	36	37	38	39	40
		D3	41	42	43	44	45	46	47	48
High	Long	D1	49	50	51	52	53	54	55	56
		D2	57	58	59	60	61	62	63	64
		D3	65	66	67	68	69	70	71	72
	Mod.	D1	73	74	75	76	77	78	79	81
		D2	81	82	83	84	85	86	87	88
		D3	89	90	91	92	93	94	95	96

[ ] : Unlikely operating modes

operator/driver intervention at the panic button level only, intensive guideway instrumentation, possibly powered roadway and electric vehicles (EVs).

3. Heavy vehicle strategy (two options: Mixed - Separate).

Maximum operating speed is treated as an operating variable coupled with average vehicle spacing. Two maximum operating speed options (100 & 150 kph) are examined. Two average "spacing" alternatives are examined. The "moderate spacing" alternative is compatible with an older longitudinal control demonstration by PATH in San Diego [6] (average separation of 10 meters at 34 meters/second). Spacing on the average twice the size of "moderate spacing" is examined as an alternative (long) spacing variable value. It should be noted that in a more recent demonstration during the writing of this final report (8/94), 4 meter spacing was achieved with a much smoother ride quality. Three alternative travel demand scenarios (high, moderate, low) are investigated to capture the probable differences between the urban and rural environments.

In the case of a "separate" guideway it is very likely that at least two lanes (per direction) will be needed. The need for a continuous "second" lane is dictated for a variety of reasons including emergency stops, snow/debris removal and maintenance activities. It is furthermore suggested that the two lanes (per direction) be identical in technical characteristics and capabilities so that they are fully interchangeable. In this latter case they could both be used as regular lanes for short time period and/or segments as long as emergencies and maintenance or other needs are not present. This would greatly enhance overall AHS network capacity since very short (in time and/or space) bottlenecks frequently constrain such capacities. However, this need of design "by at least two" of separate facilities creates a high per kilometer cost and complications at interchanges that will be costly to absorb in rural areas and physically difficult to accommodate in urban ones. On the positive side, it provides some extra safety cushioning and several operational options that would not be available with only one lane. Safety enhancements may include trail vehicle switching lanes instead of braking in the cases of lead vehicle hard braking, and longer spacing in the cases of operating both lanes at low demand. Vehicle overpassing will also be available in the case of two lanes as well the capability to create sequences and/or platoons with compatible destinations. Separating the AHS equipped heavy vehicles will also be more feasible under this requirement. At this stage of AHS design development, the only "safe" method of quickly creating the platoons suggested for I_4 is through lateral merging and in order to have that capability outside the entry/exit facility, a continuous second lane is needed. Alternatively, platoons have to be created through high speed differentials (in the same lane), a potential safety hazard.

1.3 AHS Operating Mode Descriptions

The input matrix (table1) presents the AHS becoming more complex and advanced as we move from left to right and from top to bottom. As mentioned in the Instrumentation, Authority/Intelligence Distribution (I_x) outline, the introduction of separate AHS lanes almost coincides with the introduction of I_3. Manual traffic will be highly unlikely to be allowed in stage I_4. Attention is also suggested in the meaning of "platooning"[4]. Four AHS "eras" are up for evaluation, one for each I_x "instrumentation" stage. The exclusion/inclusion of heavy vehicles introduces an issue that is to be examined separately for each I_x. The two alternative speeds also create some variability within the same "instrumentation" group that needs to be evaluated.

Consequently the groups of cells that now need to be described and evaluated are the following:

Group Under I_1

Operating Mode Group O_{1M}[5] : Cells #1,9,25,33
Operating Mode Group O_{1S} : Cells #10,18,34,42
Operating Mode Group O_{1SF}: Cells #50,58,82,90

This operating mode group contains configurations similar to the highway system today plus automation of the longitudinal control of vehicle. Longitudinal control features include systems such as autobrake and autogap,[7] and/or AICC as described by Ioannou.[2] The longitudinal control systems provide the capability to reduce headways between vehicle and relieve the driver of tactical activities in velocity control such as throttle and braking for position keeping. Several scenarios for the staging of implementation are presented. The most likely one, supported by the latest industry developments calls for the introduction of Intelligent Cruise Control (ICC) first. ICC equipped vehicles will be able to follow a vehicle at a fixed time or space headway with a certain maximum speed restriction and only "soft braking" capabilities. Soft braking denotes that the driver will be responsible for hard deceleration maneuvers if needed. In the future, ICC is expected to be enhanced with a collision avoidance capability where the trail vehicle will perform the hard deceleration maneuver automatically when needed. There are some additional implicit assumptions that need to go into the calculation of the "safe" autogap. Assumptions include the vehicle speed differential and the braking capability differential between the lead and trail vehicles. Sample calculations in this area and resulting capacities are shown in section nine of this study. System reaction time is accepted to be a few tenths of a second (0.1 to 0.3 sec). Uncertainty in this area is the overhead that the malfunction analyses teams will add as a need for the redundant system(s) to react. Initial indications are that it will not be more than two tenths of a second. However, the initial question on the absolute value as well as the differential of braking capabilities between the lead and trail cars in the absence of inter-vehicle communications is a major one. Detailed analyses are needed to assess the safety boundaries for each combination of speed and braking capability differential, expressed in a minimum space or time headway. The time headway in turn, defines the theoretically maximum throughput system ability. Initial actual system capacities will be governed by "local" market penetration of the technology. The driver is still responsible for lateral control (steering) of the vehicle.

Group Under I_2

Operating Mode Group O_{2M} : Cells #11,19,35
Operating Mode Group O_{2S} : Cells #20,44
Operating Mode Group O_{2SF}: Cells #52,60,92

This operating mode group includes the addition of vehicle lateral control capabilities. It is expected that initially this will be performed through tracking of markers on or inside the pavement. Alternatives include magnetic and/or visual markers or reference points. Several tests and working installations (mainly for transit systems) at this stage, show that lateral control is technically feasible

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[5] Numbers in the subscript show the "I" stage to which the operating mode belongs.
Subscript M denotes heavy vehicles mixed with light duty vehicles in the same traffic stream. S denotes AHS activities in lanes where heavy vehicles are not allowed. For stages $_1$Iand I_2 where manual and AHS traffic are mixed the separation of heavy vehicles will occur through prohibition of the use of the one of two left lanes in facilities with more than two lanes in each direction. In the case of only two lanes in each direction it will not be feasible to separate heavy vehicles. This limitation is likely to reduce "S" combinations for rural cases in the initial I_1 and I_2 stages. This in turn is likely to reduce the likelihood of high speed capabilities in the rural cases where high speed is desirable.
Subscript F denotes high speed 150 kph (94 mph). Spacing and demand are not shown in subscript form.

and provides a smoother ride with more accurate tracking than manual steering. Difficulties and uncertainties arise when automatic lateral control is combined with automatic longitudinal control (even for steady state operations). Such uncertainties include the impacts of one activity automation on the other; like braking and acceleration initiatives while on a turn or a tracking correction; or the other way around. Another issue is that this combination of longitudinal and lateral control will be the first time that the driver is able to "retire" from all driving duties while system design requires him/her to be alert. Such concerns gave birth to the idea of prohibiting the ability to use both longitudinal and lateral control at the same time. This initial design will permit study of both systems and their potential interaction as well as human factors assessments on the ways to enforce driver alertness. This stage is initially expected to share lanes with manual driving which adds another level of uncertainty requiring driver alertness. Vehicle to roadway communication capabilities are recommended (but not required) in this phase and inter-vehicle communications would help reduce the traffic stream instabilities and braking capability uncertainty.

Group Under I_3

Operating Mode Group O_{3M} : Cells #13,37
Operating Mode Group O_{3S} : Cells #22,46
Operating Mode Group O_{3SF}: Cells #62,70,94

This operating mode group introduces the integration of longitudinal and lateral control systems to the point where complete maneuvers like lane changes, merging and weaving can be performed. It is likely that by this stage, the market penetration of AHS will be able to justify separated from manual traffic lanes. However, the system should be able to accommodate occasional manual vehicle introduced either by error or intention. Driver ability to take control of the vehicle will begin to be restricted and reactions will be limited to standardized emergency procedures or "emergency panic button" level alternatives. Substantial infrastructure changes will be required including the addition and/or conversion of lanes, the development of special entry/exit configurations, and considerable roadside instrumentation. Roadway to vehicle communications are required and inter-vehicle communications are also highly recommended/probable at this stage for maneuver coordination. Due to the high cost (capital and operating) of transition into I_3, - at least two AHS dedicated lanes in each direction, one regular and one emergency - deployment of this stage, particularly in the rural areas is likely to be quite slow.

Group Under I_4

Operating Mode Group O_{4M} : Cells #15,39
Operating Mode Group O_{4MF}: Cells #63
Operating Mode Group O_{4S} : Cells #24,48
Operating Mode Group O_{4SF}: Cells #64,72,96

This operating mode group introduces the more advanced AHS design. Although the exact system characteristics are currently under examination, it appears that in the cases of only one AHS dedicated lane, safety considerations may force platoons to be formed at the entry/exit facilities and formations kept constant during the enroute sections in the presence of high demand. This is actually one of the reasons designs of AHS lanes in "pairs" was suggested. High demand is assumed to be the reason for the switch from I_3 to I_4. In the cases of more than one AHS lane, platoon switching and formation could be achieved enroute as well. Platoon joining and braking will be performed through lateral merge of vehicles rather than longitudinal control maneuvers. Presently this appears to be a "safer" design. The driver reaction alternatives at this configuration will be at the "emergency panic button" level only.

Some evaluations are performed at "I_x" levels while others are performed at the "O_{xy}" or "O_{xyz}" level. Evaluation at a more desegregate level is applied wherever the variability within an "I_x" is such that creates significantly different results for different operating groups "O_{xyz}". The "average trip" for the "urban" AHS system is a home to work trip of approximately 24 kilometers (15 miles) each way requiring today approximately 30 minutes. Such trips are responsible for about half the vehicle kilometers (miles) in most urban environments and represent about one fourth to one third of the total number of trips. Non home to work trips (and "other") are more in number but are usually shorter and unlikely to be impacted by the introduction of AHS at least in the initial stages. Most of the statistical information about "urban" trips was deducted from the summary of a recent Southern California Association of Governments (SCAG) study using a 1991 survey to develop trip tables for the Los Angeles area. The "average" rural trip "today" is assumed to be intercity travel of 241 kilometers (150 miles) at an average speed similar to the "moderate" AHS speed. In the G1 configurations of mixed traffic, entry/exit facilities are assumed to be similar to what the freeway system has today. In the G2 configurations entry exit facilities are assumed to be spaced every three kilometers (two miles) in the urban areas, and every 16 kilometers (ten miles) in the rural areas.

1.4 Subtask Activity Descriptions

The project problem was analyzed by partitioning of the initial questions in subsets of issues. Depending on the task assigned, every group developed an analytical framework in order to address the issues raised in a systematic way and reach conclusions. Eventually, groups addressed the differences and similarities between urban and rural AHS deployments as viewed through the prism of the group-specific issues. The categories of issues studied are the following:

AHS impacts to users.
AHS impacts to society.
AHS and the TMCs.
AHS and CVOs.
Design Impacts of CVOs.
AHS and air quality.
AHS and the legal system.
Impacts of vehicle braking capability and potential AHS capacities.

As mentioned above, analytical frameworks (in each one of the affected areas) were developed in order to assess the various AHS operating mode impacts.

The impacts to users framework was based on the following variables:

Travel Time.
Actual Safety.
Perceived Safety.
Comfort.
Flexibility.
User Friendliness.

The above variables with their possible states and values are shown in table 2. Section three of the study documents the work performed by the impact to users group.

The group evaluating impacts to society developed the following evaluation dimensions:

Capacity - Potential Utilization.
Environmental Impacts:
- Meeting air quality goals.
- Land (wetlands, aesthetics, flora & fauna).
- Noise.

Table 2. Group A (Impacts to Users) output variables.

Variable	A	B	C	D	F
Travel Time (speed, mean travel time, reliability, and wait-to-go ratio)	145 kph (90 mph) on AHS U=21 min, R=161 min 5% variation 0 minutes wait	97 kph (60 mph) on AHS U=26 min, R=211 min 10% variation 1 minute wait	64 kph (40 mph) on AHS U= 30 min, R= >211 20% variation 2 minutes wait	32 kph (20 mph) on AHS U = > 35 < 40 min 25% variation 5 minutes wait	< 32 kph (20 mph) R = > 40 min > 20% variation > 5 minutes wait
Safety <u>Perceived Safety</u> (taking away user control, fail soft - fail safe) (Airbags, 8 kph (5 mph) bumper, and pre-entry validation check assumed for all configurations.) <u>*Actual Safety</u> [fatalities/injuries/damage per 1,609,000 passenger km (1,000,000 passenger miles)]	G2 Physical Barrier No Trucks in AHS Lanes Absolute Safety	G2 Physical Barrier AHS Trucks Only Allowed in AHS Lanes. Rail, Air and -90%	G1 Striped Barrier No Trucks, or AHS Trucks Only Allowed in AHS Lanes. -50%	Today's freeway with High Occupancy Vehicle (HOV) lane Today's freeway and surface streets	Worse than today Worse than today
Comfort (rate of change of acceleration)	Intercity Rail 1994 PATH Demo	1991 PATH Demo	Today's freeway and surface streets	Today's freeway with HOV lane access/egress in peak period Urban rail	
Flexibility (ability to make mid-course corrections, number of minutes to leave AHS or to change destination)	1 minute	2 minutes	3 minutes	5 minutes	>5 minutes
User Friendliness (easy to learn, easy to use, no fight for access)	1 button fully automatic	**semi-automatic normal = automatic event = alarm to manual situation = revert to manual	assisted manual intelligent cruise control manual steering	Today's freeway and surface streets	Worse than today

* Proposed rating for use when actual AHS safety statistics become available.

** AHS is fully automatic under normal conditions. In the event of a system or vehicle emergency, AHS will provide an alarm to alert the driver, and the vehicle will revert to manual control. A driver can also choose to revert to manual control if desired.

Business & Economy:
- Local job creation (temporary & permanent).
- Increased business productivity (narrow or broad-based).
- Tax revenues (fuel, sales, tolls).

Equity:
- Cost of personal travel.
- Service to travel needs of rich & poor.

Feasibility & Acceptability:
- Technical feasibility.
- Institutional feasibility (institutional, insurance & liability implications).

Groups of cells of the operating matrix were then evaluated with a delphi process for potential AHS performance on a -10 to +10 scale with 0 being the system performance today. The group included two very experienced highway operations and design consultants, two university professors specializing in transportation and one graduate student of the transportation engineering program with a legal background. Detailed results and conclusions are included in section four of the study.

Additional variables were introduced to analyze form and function of the Transportation Management Centers (TMCs). The variables can be grouped as follows:

Control activities (vehicle control, inter-vehicle coordination, vehicle management, traffic flow management and incident management).
Location of activity (on-board, at the zone level, and /or regional level control center).

The group proceeded in defining TMC operational requirements for all stages of AHS and then looked into the possible evolution scenarios in the urban and rural environments. Detailed description of TMC requirements and impacts on the AHS are included in section two of the study.

In the area of CVOs, two separate analyses were attempted. One deals with the size of the industry and the potential for industry changes due to the introduction of the AHS, and the second looks at the design changes (augmentations) required in order to accommodate heavy vehicles in the shape and form that they present themselves today. The industry structure analysis is performed at the macroeconomics level and the design analysis looks mainly at vehicle sizing, weight and performance capabilities. Detailed descriptions of industry status and vehicle data are included in sections five and six of the study.

In the area of vehicle emissions and air quality, the team started from a big picture investigation. Recent changes in vehicle emissions and how that impacts air quality were later researched. It was quickly determined that air quality is influenced by a wide variety of other factors which are not likely to be changed through the deployment of AHS. To address the impacts of potential speed changes, the team conducted a conversion of current model inputs used for emissions calculation in the Los Angeles region. One moderate and one aggressive average AHS speed profile description were developed. The sequence of model runs as developed by the California Department of Transportation (Caltrans) and the California Air Resources Board (CARB) was replicated for the AHS speed scenarios. Results, further details about the assumptions, and impacts on the rural/urban debate are included in section seven of the study.

Three areas were chosen for investigation on legal issues and AHS :
Product liability.
Negligence.

Governmental immunity.

After an introductory literature search on the issues raised around these concepts in previous highway related cases, an effort was made to picture some parallel situations stemming from AHS operations. Finally the team attempted to compare potential urban versus rural cases (on the above mentioned areas) in terms of frequency and difficulty to handle. Further literature details are included in section eight of the study.

According to the initial discussion on the AHS stages, a lot rides on capacity improvements as well as accurate estimation of safe separation distances between vehicles. After a moderate literature search it was found that significant work needs to be performed in the area of real time estimation of the vehicle braking capabilities. This work should identify methodologies and sensors measuring the maximum friction that the tires are able to achieve during all phases of deceleration, and the vehicle's ability to identify and perform this “optimum” braking maneuver. At this stage, very little published work is available in this area. It is possible that proprietary vehicle manufacturer information exists. Friction coefficients included in published calculations are averages when indeed it is known that they are speed dependent. Besides the fact that experimental data is scarce, in the case of a speed dependent friction coefficient the braking capability calculations are a little more complex. An effort was made with the best available at this time data, to show the methodology that will accurately estimate real time differential braking capabilities for a variety of lead-trail combinations and system reaction times. Corresponding lane capacities were also estimated. A complete presentation of the analysis resides in section nine of the study.

Finally section 10 of the study attempts to group conclusions and address the project questions in a global way. Similarities and differences in sections two through nine, and common conclusions and results are identified. The rural versus urban AHS debate is brought once again in the forefront of discussion and concluding remarks on the likelihood/feasibility of exclusive and common systems are recorded.

2. ROLE OF TRANSPORTATION MANAGEMENT CENTERS

2.1 Introduction

In approaching the general issue of AHS development and the role of supporting command and control components in urban verses rural environments, it was necessary to identify and review key concepts in this evolving transportation system. The concepts examined in this preliminary exercise touched on many functional issues including remote surveillance, vehicle control/coordination, flow management/optimization, emergency/maintenance crew dispatch, control center design/staffing, toll collection, enforcement, commercial vehicle operations, exit/entry operations, and incident anticipation/avoidance/response, as well as many technical issues including degrees of automation, artificial intelligence, communications architecture, intelligence distribution, and system redundancy. This list is not meant to be inclusive of all issues related to AHS command and control, but is meant to be representative of the types of functional and technical issues considered in the ensuing analysis. It should also be mentioned that the analysis is not aimed at solving the technical challenges of AHS TMS's but merely providing a qualifier for the urban/rural comparison.

2.2 Methodology: Modeling the Evolution of the AHS Command & Control Component (CCC)

During the course of this research, a variety of approaches were considered. One approach focused on defining the AHS in terms of operating mode characteristics such as speed, spacing, demand, etc.; another reflected a system-theoretic perspective that examined the problem in terms of system inputs, dynamics, and outputs; a third was oriented primarily toward desired characteristics such as smooth traffic flow, expedient mayday handling, safety preservation, etc.; and a fourth addressed only communications processing requirements such as bandwidth, network structure, and network depth.

The evaluation methodology actually adopted in this study builds directly upon the AHS command and control discussion outlined in a paper authored by William B. Stevens,[8] "The Use of System Characteristics to Define Concepts for Automated Highway Systems" and their relation to the five AHS evolutionary stages described herein. This approach was selected as being most appropriate for the analysis of AHS TMC roles and responsibilities because it explicitly addresses the evolution of key command and control functions. Stevens' focus is on AHS Command and Control, where he identifies five command and control functions:

Vehicle Management.
Vehicle Control.
Inter-vehicle Coordination.
Traffic Flow Management.
Incident Management.

The analysis will show that as the AHS evolves, the implementation of each command and control function also evolves. The five command and control functions have been somewhat adapted for the purposes of the present study and are defined below in the precise form that guided the analysis.

Vehicle Logistics:
This is the function of monitoring vehicle fluid levels and electro-mechanical performance; asserting driver entry, exit, and lane change requests; and assessing the need for service, repair, pre-destination

refueling, operational adjustments (turn lights on/off, shift up/down, dis/engage autogap, etc.), or an emergency stop. Note the distinction between these logistical activities and the sensing and actuating activities listed under the vehicle control function to follow.

Vehicle Control:
This is the function of sensing the vehicle's lateral and longitudinal position and directing the vehicle's throttle, brake, and steering actuators to maintain the desired position or perform the desired entry, exit, merge, lane change, or halt maneuver.

Inter-vehicle Coordination:
This function involves tracking the relative positions of neighboring vehicles, monitoring and responding to their impending movements, identifying merging, exiting, and lane changing opportunities, and developing "control profiles" for the vehicles involved in the intended maneuver. Once developed by the inter-vehicle coordination function, control profiles are transmitted to the vehicle control function for execution. Subsumed under this function is the detection of impending incidents (example: wandering vehicle or unauthorized vehicle downstream), the development of evasive "control profiles" for affected vehicles, and the transmission of a potential incident notification to the TMC.

Flow Management:
This function involves sensing current flow conditions, monitoring conditions that may impact traffic flow (the environment, roadway impediments, system/vehicle malfunctions, special events, etc.) and adjusting the traffic flow parameters (speed per lane segment, vehicle/platoon spacing, lane use/merging restrictions, etc.) that govern the development of control profiles.

Incident Response:
This is the function of identifying potential incidents, verifying the nature and location of actual incidents, deploying emergency responders/resources to verified incidents, disseminating motorist information and media advisories, clearing incidents, and restoring traffic flow.

Stevens also identifies three command and control processing locations: on-board the vehicle, at the zone roadside, and in the regional control facility, or TMC. The team elected to segment the command and control component even further by identifying the two operating modes by which command and control functions can be executed: manual and automated. Manual execution involves the active human involvement (possibly aided by a computer), while automated execution has no human presence (except in handling system failures.)

The team next developed a configuration matrix that encompasses all of these facets of AHS command and control. This matrix is termed the Command and Control Functional Distribution Matrix (CCFDM) and is shown in table 3 below. When the matrix is completed, it offers a quantitative representation of the CCC configuration for a given AHS evolutionary stage.

Table 3. Command and control functional distribution matrix.

	Vehicle Logistics	Vehicle Control	Inter-vehicle Coordination	Flow Management	Incident Response
On-Board the Vehicle					
Manual	-	-	-	-	-
Automated	-	-	-	-	-
At the Zone Roadside					
Manual	-	-	-	-	-
Automated	-	-	-	-	-
In the TMC					
Manual	-	-	-	-	-
Automated	-	-	-	-	-
Total	100	100	100	100	100

Matrix cell entries obey the constraint that the sum of the numbers in each matrix column is equal to 100; thus the cell entries may be regarded as percentages[1] For example, in describing the vehicle control function of a given AHS evolutionary stage, the team determined the percentage of vehicle control executed in a manual fashion on-board the vehicle, the percentage of vehicle control executed in an automated fashion on-board the vehicle, the percentage of vehicle control executed in a manual fashion at the zone roadside, and so on, such that the sum of all the cells in the vehicle control column equals 100 percent. In making these determinations, the team felt it was important to consider these functions strictly as defined in this report.

2.3 Five Stages of Evolution: Definitions

AHS deployment is evolutionary and concerned with the successive introduction of increasingly more powerful enhancements of today's cruise control, beginning with autobrake and autogap, and ultimately advancing to a fully-automated highway system complete with dedicated AHS lanes, automatic

[1] Please note that the values entered by different evaluators in the matrix could vary. Such variations are not in principle inconsistent with the overall level of accuracy governing operating mode specifications at this stage.

lane-changing, and platoon formation. The CCC evaluation process individually addressed each AHS evolutionary stage as described below.

Stage I_0		Today
Stage I_1	Intelligent cruise control (ICC)	Autobrake/Autogap
Stage I_2	ICC and lateral position holding	Autolane
Stage I_3	Stage I_2, w/dedicated lanes & auto lane change	Dedicated Autolane
Stage I_4	Stage I_3, w/platooning	Platooning

Completed matrices for each of these AHS evolutionary stages are provided, and examined in detail in the following section. The numerical entries in these matrices can be put to a variety of uses, typically indicating trends in AHS development and in command and control attributes. For example, a configuration that appears to be equally dispersed across all three processing locations carries with it different implications in terms of the required communications architecture than does a configuration in which most of the processing takes place on-board the vehicle. The former case suggests a mature, distributed architecture while the latter case suggests an architecture in which infrastructure enhancements are minimal and in which essentially all technological improvements are within the in-vehicle systems themselves. Graphs can be drawn for given matrix entries over several stages of evolution, yielding qualitative information about patterns of involvement at different processing locations.

2.4 Discussion of Stages I_0-I_4

The resulting CCDFMs are shown on the following pages. The matrices for each stage are accompanied by descriptions that address the rationale behind the numbers shown in the matrix; the implications of the resulting configuration with respect to TMC roles, responsibilities, and requirements; and the implications of the resulting CCC configuration with respect to urban versus rural AHS deployment. The TMC discussions also cover issues of staffing, equipment, and field resources.

2.4.1 Stage I_0: Today

I_0 describes today's highway system which includes vehicle automation only in the form of standard cruise control. The role of the driver is dominant and traffic control is widely distributed.

Table 4. CCFDM for Stage I_0.

	Vehicle Logistics	Vehicle Control	Inter-vehicle Coordination	Flow Management	Incident Response
On-Board the Vehicle					
Manual	90%	90%	100%	30%	20%
Automated	10%	10%	0%	0%	0%
At the Zone Roadside					
Manual	0%	0%	0%	10%	60%
Automated	0%	0%	0%	40%	0%
In the TMC					
Manual	0%	0%	0%	10%	10%
Automated	0%	0%	0%	10%	10%
Total	100 %	100%	100%	100%	100%

Vehicle Logistics:
In I_0, the automation of vehicle logistics is limited (10 percent) to in-vehicle gauges that display measurements of vital parameters (gasoline supply, engine temperature, battery charge, vehicle speed, revolutions/minute, distance traveled, etc.) and/or diagnostic indicator lights. The driver (90 percent) is responsible for monitoring a host of other on-board systems, preventing/assessing/correcting vehicle malfunctions, and initiating vehicle maneuvers.

Vehicle Control:
Automated control activity on-board the vehicle in I_0 is limited (10 percent) to cruise control features that maintain constant speed. The driver (90 percent) is responsible for sensing lateral/longitudinal position and directing the actuators to maintain the desired gap and lateral position and to perform the desired maneuver.

Inter-vehicle Coordination:
Drivers are solely responsible (100 percent) for all inter-vehicle coordination including tracking the relative positions of neighboring vehicles, identifying merging, exiting, and lane changing opportunities, and plotting safe, smooth lane change/merge profiles, and detecting/evading impending incidents.

Flow Management:
Most flow management (40 percent) stems directly from stated traffic regulations (right-of-way rules, maximum speed limits, lane use restrictions, etc.) which operate automatically from the roadside via lane markings, signals, and signs. A small portion (10 percent) can also be attributed to patrolling police officers who manually enforce traffic laws or field personnel that direct problem traffic (example: low visibility speed reduction). A larger portion (30 percent) reflects the driver's responsibility for adhering to vehicle codes, signs/signals, and police direction and the driver's ability to freely control vehicle movement while remaining within these formal constraints. Some flow

management activity takes place in the TMC which remotely monitors current flow patterns (10 percent) and can manually adjusts ramp metering rates (10 percent).

Incident Response:
Some incident response activity (20 percent) involves only on-board drivers who detect and clear minor incidents themselves. Most incident response activity (60 percent) involves either a third party passing motorist who reports the incident and/or emergency responders who are dispatched to the roadside scene to manually verify, respond, clear, and restore. The TMC automatically detects some incidents before they are otherwise reported (10 percent) and helps to restore traffic flow by dispatching response teams to protect against secondary incidents and by disseminating motorist information to divert traffic away from the problem area (10 percent).

TMC Roles/Responsibilities:
Many of today's large, urban TMCs are jointly staffed by engineers or technicians from the State Department of Transportation (DOT) traffic operations branch, traffic or media information officers from the State Highway Patrol, and/or dispatcher supervisors or clerks from the DOT maintenance branch. The number of operators on duty during typical morning or afternoon peak periods is seven to nine and includes one supervisor, one or two engineers and/or technician, one or two radio dispatchers, one or two media information officers, and two to three on-call field units. Note that the majority of these individuals have little more than a high school education. The number of operators on duty during a crisis situation may be more than twice the typical staffing level while the number of operators on duty during the evening off-peak period may be less than half of the typical staffing level.

The TMCs are usually equipped with a host of "high-tech" computer, display, and communications equipment. Due to the rapid changes in technology, one sometimes finds a mix of incompatible equipment, as Government resources cannot keep up with available technological improvements. Common inputs to these systems include traffic detectors, closed-circuit television cameras, radio scanners, computer aided dispatch terminals, commercial television, patrolling personnel, and motorist phone calls. In many facilities, graphic, map-based display systems are used to depict flow conditions and locate potential incidents.

The majority of TMC outputs are tools of the facility's own motorist information system. These tools include stationary and/or portable Changeable Message Signs (CMSs) that can display short advisory or regulatory messages, stationary and/or portable Highway Advisory Radio (HAR) transmitters that can broadcast detailed advisories on the AM and FM radio bands, and fax machines that disseminate incident advisories to key media organizations.

A smaller portion of TMC outputs are tools of the incident response system. These control tools include on-call Traffic Management Teams (TMTs) that can be deployed to prevent secondary incidents from occurring; maintenance crews who can be dispatched to clean up a spilled load, shut down a lane, or mark off a detour; and tow trucks that can be called out to remove disabled vehicles.

An even smaller portion of TMC outputs are tools of the traffic management system; the TMC's ability to adjust ramp metering rates is severely limited because onramp flow restriction can adversely impact the surrounding surface streets.

Above all else, today's TMCs are responsible for mitigating the impact of planned and unplanned freeway closures on the overall transportation system. To mitigate the impact of an accident induced lane closure, TMC operators strive to reduce the duration of the closure, in part, by doing what they can to expedite response and cleanup activities. To mitigate the impact of any closure, TMC operators strive to reduce the duration of the traffic recovery period that lags after incident removal. The amount of time required for the traffic to fully recover is a function of the volume of traffic trapped behind the incident scene when the incident is cleared. This volume can be kept low by taking steps to divert traffic away from the problem before it becomes part of the problem. These steps typically include posting "accident ahead" messages on upstream CMSs, broadcasting alternate route information on the HAR, deploying TMTs, and issuing incident advisories to the various radio and television stations in a timely manner.

Urban/Rural Issues :
Standard cruise control requires no special roadway infrastructure and operates as easily in rural as in urban environments. Standard cruise control does not, in itself, impose any urban/rural AHS CCC distinction. Because rural highway operations are less complex than most urban operations, and because it is often less cost-effective to instrument rural areas with the necessary supporting infrastructure, most rural highways operate without the assistance of a TMC. Those TMCs that do operate in rural environments focus primarily on environmental and roadway hazard response rather than on congestion mitigation. Remote incident detection and rapid incident response are also key issues in less traveled and more remote rural areas.

2.4.2 Stage I_1: Intelligent cruise control (autobrake/autogap)

I_1 introduces autobrake and autogap, but no autolane facilities or further forms of vehicle control. Its primary enhancements are therefore in-vehicle ones and the role of the driver is still significant, if diminished somewhat with respect to maintaining longitudinal spacing.

Table 5. CCFDM for Stage I_1.

	Vehicle Logistics	Vehicle Control	Inter-vehicle Coordination	Flow Management	Incident Response
On-Board the Vehicle					
Manual	80%	75%	90%	25%	20%
Automated	15%	25%	10%	5%	0%
At the Zone Roadside					
Manual	0%	0%	0%	10%	60%
Automated	0%	0%	0%	40%	0%
In the TMC					
Manual	5%	0%	0%	10%	10%
Automated	0%	0%	0%	10%	10%
Totals	100%	100%	100%	100%	100%

Vehicle Logistics:
Automated on-board vehicle logistics is expanded in I_1 (15 percent) to reflect more in-vehicle gauges/lights that more closely monitor a greater number of parameters and systems, including the autogap function. The driver (80 percent) is still responsible for monitoring and maintaining

secondary systems; responding to all malfunctions; and asserting entry, exit, and lane change requests. There could be situations where TMC operators manually instruct drivers (five percent) to disengage autobreak/autogap via HAR/CMS (example: traffic approaching a major incident).

Vehicle Control :
In I_1, automated control activity on-board the vehicle is expanded (25 percent) to include the sensing of position relative to the lead vehicle, and the direction of the throttle and break actuators to maintain longitudinal positioning and avoid frontal collisions. The driver (75 percent) is still responsible for sensing/maintaining lateral positioning and performing desired and evasive maneuvers.

Inter-vehicle Coordination:
Driver responsibility for inter-vehicle coordination is diminished in I_1 (90 percent) by the autogap/autobreak feature which tracks the relative position of the lead vehicle and responds to its movement. The driver is still responsible for tracking the relative positions of all other neighboring vehicles; responding to their movements; identifying merging, exiting, and lane changing opportunities; plotting safe, smooth lane change/merge profiles; and detecting/avoiding impending incidents.

Traffic Flow Management:
In I_1, manual flow management activity on the part of the driver is reduced (25 percent), and automated on-board flow management is increased (five percent) to reflect the vehicle's preservation of safe following distances. All else is unchanged.

Incident Management:
No changes to the incident management function due to I_1 autobreak/autogap features are anticipated.

TMC Roles/Responsibilities:
The purpose of I_1 TMC is essentially the same as that of today's TMC. The impact of autobrake/autogap is strictly local to the vehicle itself and, although it affects traffic flow and spacing, the TMC plays no direct role in implementing these features. In terms of vehicle logistics, the TMC might well manually inform vehicle drivers (via radio, fixed/portable CMS, etc.) to disengage autobrake/autogap in certain locations or when unusual circumstances arise (example: an incident); this added function is numerically reflected in the matrices as a five percent contribution, under manual vehicle logistics activity from the TMC.

The staffing of I_1 TMC is the same as for today's TMC, but additional training may be required for TMC personnel to allow them to understand when autobrake/autogap needs to be disabled. The equipment is also largely the same, because the inputs, information outputs, and control outputs are unchanged.

Urban/Rural Issues:
I_1 AHS enhancements do not require any special infrastructure improvements, and thus are as easy to implement in a rural environment as in an urban one. The safety issue of greatest concern in both settings are rear-end collisions where the autobrake feature of an appropriately equipped lead vehicle responds more quickly than the driver of the trailing unequipped vehicle when the need for an emergency stop arises.

2.4.3 Stage I_2: ICC and lateral position holding (autolane)

I_2 includes autobrake and autogap, as well as autolane facilities (passive lateral control). Its enhancements are still in-vehicle ones, and the role of the driver is still significant, if diminished somewhat with respect to maintaining longitudinal spacing and lateral control within a lane. The driver still needs to change lanes and make other maneuvers independently.

Table 6. CCFDM for Stage I_2.

	Vehicle Logistics	Vehicle Control	Inter-vehicle Coordination	Flow Management	Incident Response
On-Board the Vehicle					
Manual	60%	50%	80%	20%	20%
Automated	30%	50%	20%	10%	0%
At the Zone Roadside					
Manual	0%	0%	0%	10%	50%
Automated	0%	0%	0%	25%	10%
In the TMC					
Manual	10%	0%	0%	15%	10%
Automated	0%	0%	0%	20%	10%
Totals	100%	100%	100%	100%	100%

Vehicle Logistics:
Automated on-board vehicle logistics is expanded in I_2 (30 percent) to reflect the likely evolution of vehicle intelligence that will not only assist the driver in monitoring key parameters and on-board systems, including autolane, but will also diagnose electro-mechanical difficulties, identify appropriate operational adjustments/corrective actions, and possibly self-correct minor vehicle malfunctions or operating deficiencies. On-board traveler information systems (navigation, traffic information, etc.) will help the driver select the appropriate lane change and exit locations. The driver will still be responsible (60 percent) for handling most correction, service, and repair needs and initiating all vehicle entry, exit, and lane change maneuvers. The role of the TMC is further expanded (10 percent) to reflect those special instances where control center operators instruct drivers to disengage their autolane, possibly in conjunction with their autogap system.

Vehicle Control:
In I_2, automated control activity on-board the vehicle is further expanded (50 percent) to include the sensing of lane boundaries and the direction of steering actuators to maintain lateral positioning. The driver (50 percent) is still responsible for executing all desired entry, exit, merge, and lane change maneuvers. Because autogap and autolane both behave as autonomous vehicle actions, the role of the roadside and the regional control center with respect to vehicle control remains unchanged from the previous stages.

Inter-vehicle Coordination:
The role of automated inter-vehicle coordination on-board the vehicle is expanded in I_2 (20 percent)

to reflect the likely evolution of proximity sensors that alert the driver that his safe zone has been violated by a vehicle or obstacle, thereby helping the driver to avoid collisions, especially during entry, exit, merge, and lane change maneuvers. The driver (80 percent) is still responsible for plotting safe, smooth lane change/merge profiles, responding to the movements of neighboring vehicles, and evading impending incidents. Because autogap and autolane both behave as autonomous vehicle actions, there is no inter-vehicle communication, and the role of the roadside and regional control center with respect to inter-vehicle coordination remains unchanged from the previous stages.

Flow Management:
Manual flow management on the part of the driver is reduced in I_2 (20 percent) and automated on-board flow management is increased (10 percent) to reflect the vehicle's preservation of lane position in addition to a safe following distance. It is also expected that, with the introduction of variable speed limit signs and traffic responsive ramp metering (now integrated with surface street signal timing systems), that a portion of the traffic regulation function will become automated and be brought into the TMC. This will decrease the automated roadside flow management activity (25 percent), increase the automated TMC flow management activity (20 percent), and provide for more manual intervention on the part of TMC operators (15 percent).

Incident Response:
In I_2, automated incident response at the roadside is increased (10 percent) and manual roadside incident response is decreased (50 percent) to reflect the likely evolution of mayday systems that would perhaps utilize roadside call boxes to pick up emergency distress signals triggered by on-board mayday systems and initiate emergency response. There are no changes due to autolane alone.

TMC Roles/Responsibilities:
I_2 TMC is largely similar to I_1. The impact of autolane/autobrake/autogap is strictly local to the vehicle itself, and although it affects traffic flow and spacing, the TMC plays no direct role in this. In terms of vehicle logistics, the TMC might manually inform drivers (via HAR, CMS, or even in-vehicle traveler information systems) to disengage autolane and/or autobrake/autogap in certain locations or under certain circumstances; this added function is numerically reflected in the matrices as an additional five percent contribution, under manual vehicle logistics activity from the TMC. Note that the driver is still ultimately in control, with the ability to override any of the automated features of I_2.

The staffing of I_2 TMC is the same as for today's TMC, but additional training may be required for TMC personnel to allow them to know where and when autobrake/autogap needs to be disabled and how to best utilize their new flow management tools. The equipment is also largely the same, because the inputs, information, and control outputs are largely unchanged. A variable speed limit sign is simply a special form of a CMS and the ramp metering equipment was previously present, although underutilized. More advanced field sensors and surveillance cameras will simply replace those that were previously in place. And while some TMC operations will undoubtedly become more automated, most computer-devised actions will be presented for operator acceptance before they are executed.

Urban/Rural Issues:
I_2 AHS enhancements in and of themselves do not require any special infrastructure improvements, save for the passive lane markers. Safety benefits will be realized in both urban and rural settings by reducing the number of instances where drivers allow their vehicles to inadvertently wander outside their lane causing them to collide with an adjacent vehicle or run themselves off the road. This later feature is expected to reduce rural accidents in particular with corresponding reduction in emergency response needs.

2.4.4 Stage I_3: ICC and autolane with dedicated lanes and automated lane changing

In I_3 of the AHS evolution, separate AHS guideways are introduced. As stated earlier in this report, it is assumed that dedicated AHS guideways will be introduced not as single lane facilities, but as lane pairs, thereby allowing automated lane changing. It is likely that, in urban areas, these dedicated AHS facilities will bring increased roadway instrumentation along with more distributed communications and control systems and greater participation on the part of the zone roadside controller and the TMC. A variation on this deployment concept for less developed rural regions is also presented.

Table 7. CCFDM for Stage I_3 - In a urban setting.

	Vehicle Logistics	Vehicle Control	Inter-vehicle Coordination	Flow Management	Incident Response
On-Board the Vehicle					
Manual	20%	10%	5%	0%	0%
Automated	60%	70%	60%	15%	0%
At the Zone Roadside					
Manual	0%	0%	0%	0%	40%
Automated	0%	10%	15%	50%	20%
In the TMC					
Manual	10%	0%	10%	10%	20%
Automated	10%	10%	10%	25%	20%
Totals	100%	100%	100%	100%	100%

Vehicle Logistics:
Automated on-board vehicle logistics is expanded in I_3 (60 percent) to reflect not only the further evolution of on-board intelligence, but also new vehicle capabilities in initiating automated lane change and merge maneuvers as the vehicle negotiates its way to the desired destination. The driver will still be responsible for some operational corrections and for initiating some entry/exit/lane change maneuvers (20 percent). It is likely that the roadside infrastructure enhancements that will

accompany the use of dedicated AHS facilities, will allow the TMC to monitor in-vehicle equipment (10 percent) and road side/surface conditions so that it may obtain and process information about relevant vehicle characteristics, such as weight, stopping power, acceleration capabilities, maneuverability, and so on.

Vehicle Control:
Automated control activity on-board the vehicle is further expanded in I_3 (70 percent) to include the direction of steering, throttle, and breaking actuators to execute lane change and merge maneuvers. The driver (10 percent) will be involved in the AHS facility entry and exit process and in resuming vehicle control when major problems arise. Assuming the I_3 roadside infrastructure will have the capability to sense individual vehicle position and detect abnormal vehicle movement, the role of the roadside controller in this activity will increase (10 percent) and it is also likely that the TMC will have some responsibility for remotely monitoring these activities (10 percent), providing global information and strategic instructions that can influence vehicle control.

Inter-vehicle Coordination:
With the enhanced roadside infrastructure providing the communications coordination that allows interacting vehicles to communicate with one another and receive local/global condition information, the role of automated inter-vehicle coordination among vehicles in a cluster is greatly expanded (65 percent). The data exchange process should allow a vehicle to track the relative positions of all neighboring vehicles; monitor and respond to their impending movements, identify merging, exiting, and lane changing opportunities; and develop safe, smooth "control profiles" for each maneuver. It is assumed that this data exchange process will utilize the roadside controller as the communications hub through which all nearby vehicles exchange information about the current and planned trajectories. While each vehicle is responsible for executing their own planned movement, each vehicle is also responsible for adjusting their movement to coordinate with the current and impending movements of others.

The roadside controller will also track the relative positions and impending movements of all nearby vehicles and will modify control profiles to negotiate traffic around planned/unplanned lane closures downstream when the need arises to prevent abnormal vehicle interaction; thereby bringing some (15 percent) inter-vehicle coordination to the roadside. With these elements of inter-vehicle coordination also operating from the roadside, the AHS should be able to respond to these unusual events more intelligently and adapt more smoothly. Remote monitoring (10 percent) and manual intervention (10 percent) over these activities from the TMC is also expected. The additional information available from the global perspective of the TMC should provide additional benefits in preserving smooth AHS operation.

The distribution of activity between the driver, vehicle, roadside, and TMC described above is one where the role of the driver is dramatically reduced. Once the vehicle is fully engaged on the automated highway facility, the vehicle assumes full responsibility for all automated movement during normal operating conditions; the roadside infrastructure monitors local operation and initiates control profile adjustments when abnormalities are detected, and the TMC provides global oversight over system operation, intervening only occasionally with vehicle movement through the roadside controller.

Flow Management:
Overall flow management will be automated and will be handled by the regional control center (25

percent). On a system-wide basis, the regional control center will remotely monitor traffic flow patterns, survey system-wide conditions that may impact traffic flow, and communicate the required adjustments to regional flow parameters to the appropriate roadside controllers. Some manual intervention (10 percent) is anticipated on the part of TMC operators who will also be responsible for overseeing operations at the check-in, check-out, and toll collection points as part of their demand management and violator detection functions. Within the constraints set by the regional control center, local flow management will be automated and will be handled by the roadside controller (50 percent). On a regional basis, the roadside controller will monitor local traffic flow patterns, survey conditions that may impact traffic flow, and communicate the required adjustments to local flow parameters to the vehicles and check-in controllers. The roadside communicates to the vehicles such parameters as speed per lane segment, vehicle spacing, lane use/merge restrictions. Within the constraints set by the local roadside controller, individual vehicle speed and spacing will be handled by the vehicle (15 percent). The roadside will also communicate demand management parameters to the check-in controllers to meter or otherwise restrict vehicle access when necessary.

Incident Response:
The anticipated buildup of electronic and video roadway surveillance that are expected to accompany I_3 infrastructure enhancements will further expand (20 percent) the TMC's role in remote roadway hazard and incident detection/verification. Likewise, the oversight and intervention capabilities of the individual roadside controllers and TMC operators with respect to the development of evasive control profiles will enable better incident anticipation and more centralized incident management activity. These will expand the automated incident response activity of the roadside controllers (20 percent) and the manual incident response activity of TMC operators (20 percent). On the dedicated guideway, it is doubtful that any incidents will be handled without third party assistance, thereby decreasing (0 percent) manual on-board incident response. Roadside incident response activity on the part of emergency responders (40 percent) will see some changes in I_3, as emergency response vehicles will have to access the automated highway facility and possibly interrupt AHS operations. Accessing the dedicated AHS guideway itself may require special response vehicles that can bypass the separation barrier.

TMC Roles/Responsibilities:
In addition to its role in I_0 to I_2, I_3 TMC now is also needed to coordinate operations with zone roadside controllers, which in turn coordinate operations with in-vehicle controllers. The TMC must provide global supervision over the inter-vehicle coordination and flow management activities taking place at both locations. Its charge is to preserve driver safety, enhance flow performance, and respond to incidents and other asynchronous events. The TMC will be responsible for global monitoring of all AHS operations, to ensure that all networked levels of systems are functioning properly and effectively communicating with one another. To do this, the TMC must be able to coordinate the monitoring, calibration, and maintenance of the zone roadside controller equipment and must also be able to monitor in-vehicle equipment and coordinate the maintenance of such equipment.

The TMC will engage in both short-term responses as well as long term planning. I_3 TMC makes use of high technology sensors and actuators and the execution of sophisticated algorithms to handle both steady state and asynchronous modes of operation. With more sophisticated detection devices on the vehicle and at the roadside, and a greater coordinating role in the TMC itself, more powerful equipment (hardware and software) will be needed in I_3 TMC. Emergency response capabilities dictate that backup systems (especially in case of power failures) be present. Newer technologies that encompass expert systems and/or neural networks may come into play, with features that allow the AHS management system to be trained and to learn from experience. Sophisticated, integrated, human-computer interaction will be prevalent and data networking will begin to manifest itself, with communication packets arriving at I_3 TMC from roadside and in-vehicle sensors via a network of zone controllers.

Due to the high degree of automation, many low-level staffing functions will disappear in the evolved TMC. However, such increased automation leaves open the possibility of potentially disastrous failures. People need to be present to be responsible for flow management, equipment malfunctions, and incident response. While staff size may not need to increase beyond that which is typical of a peak period I_0 TMC, minimal staffing will be required around the clock, and the majority of the team members must possess expert level skills and have completed extensive training. Economic and political factors may dictate the entrance of the private sector into I_3 TMC. There will also be a great need for on-call experts in computer, network, and sensor technologies to ensure proper operation and functional backup systems.

Urban/Rural Issues:

Many of the functional descriptions contained in this section assume that substantial roadway and TMC surveillance and control infrastructure enhancements will accompany the installation of dedicated AHS guideways. The proposed configurations of these command and control functions take advantage of that infrastructure and distribute portions of the control activity among them in ways that may not be possible in lesser developed rural regions. The reason for centralizing portions of the inter-vehicle coordination activities at the roadside controller and/or TMC is that the AHS will be able to initiate more intelligent, adaptive vehicle maneuvers, rather than resorting to crude, reactive full motion halt or autogap/autolane disengage commands, in response to unexpected events. Such infrastructure also supports more efficient traffic flow optimization and more expeditious incident detection and response. A mature roadside and TMC infrastructure provides a more complete picture of all local and global activity for better decision-making and allows more intimate vehicle-to-roadside interaction for more refined control. While a lesser developed infrastructure can easily support the basic functionality of I_3 AHS, it would have to operate less intelligently, and therefore would likely be subject to more frequent and more prolonged interruptions. A CCDFM for I_3 AHS that might operate in a rural setting is presented in table 8. This matrix transfers TMC-based activity to the vehicle and/or the baseline roadside infrastructure required to allow I_3 AHS to function.

Table 8. CCFDM for Stage I_3 - In a rural setting.

	Vehicle Logistics	Vehicle Control	Inter-vehicle Coordination	Flow Management	Incident Response
On-Board the Vehicle					
Manual	25%	20%	5%	0%	10%
Automated	65%	80%	80%	25%	0%
At the Zone Roadside					
Manual	0%	0%	0%	0%	60%
Automated	10%	0%	15%	75%	30%
In the TMC					
Manual	0%	0%	0%	0%	0%
Automated	0%	0%	0%	0%	0%
Totals	100%	100%	100%	100%	100%

2.4.5 Stage I_4: Stage I_3, plus platooning, using origin/destination information

I_4 represents the fully-evolved AHS system present in I_3 with the added ability to form vehicle platoons.

Table 9. CCFDM for Stage I_4.

	Vehicle Logistics	Vehicle Control	Inter-vehicle Coordination	Flow Management	Incident Management
On-Board the Vehicle					
Manual	20%	10%	5%	0%	0%
Automated	60%	70%	80%	10%	0%
At the Zone Roadside					
Manual	0%	0%	0%	0%	40%
Automated	0%	10%	5%	50%	20%
In the TMC					
Manual	10%	0%	5%	15%	20%
Automated	10%	10%	5%	25%	20%
Totals	100%	100%	100%	100%	100%

Vehicle Logistics:
No changes in the vehicle logistics function due to I_4 platooning are anticipated.

Vehicle Control:
No changes in the vehicle control function due to I_4 platooning are anticipated.

Inter-Vehicle Coordination:
While the strategic platoon-deplatoon decision will be made from the TMC, it is the roadside controllers, which benefit from the full local picture, that will actually relay these platoon decisions to the vehicle. The controllers will accomplish this by adjusting the control profiles of nearby vehicles as local conditions allow, so that the vehicle control function on-board these vehicles can execute the required maneuvers. These maneuvers will be executed by the vehicle following automated procedures. This may increase automated on board inter-vehicle coordination in I_4, an increase that is offset by a decrease in automated inter-vehicle coordination at the roadside and the TMC as well as manual activities. All else is unchanged.

Traffic Flow Management:
Assuming that platooning will be limited to situations where better capacity utilization is needed, the strategic platoon-deplatoon decision will likely be delegated to the TMC operators, thereby increasing (15 percent) manual flow management activity in the TMC in I_4, at the cost of decreasing (10 percent) automated flow management on-board the vehicle. All else is unchanged.

Incident Management
No changes in the incident management function due to I_4 platooning are anticipated.TMC Roles/Responsibilities:
Platoon-deplatoon decision making is added to the set of TMC responsibilities in I_4. While this may require additional operator training, the highly skilled operators that staff I_3 TMC should be more than capable of taking on this responsibility. Additional hardware or software assistance could be provided in the form of expert systems. It could also be possible to fully automate the platoon-deplatoon in later more advanced AHS stages.

Urban/Rural Issues:
The rural AHS that operates in I_3 without the benefit of a TMC or extensive roadside command and control infrastructure may not be able to move forward to I_4 until the necessary supporting infrastructure is in place. Platooning is a potentially complex maneuver that is not spontaneously implemented by the vehicle cluster. The TMC and/or the local roadside controller is needed to determine that platooning is indeed desirable, determine that local conditions will allow the safe execution of platooning maneuvers, initiate the platooning process, and supervise the otherwise autonomous platooning activity.

2.5 Examining Stages I_0 to I_4 Further: Trends

The numerical values contained in the matrices suggest trends that can be better identified when they are viewed alongside one another as shown in table 10.

Table 10. CCFDM summary for Stages I_0 to I_4 .

	STAGE 0	STAGE 1	STAGE 2	STAGE 3 URBAN	STAGE 3 RURAL	STAGE 4
Vehicle Logistics						
On-Board the Vehicle - Manual	90	80	60	20	25	20
On-Board the Vehicle - Automated	10	15	30	60	65	60
At the Zone Roadside - Manual	0	0	0	0	0	0
At the Zone Roadside - Automated	0	0	0	0	10	0
In the TMC - Manual	0	5	10	10	0	10
In the TMC - Automated	0	0	0	10	0	10
Vehicle Control						
On-Board the Vehicle - Manual	90	75	50	10	20	10
On-Board the Vehicle - Automated	10	25	50	70	80	70
At the Zone Roadside - Manual	0	0	0	0	0	0
At the Zone Roadside - Automated	0	0	0	10	0	10
In the TMC - Manual	0	0	0	0	0	0
In the TMC - Automated	0	0	0	10	0	10
Inter-Vehicle Coordination						
On-Board the Vehicle - Manual	100	90	80	5	5	5
On-Board the Vehicle - Automated	0	10	20	60	80	80
At the Zone Roadside - Manual	0	0	0	0	0	0
At the Zone Roadside - Automated	0	0	0	15	15	5
In the TMC - Manual	0	0	0	10	0	5
In the TMC - Automated	0	0	0	10	0	5
Flow Management						
On-Board the Vehicle - Manual	30	25	20	0	0	0
On-Board the Vehicle - Automated	0	5	10	15	25	10
At the Zone Roadside - Manual	10	10	10	0	0	0
At the Zone Roadside - Automated	40	40	25	50	75	50
In the TMC - Manual	10	10	15	10	0	15
In the TMC - Automated	10	10	20	25	0	25
Incident Response						
On-Board the Vehicle - Manual	20	20	20	0	10	0
On-Board the Vehicle - Automated	0	0	0	0	0	0
At the Zone Roadside - Manual	60	60	50	40	60	40
At the Zone Roadside - Automated	0	0	10	20	30	20
In the TMC - Manual	10	10	10	20	0	20
In the TMC - Automated	10	10	10	20	0	20

To further the analysis, graphs can be constructed for individual matrix cells across each evolutionary stage to map out the evolution of command and control activity for any of the location/mode/function combinations. Graphs have been constructed for each matrix entry (30 in all); due to space limitations, only three are presented here.

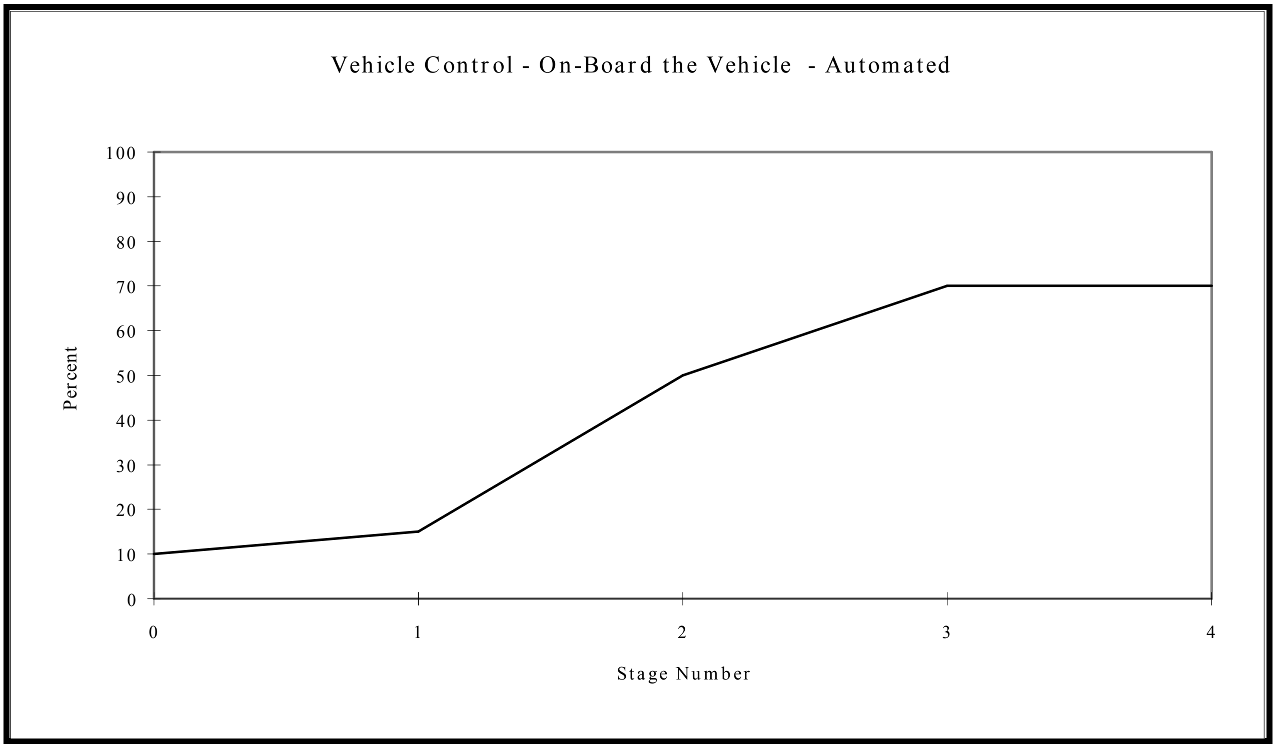

Figure 1. Decreasing role of the driver in vehicle control.

As shown in figure 1 above, the automated vehicle control activity from on-board the vehicle steadily increases across AHS I_0 to I_3 and levels off at I_4. This indicates the continually decreasing role of the driver in vehicle control.

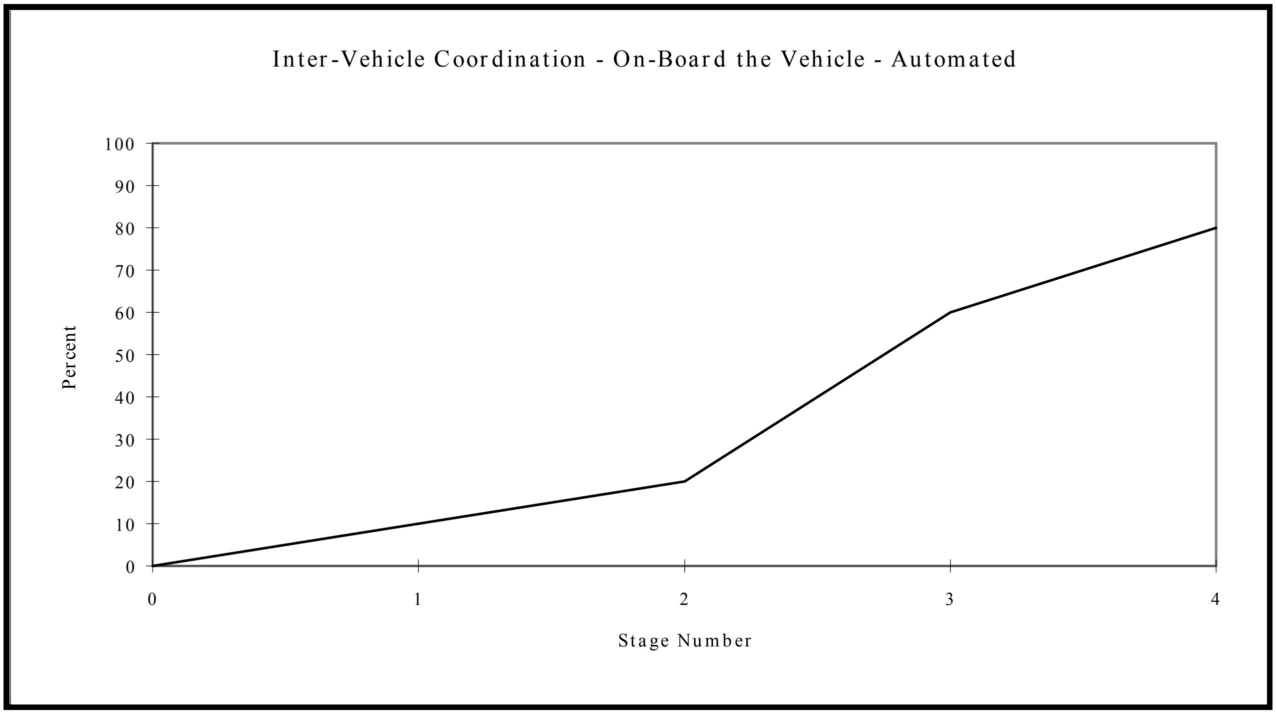

Figure 2. Replacing flow management by traffic laws with flow management by AHS.

As shown in figure 2 above, automated inter-vehicle coordination on-board the vehicle increases only slightly across AHS I_0 to I_2 and then takes a dramatic jump in moving from AHS I_2 to I_3. This indicates that the role of the driver in this function does not significantly diminish until the AHS moves to dedicated lanes. The figure also shows that automated inter-vehicle coordination on-board the vehicle continues to increase in moving from AHS I_3 to I_4.

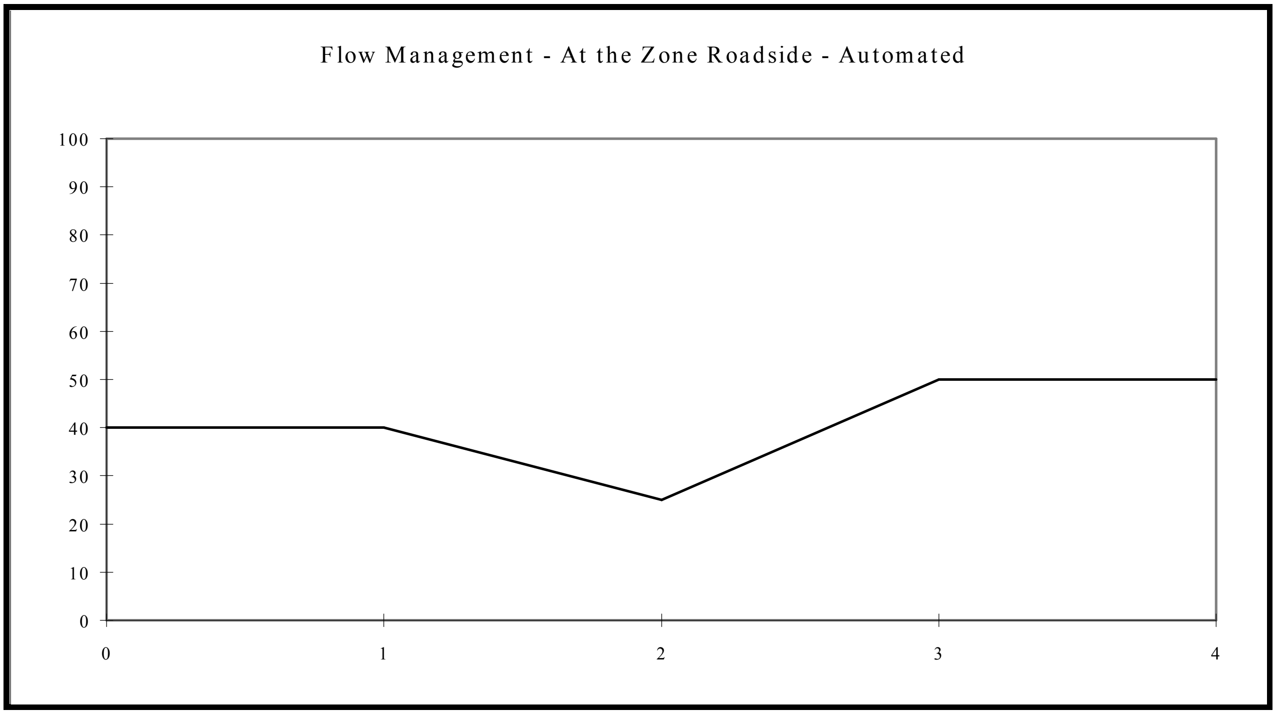

Figure 3. Stepping up from manual to automated on-board inter-vehicle coordination.

As shown in figure 3 above, the role of the roadside infrastructure in traffic flow management first decreases in moving from AHS I_1 to I_2, and then increases in moving from AHS I_2 to I_3. This indicates the initially decreasing role of the traffic laws and increasing role of the automated vehicle in regulating traffic flow. This also indicates a subsequently decreasing role of the automated vehicle and an increasing role of the roadside controller in regulating traffic flow.

2.6 Conclusions

In the early stages of AHS evolution (I_1 and I_2) there is essentially no TMC involvement of an automated nature in any area of AHS implementation. With the automated systems essentially being on-board the vehicle, there is little difference between the rural and urban deployment of the AHS in these Stages.

As AHS approaches I_3, we see some divergence between urban and rural AHS characteristics. Rural environments may not be able to support extensive TMC-zone roadside controller networks. For this reason, rural AHS systems will feature more distributed, vehicle-based operations, while urban regions will feature most centralized operations that are supervised and coordinated by a network of roadside controllers, which are in turn supervised and coordinated by a regional control facility such as the TMC. Nonetheless, drivers will be able to operate their vehicles in either environment, albeit more smoothly resulting in higher throughput for urban regions whose roadside command and control infrastructure offers more intelligent traffic responses to operating abnormalities. It is expected that, in time, rapid improvements and reduced costs in technology will allow unified instrumentation and infrastructures to be used for both urban and rural environments.

3. IMPACTS TO USERS - GROUP EVALUATION

3.1 Introduction and Result Summary

Group evaluations of the impacts to users[1] were completed for the 36 cells as shown in the Operating Mode Input Matrix (table1). Evaluations were based on the updated system descriptions for each of the 35 cells previously identified, and cell 87, which is included in the overall evaluation.

The results of the evaluation of impacts to users are as follows:

If the same technology is selected for use in both urban and rural areas, $G2/I_3/S$ is the preferred long-term system configuration (Cells 62, 70, 94). This system is described as separate lanes for AHS, vehicle-based system offering lateral and longitudinal control allowing lane change maneuvers and network flow coordination, with heavy vehicles restricted.

The system configuration $G1/I_2/S$ is the best starting point (Cells 52, 60). This system is described as AHS mixed with manual traffic, vehicle-based system offering some form of lateral and longitudinal control, with heavy vehicles restricted.

If only urban areas are considered, $G2/I_3/S$ is still the best long-term configuration (Cells 62, 70, 94) and $G2/I_2/S$ is still the best starting point (Cells 52, 60).

If only rural areas are considered, either $G2/I_4/M$ (Cells 63, 87) or $G2/I_4/S$ (Cells 64, 72, 96) is the best long term configuration. This system is described as separate lanes for AHS, vehicle-based system offering lateral and longitudinal control allowing lane change maneuvers, platooning, and network flow coordination, with heavy vehicles either mixed[2] with or restricted from the AHS traffic flow.

$G2/I_3/M$ (Cells 13, 37) is the best starting point. This system is described as separate lanes for AHS, vehicle-based system offering some form of lateral and longitudinal control, with heavy vehicles allowed in the AHS traffic flow.

Details of the evaluation methodology are described in section 3.3.

3.2 System Descriptions

Group members felt that, in most cases, the revised system descriptions provided sufficient information to complete the evaluation of impacts to AHS users. The evaluation includes the following assumptions which were used to complete or refine the system descriptions:

All definitions were assumed as previously stated, unless otherwise indicated.

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[1] "System Users" were regarded for this analysis the users of light AHS type vehicles (passenger cars and light undersize heavy vehicles).

[2] But with proper longitudinal separations.

The description "short/long"[3] spacing in previous documents was changed to "moderate/long" in more recent text; however, the values of 10-12 meters and 20-25 meters (33-39.6 feet and 66-82.5 feet) were not changed.

The evaluations were completed on the entire trip which includes the portion on access roads.

In the I_3 configuration, it was assumed that a driver can form his/her close spacing configuration or choose to be independent. Information is provided to the driver, who can then adjust his/her destination in the vehicle computer (which notifies the system to make the change). The driver can switch to manual control in emergency situations.

A market penetration of 50% is assumed for each type of instrumentation authority/intelligence distribution. This assumption relates directly to the group's view of how the G1 and G2 configurations will actually operate. Tables 11 and 12 illustrate these differences:

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[3] Compared to earlier proposal definitions.

Table 11. Description of the G-1 configuration.

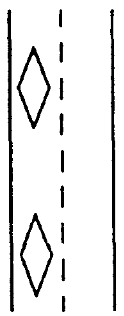
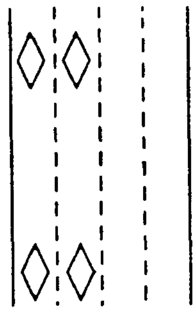
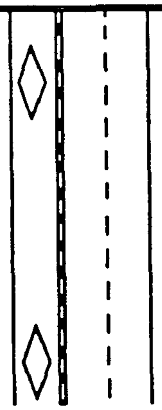
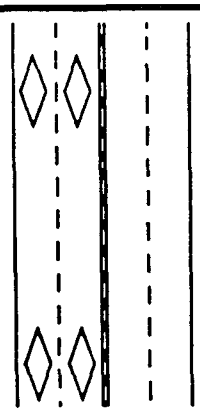
	Rural G-1	Urban G-1
<u>Rural</u> 2 lanes with one AHS ♦ lane <u>Urban</u> 4 lanes with 2 AHS ♦ lanes		
Separate Trucks	AHS and non-AHS trucks pass in the AHS (♦) lane.	No trucks in the AHS(♦) lanes.
Mixed Trucks	AHS trucks are in the ♦ lane. Non-AHS trucks pass in the ♦ lane.	AHS trucks are in the ♦ lane. No non-AHS trucks are in the ♦ lane.

Table 12. Description of the G-2 configuration.

	Rural G-2	Urban G-2
<u>Rural</u> 2 lanes <u>PLUS</u> one new barrier-separated AHS ♦ lane <u>Urban</u> 4 lanes with two barrier-separated AHS ♦ lanes		

3.3 Evaluation Methodology

The basic approach used for the evaluation included the following step:

Several group meetings were held to develop and refine the output variables that were used in the evaluation process. This required several iterations, based on the information available at that time.

Each group member worked individually to rate each cell, based on current information.

A group meeting was held, and each member was given the opportunity to present his/her results. The group discussed any problems that surfaced with regard to the values chosen for the output variables. The output variables were then refined as necessary, and a copy of the final version of the output variable matrix was produced, as presented in table 2.

Additional group meetings were held to develop the group evaluation and to determine the best methods for scoring, grouping, and presentation.

The output variables chosen for the evaluation of impacts to users are as follows: travel time, safety, comfort, flexibility, and user friendliness. Each of these variables is discussed below.

Travel Time

Travel time was defined by the group as a combination of average speed, mean travel time, travel time reliability (variation in travel time), and the ratio of time spent waiting vs. the actual time spent in travel. As noted above, evaluations were completed on the entire trip which includes the portion on surface access roads and streets.

Safety

In group discussions, a consensus was reached that concerns about safety were of two distinct types: actual safety and perceived safety. Actual safety is used to describe the statistical data related to accident frequency, severity, and cost. Actual safety may be measured by number of fatalities and injuries and cost of property damage and is based on data, without regard to personal experience or feelings.

Perceived safety may or may not have a direct correlation to actual safety. A perception is an attitude, feeling, or opinion and, because it is unique for each individual, there is no definitive measurement. Personal safety is perceived to be compromised in the case of lack of adequate information about an event or situation, absence of user control, and inability to influence a possible outcome.

In defining the output variables for the evaluation of impacts to users, both actual and perceived safety were considered. Actual safety can be rated according to current safety statistics of today's modes of transportation. Perceived safety can be influenced by factors which may not be supported by actual safety statistics, such as the presence of a physical barrier to segregate AHS users from non-AHS users, the presence of heavy vehicles in the traffic stream, and reductions in the spacing between vehicles.

Group members felt that the difference between the definitions of actual safety and perceived safety is significant, and that both will play an important role in public acceptance of an automated system. In completing the analysis, however, this distinction was not readily apparent. Because actual safety statistics of an automated system are not yet available, and the system is not yet clearly defined, group members relied on their perceptions of how the different input variables may affect actual safety statistics.

When additional research is completed, the design of the system is finalized, and the prototype system is built and tested, actual safety measures can be developed and used to evaluate the alternative configurations, and perceived safety measurements can be made through human factors experiments.

Comfort

Group members defined comfort as the rate of change of acceleration on the AHS as well as transfers between manual and automated systems. It was assumed that AHS will be provided for existing vehicle designs, and therefore issues of personal comfort related to vehicle characteristics will be inherent in the automated system. There may be some concerns associated with aesthetics regarding system components which were not addressed in the evaluation.

Flexibility

Flexibility was defined as the ability to make mid-course corrections. Group members felt that an important attribute of an automated system will be to allow a change in destinations. A measurement of flexibility was defined as the number of minutes to leave the AHS or to change destinations within the system.

User Friendliness

Group members defined user friendliness as a measure of how easy the system is to learn and use. As an illustration of the range of measurement, the difference between learning and using cruise control as compared to a video cassette recorder (VCR) was mentioned. It is important that the system have a low learning curve, be automatic whenever possible, and be designed to minimize difficulties with system access and egress. Group members also felt that, in an automatic system, an option must exist to revert to manual control in an emergency situation.

The following approach in rating each cell or groups of cells was used.

Several groups of cells were identical, except for one operating or demand variable. Group members isolated the possible changes in these input variables to determine their effect on the output variables described above.

Effect of Increases in Speed:

Travel Time - Can reduce travel time on the AHS portion of a trip.

Safety - I_1 and I_2 configurations (mixed with non-users) with higher speed in high demand are perceived as less safe (many targets and speed differential).

Comfort - No effect.

Flexibility - No effect.

User Friendliness - No effect.

Effect of Reductions in Spacing:

Travel Time - In I_3 and I_4 configurations, decreases in spacing can increase capacity in high demand (user may get on, less wait for system).

Safety - A decrease in spacing decreases perceived safety. In evolution of the system, the driver should be able to set his own level of comfort for spacing.

A decrease in spacing may also decrease actual safety. The proposed rating system for use when actual AHS safety statistics become available assumes that there is no absolute safety - no "A" rating. Actual safety does not go below a "D", which represents today's surface streets.

Comfort - No effect.

Flexibility - No effect.

User Friendliness - No effect.

Increase in Demand:

Travel Time - Increases in demand in I_4 configuration may effect wait time at entry/exit points.

Safety - No effect. The user may feel more boxed in, but that is more a function of spacing.

Comfort - No effect.

Flexibility - In G1 configurations, in high demand, the user's ability to change course or exit may be restricted due to weaving across the regular traffic.

User Friendliness - No effect.

In addition, the differences between guideway configuration alternatives, instrumentation authority/intelligence distribution, and heavy vehicle strategies were also examined to determine which, if any, would have an effect on the output variables, and what the likely effect would be.

Effect of Guideway Configurations:

Travel Time - Separate entry/exit points for G2 AHS may result in reduced wait times.

Safety - Users separated from non-users is the most desirable configuration to maximize a feeling of perceived safety.

Comfort - No effect.

Flexibility - G1 has most flexibility, except in high demand when the driver must cross several regular traffic lanes. G2 exit spacing is limited to approximately every 2 miles in urban and 10 miles in rural.

User Friendliness - No effect.

Effect of Instrumentation Authority/Intelligence Distribution

Travel Time - I_4 may have longer idle times than I_3 because of waiting for platoons. Overall travel times for I_4 could be reduced compared to I_3 due to capacity increases.

Safety - In I_1 and I_2 configuration, the driver maintains the ability to override the system and exercise control. In I_3, the driver can assume control in emergency situations. In I_2 rural configurations, and all I_3 and I_4 configurations, the driver can relax more. In I_4, the driver passes over complete control except for one button emergency override. There is no "A" rating because a portion of the trip is on non-AHS facilities. Today's system has a perceived safety of "D" which is likely to increase with each stage of evolution.

$I_4 > I_3 > I_2 > I_1$. In I_2 rural configurations, the driver can relax more and is more likely to be less attentive. In I_3, driver has some manual control in emergency conditions. Both circumstances are likely to affect actual safety.

Comfort - Both I_1 and I_2 offer longitudinal control. I_2 provides a "smoother ride" for the lateral control during the AHS portion of the trip; however, lateral comfort is a smaller portion of comfort and therefore not significant. I_1 and I_2 require cutting across lanes to access the AHS lanes. I_3 and I_4 have their own entry/exit points, and no cutting across several lanes is required, thereby achieving a smoother trip.

Flexibility - No effect.

User Friendliness - I_4 configuration is best for user friendliness - one button automatic, and a panic button. I_1 expects the most interaction from the driver, followed by I_2 and I_3.

Effect of Heavy Vehicle Strategy:

Travel Time - No effect.

Safety - Trucks allowed in the mix results in a low safety rating.

Comfort - No effect.

Flexibility - No effect.

User Friendliness - No effect.

Table 13 was used to determine the flexibility of a particular configuration. As previously noted, flexibility was defined by the group as the ability to make mid-course corrections and is determined by the number of minutes required to leave AHS or to change destinations. (Values given are miles between exits, minutes to the next exit, and the resulting rating as used to complete the individual cell evaluations.)

Table 13.[4] Flexibility of configurations.

	G-1			G-2		
	Miles	Minutes	Grade	Miles	Minutes	Grade
Rural 60 mph	5	5	D	10[5]	10	F
90 mph		3	C		7	F
Urban 60 mph	1	1	A	2	2	B
90 mph		1	A		1	A

This approach led to the development of the Group evaluation which is presented in the following tables:

Table 14. Overall evaluation in rural applications.
Table 15. Overall evaluation in urban applications.
Table 16. Individual ratings for each output variable in rural applications.
Table 17. Individual ratings for each output variable in urban applications.

4 Miles (mi) x 1.602 = kilometers (km)
5 The assumption of less frequent spacing of entry/exit facility was based on potential costs of such facilities under a separate guideway configuration. This assumption influences strongly flexibility grades for G-2 configurations.

Table 14. Overall evaluation in rural applications.

G1/I1/M	G1/I1/S	G1/I2/M	G1/I2/S	G2/I3/M	G2/I3/S	G2/I4/M	G2/I4/S
Cell # Score	Cell # Score	Cell # Score	Cell # Score	Cell # Score	Cell # Score	Cell # Score	Cell # Score
1 10	10 9	11 12	20 11	13 15	22 15	15 16	24 16
9 10	18 8	19 11	44 11	37 15	46 15	39 16	48 16
25 9	34 8	35 12	52 14		62 16	63 17	64 17
33 9	42 8		60 14		70 16	87 17	72 17
	50 11		92 11		94 16		96 17
	58 11						
	82 11						
	90 11						

The score for each cell is the sum of the ratings for each output variable.
(A=4, B=3, C=2, D=1, F=0)

All output variables are weighted evenly.

Table 15. Overall evaluation in urban applications.

G1/I1/M		G1/I1/S		G1/I2/M		G1/I2/S		G2/I3/M		G2/I3/S		G2/I4/M		G2/I4/S	
Cell #	Score	Cell #	Score	Cell #	Score	Cell #	Score	Cell #	Score	Cell #	Score	Cell #	Score	Cell #	Score
1	13	10	14	11	13	20	14	13	18	22	18	15	16	24	16
9	13	18	13	19	12	44	14	37	18	46	18	39	16	48	16
25	12	34	13	35	13	52	16			62	20	63	17	64	17
33	12	42	13			60	16			70	20	87	17	72	17
		50	15			92	13			94	20			96	17
		58	15												
		82	13												
		90	12												

The score for each cell is the sum of the ratings for each output variable.
(A=4, B=3, C=2, D=1, F=0)

All output variables are weighted evenly.

Table 16. Individual ratings for each output variable in rural applications.

G1/I1/M	G1/I1/S	G1/I2/M	G1/I2/S	G2/I3/M	G2/I3/S	G2/I4/M	G2/I4/S
1 BCDDDC	10 BDDDDC	11 BCCDDB	20 BCCDFB	13 BBBBFB	22 BBBBFB	15 BBBBFA	24 BBBBFA
9 BCDDDC	18 BDDDFC	19 BCCDFB	44 BCCDFB	37 BBBBFB	46 BBBBFB	39 BBBBFA	48 BBBBFA
25 BDDDDC	34 BDDDFC	35 BCCDDB	52 ACCDCB		62 ABBBFB	63 ABBBFA	64 ABBBFA
33 BDDDDC	42 BDDDFC		60 ACCDCB		70 ABBBFB	87 ABBBFA	72 ABBBFA
	50 ADDDCC		92 ADDDDB		94 ABBBFB		96 ABBBFA
	58 ADDDCC						
	82 ADDDCC						
	90 ADDDDC						

Order: Travel Time, Actual Safety, Perceived Safety, Comfort, Flexibility, and User Friendliness.

Table 17. Individual ratings for each output variable in urban applications.

G1/I1/M	G1/I1/S	G1/I2/M	G1/I2/S	G2/I3/M	G2/I3/S	G2/I4/M	G2/I4/S
1 BCDDAC	10 BCCDAC	11 BDDDAB	20 BCCDBB	13 BBBBBB	22 BBBBBB	15 BBBBFA	24 BBBBFA
9 BCDDAC	18 BCCDBC	19 BDDDBB	44 BCCDBB	37 BBBBBB	46 BBBBBB	39 BBBBFA	48 BBBBFA
25 BDDDAC	34 BCCDBC	35 BDDDAB	52 ACCDAB		62 ABBBAB	63 ABBBFA	64 ABBBFA
33 BDDDAC	42 BCCDBC		60 ACCDAB		70 ABBBAB	87 ABBBFA	72 ABBBFA
	50 ACCDAC		92 ADDDBB		94 ABBBAB		96 ABBBFA
	58 ACCDAC						
	82 ADDDAC						
	90 ADDDBC						

Order: Travel Time, Actual Safety, Perceived Safety, Comfort, Flexibility, and User Friendliness.

3.4 AHS Impacts to Users Rating Summary and Impacts for Urban/Rural Comparison

The following is a summary of the matrix cell numbers that received the highest ratings in the evaluations conducted by the impacts to users group:

Best for Travel Time
(same for rural and urban systems)

50,58,82,90
52,60,92
62,70,94
63,87
64,72,96

Best for Safety
(same for rural and urban systems)

No A's given
13,37
22,46,62,70,94
15,39,63,87
24,48,64,72,96

Best for Comfort
(same for rural and urban systems)

No A's given
13,37
22,46,62,70,94
15,39,63,87
24,48,64,72,96

Best for Flexibility
Rural systems - Best rating given was a C

50,58,82
52,60

Urban systems

1,9,25,33
10,50,58,82
11,35
52,60
62,70,94

Best for User Friendliness
(same for rural and urban systems)

15,39,63,87
24,48,64,72,96

Best Overall
Rural

63,87
64,72,96

Urban

62,70,94
63,87
64,72,96

In the evolution of the AHS, public acceptance is critical to each stage of the design, implementation, and operation of the AHS. It is important to understand that public perception is difficult to predict. With the group addressing impacts to users, it was clear that individual opinions are diverse and strongly held.

It is equally important to recognize those factors that influence the public perception. Decisions and/or opinions are formed using past experience, personal research/knowledge, interaction with others, and a personal instinct based in part on background, personal values, strengths and weaknesses, and level of risk tolerance. The level of influence exerted by each of these factors varies with each individual. In many cases, facts can be overcome by feelings, and a perceived threat or preconceived notion may prevent acceptance of a new method, process, or idea.

Concerns about system safety can be addressed through information provided to the user, implementation of redundant systems to maximize actual safety, the presence of physical devices to create a safe environment (airbags, emergency button, restraints, etc.) and a gradual evolution based on a history of safe operation. By reducing or eliminating user control, higher standards of actual and perceived safety may be required to ensure public acceptance.

Market surveys can be used to identify individual opinions and concerns. Information provided at all stages of AHS development and deployment, involvement in a gradual system evolution, and experience using the system will allow the user to develop a feeling of comfort and trust in the system.

4. SOCIETY IMPACTS

4.1 Introduction

The evolution of an AHS will clearly have impacts on society ranging from behavior patterns to direct social costs. It also seems clear, that the “values” of these impacts are not known. However, it is possible to attempt to delineate different impacts or variables that may reasonably be expected to be affected. The next step, that of quantifying the changes to these chosen variables, is much more difficult, and at this time, far less defensible. Anytime society tries to predict future trends and activities past five years, or current political terms, it is risky to rely upon the figures.

However, such efforts can be useful in defining the key variables to consider and track. Also, by “recalibrating” every few years feedback of values of variables/parameters as new input, this process can be effective. A good example of this process is shown through the transportation planning process and travel demand management/forecasting by regional planning agencies for land use and transportation.

Two major approaches may be considered: a quantitative modeling approach and a qualitative prediction approach. If the variables/ parameters are well defined and have well understood limits, then a quantitative model may be appropriate, that is, if we know reasonably well how the “system” works. If the system and its dynamics are considerably less defined and intercorrelations of variables less understood - as in the case when dealing with human behavior - then a more qualitative and perhaps a qualitative ranking of impacts may be done.

The society group decided to approach the impact on society with the latter approach. The specific method chosen was the delphi method, where the group members determined variables that measured social impacts and then ranked each variable relative to the current (existing) situation of today's roadway system. After each member in the group performed their rankings privately, they were then discussed/defended as a group. Changes were then allowed, if the individuals wished, that reflected the discussion comments.

The society group consisted of five transportation professionals as referenced in section one of the report. Six variables were determined to reflect societal impact. These were capacity, environment, economy, equity, technical feasibility, and acceptability. Capacity refers to roadway capacity; does it change? Acceptability refers to the acceptability to the users of the system. A Delphi comparison was then done on these variables, ranging through the previously discussed scenarios of AHS deployment: I_1, I_2, I_3, I_4, where I_1 represents the first stage beyond today's roadway system. A ranking scale ranging from -10 to 10 was used where the scale was interpreted by putting 0 as the same as today. Thus, -10 would be very unlikely or bad, while 10 would be very likely or good, relative to current conditions. The various I modes on the evolutionary path were further broken down into the operating mode groups O, which contain one or more cells from the Operating Mode Input Matrix. Thus, under I_1, three matrices were made, under I_2 and I_3 three matrices each were made, and under I_4, four matrices were made.

4.2 Stage I_1 Evaluations

Cells #1, 9, 25, and 33[1]: These represent mixed AHS vehicles with non-AHS equipped vehicles, low to moderate demand, mixed trucks, and both moderate and long spacing. The following is the matrix produced:

Table 18. Individual ratings of impacts for I_1.

Cells 1,9,25,33	DG[2]	HC[2]	JT[2]	PS[2]	ES[2]
Capacity	1	0	1	1	1
Environment	1	0	1	0	1
Economy	0	0	1	1	1
Equity	-2	0	-1	0	-1
Technical Feasib.	-1	0	-1	0	-1
Acceptability	3	2	1	1	3

Capacity:
With the advent of intelligent cruise control and soft braking capabilities, the longitudinal control of the vehicle will be a bit safer under AHS on-board vehicle sensors than under the manual control of the driver. Thus, the group saw on average a slight increase in capacity and fewer accidents. (However, it was noted that only a small portion of the initial impact accidents are rear-enders.)

[1] See table 1 for cell definitions.

[2] DG = Denny Gier, Systems Engineer/Consultant.
HC= Henry Case, Traffic Engineer/Consultant.
JT= John Tolle, Research Professor.
PS= Patrick Sparks, Graduate Student in Transportation.
ES= Edward Sullivan, Professor.
Above noted definitions are applicable to all tables that follow.

Environment:
A slight improvement in the environment was noted by most of the participants, as a more constant speed will improve the air quality since fewer vehicle emissions are produced when vehicle speeds do not fluctuate.

Economy:
The majority of the participants saw a slight improvement in the economy due to the sale of a more expensive type of cruise control. Those who saw no change from today note the market penetration, at under 10 percent, and the difference in price from the old cruise control as part of an optional package would not create any real improvements for the economy.

Equity:
The majority saw a decline in relative equity. Not as many will be able to purchase an ICC. However, the other two participants saw no change as an ICC would be an optional feature with low market penetration, and therefore create no real equitable differences in either the cost of personal travel or service to the travel needs of the rich and poor.

Technical Feasibility:
Technical feasibility was determined to be at most zero, as all AHS features would be no more feasible than what currently exists. The ICC is just around the corner. Thus, the technical feasibility was rated a slight negative by most or zero.

Acceptability:
When considering the acceptability of the ICC, the group felt favorable. Insurance, liability, and institutional implications would not be much more complex than today. Most people would want to have the opportunity to use a better cruise control which provides some soft braking and an emergency signal for taking over the hard braking in emergency situations. Thus, the acceptability was favorably rated as the downside to introducing the technology to the marketplace is small, but the upside is strong.

Cells #10, 18, 34, and 42: The differences from the previous evaluation are no trucks in the AHS lanes, and higher levels of demand. Table 19 illustrates the matrix of individual ratings.

Table 19. Individual ratings of impacts for I_1.

Cells 10,18,34,42	DG	HC	JT	PS	ES
Capacity	1	2	2	2	2
Environment	1	0	1	0	1
Economy	1	1	1	1	1
Equity	-3	0	-1	-1	-1
Technical Feasib.	-2	0	-2	0	-2
Acceptability	4	3	2	-1	2

Capacity:
Most of the participants saw a slight improvement in capacity because the trucks were removed from

the AHS lanes. The vision was that the trucks would be relegated to the current truck lanes, with the AHS users being required to use the left lanes.

Environment:
No changes were made from the previous numbers on the environment.

Economy:
On the economy scale, the two members with zero in the previous matrix moved to one, a very slight improvement due to persons getting to work in a more timely manner.

Equity:
The equity scores went down for some of the participants under these operating modes because the trucks will not be able to participate in the AHS.

Technical Feasibility:
Technical feasibility also went down slightly because of the possibility of AHS equipped cars being in conflict with trucks that are not equipped. It was felt that there may be problems in knowing when the cars using AHS continue to use the AHS equipment while traveling in the truck lanes.

Acceptability:
Acceptability took on different numbers for the participants, with some going toward more acceptability, and others going toward less. By separating out the trucks, the cars will be safer, and hence the ICC under this operating mode would be more acceptable. However, by eliminating the trucks from the AHS evolution, the lobby groups for the truckers will make the institutional acceptability less likely.

Cells #50, 58, 82 and 90: These are similar to the set above, except at higher speed. Table 20 illustrates the matrix of individual ratings.

Table 20. Individual ratings of impacts for I_1.

Cells 50,58,82,90	DG	HC	JT	PS	ES
Capacity	3	2	4	2	5
Environment	0	0	0	0	-3
Economy	2	1	3	3	4
Equity	-2	0	-1	-1	-2
Technical Feasib.	-2	-2	-3	-3	-4
Acceptability	-3	3	-4	-6	-6

Capacity:
The capacity was seen on the whole to improve under these operating modes as the higher speed of 150 kph (94 mph) will bring increased capacity. Those which did not change their numbers from above noted the capacity impact as small.

Environment:
The change to the environment was seen as neutral by most. However, at higher speeds, more pollutants will be put into the air by automobiles, and ultimately this could have a negative impact on

the environment should other measures such as cleaner cars not coincide with the ICC portion of the AHS evolution. On the other hand, smoother flow and enrichment reduction could result in less pollutants. Tire noise impacts are also of concern in urban and suburban settings.

Economy:
With the increase in speed, tax revenues should increase as more fuel is consumed. Also, at higher speeds, persons will choose to live farther away from the central business district (CBD), where land is less expensive and the price of commuting has not changed in terms of time. Increased business productivity was noted as both goods and people will reach destinations more quickly. Thus, the impact on business and the economy was seen as improving across the board by the participants.

Equity:
Equity stayed slightly negative, with most of the participants retaining the same numbers.

Technical Feasibility:
The technical feasibility was seen to decrease on the whole, with the entry and exit at high speed a harder task when the trucks will be going slower in the truck only lanes.

Acceptability:
The acceptability of having two different speed limits on a highway created problems for most of the participants who rated the acceptability quite negatively. The jump from the previous numbers should be noted as the swing in negative numbers was six to eight points in the scale. The institutional, insurance, and liability implications are most troublesome for the group at this set of operating mode cells.

4.3 Stage I_2 Evaluations

The I_2 portion presents the move to lateral control of the vehicle through automation. At this point, the group decided to focus only on the changes in the Impacts to Society matrices. The capacity and environmental impacts were determined to be the same. Thus, the numbers for the economy, equity, technical feasibility, and acceptability were where the changes were made.

Cells #11, 19, and 35: These are like the I_1 cells #1, 9, 25, and 33, with slightly more demand. Table 21 illustrates the matrix of individual ratings.

Table 21. Individual ratings of impacts for I_2.

Cells 11,19,35	DG	HC	JT	PS	ES
Capacity	1	0	1	1	1
Environment	1	0	1	0	1
Economy	1	0	2	3	2
Equity	-2	0	-1	-1	-1
Technical Feasib.	-2	0	-2	-2	-2
Acceptability	3	2	2	-2	4

Economy:
Three of the participants expected the economy to improve from the I_1 level because of the addition

of new equipment to the vehicles. Depending on the type of lateral control ultimately chosen, the impacts on the economy could be even greater i.e. machine based vision will cost more to make, and therefore will improve the economy presuming the United States is the dominant manufacturer. However, with market penetration held to between 10 to 20 percent, the impact on the economy will not be startling.

Equity:
Equity remains similar, and slightly more negative since fewer will be able to afford the more expensive systems.

Technical Feasibility:
Technical feasibility goes down somewhat due to the unknowns of how the lateral control will be implemented, and the fact that the accuracy of the lateral control is still being discerned.

Acceptability:
Acceptability goes up for most of the participants, as the addition of lateral control provides more user acceptability. However the legal, liability and institutional requirements for lateral control bring a high degree of uncertainty and one of the participants rated the acceptability negatively as compared to today.

Cells #20 and 44: These compare to I_1 cells #18 and 42. Table 22 illustrates the matrix of individual ratings.

Table 22. Individual ratings of impacts for I_2.

Cells 20,44	DG	HC	JT	PS	ES
Capacity	1	2	2	2	2
Environment	1	0	1	0	1
Economy	1	1	2	3	2
Equity	-3	0	-1	-2	-1
Technical Feasib.	-3	0	-3	-2	-3
Acceptability	4	3	3	-3	3

Economy:
The impact on the economy was held constant by all except one, who improved his score to a one because the heavy vehicles were taken off the AHS.

Equity:
Equity remains close to I_1, with a slight drop off for two of the participants based on reasoning used above.

Technical Feasibility:
Technical feasibility goes down slightly as well.

Acceptability:
Acceptability remains similar to the I_1 levels, but two of the participants scored acceptability lower because of the truck lobby influence and the uncertainty of liability issues.

Cells #52, 60, and 92: These compare to the I_1 cells #50, 58, and 90. Table 23 illustrates the matrix of individual ratings.

Table 23. Individual ratings of impacts for I_2.

Cells 52,60,92	DG	HC	JT	PS	ES
Capacity	1	2	2	2	2
Environment	1	0	1	0	1
Economy	1	1	2	3	2
Equity	-3	0	-1	-2	-1
Technical Feasib.	-3	0	-3	-2	-3
Acceptability	4	3	3	-3	3

Economy:
The economy improves more than in the I_1 mode as more equipment will be produced, again assuming manufacturing occurs in the United States.

Equity:
Equity remains similar to both the I_1 and the preceding matrix.

Technical Feasibility:
Technical feasibility slides for most of the participants relative to both I_1 and the preceding matrix. Operating at high speeds with lateral control creates more of a technical problem than operating at lower speeds or at high speed with only longitudinal control.

Acceptability:
Acceptability is on the whole rated negatively by the participants. However, the insertion of lateral control makes the system more palatable for users. Thus, most of the participants did not have as high a negative number relative to I_1.

4.4 Stage I_3 Evaluations

The I_3 AHS evolution brings added infrastructure, and more market penetration (up to 60 percent), in addition to all the elements of stage two.

Cells #13 and 37: Moderate spacing and long spacing make these cells distinct. Table 24 illustrates the matrix of individual ratings.

Table 24. Individual ratings of impacts for I_3.

Cells 13,37	DG	HC	JT	PS	ES
Capacity	2	1	3	2	3
Environment	2	0	2	0	2
Economy	4	1	4	5	4
Equity	-3	-1	-2	-2	-2
Technical Feasib.	-2	0	-2	-2	-2
Acceptability	4	2	4	1	5

Capacity:
Capacity is seen to increase relative to I_2. When the AHS is separated from the traffic stream at I_3, AHS vehicles will have dedicated lanes which will improve throughput.

Environment:
The impact on the environment is also seen on the whole as more favorable relative to I_2 because the number of cars which are traveling at a more constant speed will reduce emissions.

Economy:
The economy is seen to improve relative to I_2. More infrastructure development will bring a boost to the economy as money is spent. One might argue that the money is being merely reallocated from another sector of the economy, and hence one of the participants saw the increase in the economy as only slight.

Equity:
Equity is anticipated to decrease relative to I_2. At 60 percent market penetration, the separation of the haves from the have-nots is, by this group, anticipated as more clearly a separation of rich and poor.

Technical Feasibility:
Technical feasibility is expected to be the same as in I_2.

Acceptability:
Acceptability will improve relative to I_2 according to most of the participants. The problems of lateral control on an institutional level will have been resolved by I_3. Adding more control to the automated portion and separating the AHS from the other traffic will increase the acceptability.

Cells #22 and 46: These correspond to I_2 cells #20 and 44. Table 25 illustrates the matrix of individual ratings.

Table 25. Individual ratings of impacts for I_3.

Cells 22,46	DG	HC	JT	PS	ES
Capacity	2	4	4	4	4
Environment	2	0	2	0	2
Economy	4	2	4	5	4
Equity	-3	-1	-2	-3	-2
Technical Feasib.	-3	0	-2	-1	-2
Acceptability	5	3	4	0	4

Capacity:
Most of the participants saw an improvement in capacity relative to I_2 and the preceding matrix. Separating the trucks from the cars improves the safety and speed capabilities, particularly at grades.

Environment:
The environment scores do not change relative to the preceding matrix, and improves only slightly relative to I_2 for most of the participants.

Equity:
Equity scores are similar to the preceding matrix, and slightly less than I_2. The reasons have previously been set forth.

Technical Feasibility:
Technical feasibility remains similar to the preceding matrix, and improves slightly relative to I_2 for most of the participants. Improving the system by creating separate AHS lanes is expected to be a slightly easier task than integrating AHS and non-AHS traffic.

Acceptability:
Acceptability is close to the preceding matrix, and more favorable than in I_2. Some of the participants weighed the user acceptability higher (as positive) than did the others who weighed the legal and institutional responsibilities higher (as negatives) in I_3 relative to I_2. With separate AHS lanes, more regulation and enforcement become necessary.

Cells #62, 70, and 94: These correspond to cell #60 and 92 in I_2. Table 26 illustrates the matrix of individual ratings.

Table 26. Individual ratings of impacts for I_3.

Cells 62,70,94	DG	HC	JT	PS	ES
Capacity	4	5	6	6	6
Environment	-1	0	0	-1	-4
Economy	5	3	5	7	7
Equity	-3	-1	-2	-2	-3
Technical Feasib.	-3	-2	-3	-1	-3
Acceptability	-1	0	-1	0	-1

Capacity:
At high speeds with separated trucks and increased automation improving safety, capacity improvements occur.

Environment:
The environment is thought to decline on the whole, although only slightly, because of the increase in vehicle kilometers (miles) traveled due to the higher speed (as described above).

Economy:
The economy will be at its highest value, even better than the preceding matrix because of the higher speed.

Equity:
Equity will remain about the same.

Technical Feasibility:
Technical feasibility is harder than for the preceding matrix because of the higher speed, but easier than for I_2 because of the separation of the AHS traffic.

Acceptability:
The acceptability was judged to be substantially less than the preceding matrix by most of the evaluators. They felt that the combination of higher speeds for these cells (above current design speeds) and automation would be perceived to be less safe and also less `comfortable' to occupants of the vehicles.

4.5 Stage I_4 Evaluation

The I_4 AHS evolution adds platooning capabilities. Four different input-output, (I-O), groupings were examined, consisting of cells (15,39), (63), (24,48), and (64,72,96). Since platooning was the only addition from the previous stage I_3, the evaluators considered all the groups to be within one matrix. Technical feasibility was singled out as the only variable that would significantly change from the previous I_3 matrices. The group decided that the technical feasibility would be two points lower for each of the sources recorded in I_3. Again this is a result of a combination of higher speeds and performance capabilities of trucks[3] being perceived to be less safe and creating a more uncomfortable situation for vehicle occupants. The other impacts (variable values) remained the same and correspond to values in parallel cells for I_3 matrices i.e. groups (13, 37), (22,46) and 64,72,96). Table 27 illustrates the rating for Cell 63 in the I_4 stage.

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[3] Although some operational concepts call for trucks, (when included in the AHS), to platoon with other trucks or act as "single agents", the group felt that they still would create both operational and safety burdens to the system.

Table 27. Individual ratings of impacts for I_4.

Cell 63	DG	HC	JT	PS	ES
Capacity	3	4	5	5	5
Environment	-1	0	0	-1	-4
Economy	5	3	5	7	7
Equity	-3	-1	-2	-2	-3
Technical Feasib.	-5	-4	-5	-3	-5
Acceptability	-4	-5	-5	-5	-4

Capacity:
The group assessment was that capacity increases a bit more than in cell #61. Even when the trucks are included[4], platooning provides more capacity.

Environment:
The environment, economy, and equity perform similarly to the preceding matrix for I_3.

Technical Feasibility:
Technical feasibility takes a two point drop from the preceding I_3 matrix.

Acceptability:
Acceptability drops sharply due to trucks[4] traveling at high speeds in platoons. The evaluators felt that perceived safety would decrease substantially and vehicle occupants would be uncomfortable under automatic control with trucks, even if the trucks were in separate platoons.

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4 In separate platoons from passenger cars.

4.6 Summary Table

Table 28. Summary for Impact to Society Evaluations.

Cells	Capac.	Envir.	Econ.	Equt.	Tech.	Accp.	Total
I_1							
1,9,25,33	.8	.6	.6	-.8	-.6	2	2.6
10,18,34,42	1.8	.6	1	-1.2	-1.2	2	3
50,58,82,90	3.2	-.6	2.6	-1.2	-2.8	-3.2	-2
I_2							
11,19,35	.8	.6	1.6	-1	-1.6	1.8	2.2
20,44	1.8	.6	1.8	-1.4	-2.2	2	2.6
52,60,92	1.8	.6	1.8	-1.4	-2.2	2	2.6
I_3							
13,37	2.2	1.2	3.6	-2	-1.6	3.2	6.6
22,46	3.6	1.2	3.8	-2.2	-1.6	3.2	8
62,70,94	5.4	-1.2	5.4	-2.2	-2.4	-.6	4.4
I_4							
63	4.4	-1.2	5.4	-2.2	-4.4	-4.6	-2.6

5. AHS IMPLEMENTATION AND COMMERCIAL VEHICLE OPERATIONS: POTENTIAL CHANGES IN INDUSTRY STRUCTURE

5.1 Introduction

Changes in the basic transportation systems can result in dramatic and often unforeseen consequences in many sectors of society. The adoption and deployment of AHS technologies will have widespread impacts on all user groups. No groups will be greater affected than those associated with the commercial vehicle operations on the highway system.

Many of the direct impacts on commercial operations can be estimated with relative ease, such as the level of activity and the direct impact on transportation costs. The more difficult task is estimating the long term effect on the industry structure, and the overall effects on industry and society.

This section will provide an overview examination of these issues, and estimates of the changes that will result in the cost structure of CVO operations with the implementation of the AHS, with some speculation on the long range impact of the AHS on CVO industry structure. After the basic industry structure and trends are presented, an identification of CVO factors influencing the urban/rural AHS comparison will be made. Finally, a discussion of interactions will be attempted.

5.1.1 Objective of Report

This section will look to provide an estimate of the effect of the AHS on commercial vehicle operations including:

The cost and cost structure for freight transportation.
The impact of commercial vehicle operations on the transportation network.
The changes in the freight transportation industry resulting from the implementation of the AHS.

This will be done by first examining the current operating characteristics of the highway freight transportation system. The section will then examine the potential changes in the above based on the adoption of AHS, and the impacts on firms and the freight transportation market structure. The broader social impacts of these changes will then be considered and recommendations made for further study.

The objective of this section is to provide a broad overview of these issues as they relate to the AHS. The numbers and estimates are highly speculative, and subject to the limitations discussed in section 5.2.

5.2 Background

It is beyond the scope of this section to describe in detail either the AHS or CVO. This section will start with a brief background and description of the basic CVO terms, statistics, and concepts. The initial system characteristics will help understand the nature and structure of the industry as well as recent trends.

In the broad sense, commercial vehicle operations can be defined as all vehicle operations exclusive of passenger transportation. The primary focus of CVO is the transportation of freight. In it's most basic form, freight transportation is the "goods" part of the classic definition of transportation; that is the movement of people and goods. At a somewhat more detailed level, freight transportation represents a complex system including equipment, facilities, information, people and organizations, and procedures that seeks to distribute raw materials, partially assembled components and finished goods.

Highway Freight Transportation

The highway transportation system, while carrying roughly one-quarter of the national freight tonne kilometers (ton miles), accounts for about three-quarters of the national freight revenues. In terms of absolute efficiency, trucking is not competitive with rail, water or pipeline transportation. Flexibility in the types of products carried and accessibility to delivery sites, however, allow trucking firms to provide a high level of customer service. The motor carrier system consists of approximately 6.4 million kilometers (4 million miles) of public roadway, most of which is accessible to commercial vehicles. This accessibility, combined with a distributed network of vehicles, terminals and freight handlers, has led to the domination of trucks in many markets.[9]

Much freight transportation involves more than just one mode. A growing trend in the freight transportation field is the use of inter-modal (two modes) and multi-modal (more than two) transportation of freight. The use of truck-on-flatcar (TOFC) and container-on-flatcar (COFC) systems have had a significant impact on intermodal freight operations. Intermodal freight can be moved by either a single carrier (on-line) or using multiple firms (interline). The movement toward intermodal freight transportation both requires and takes advantage of advanced logistic systems.

Carriers

Firms that provided shipping services, or carriers, can be classified along a variety of dimensions. These classifications are frequently based on carrier service type, revenues, territory served, and type of commodity carried.

Service Type

The motor carrier industry is a highly regulated industry, with many of these regulations based on the type of service provided. Private carriers include the trucking operations of firms that use the trucking services for transporting their own goods. These firms are exempt from Interstate Commerce Commission (ICC) requirements, and data on the operations of private carriers are excluded from most data sources. For-hire carriers provide transportation services to other firms and individuals, and are subject to ICC regulations.

Firms covered by the ICC are classified as common, contract, or exempt carriers. Common carriers provide haulage services to all shippers, with established and approved rates, schedules, routes, and service areas. Contract carriers serve individual shippers by contract to haul a specific load for a negotiated price. Their service is less regulated than that of the common carriers, but there are some restrictions on the services they are able to provide. Exempt carriers transport certain specified goods, such as agricultural products, that have been excluded by legislation from ICC regulation of rates and service area.[10]

Classifications Based on Revenues
ICC regulated carriers are classified by annual gross operating revenues. Class I carriers are those that have revenues of $5 million or more. Class II carriers have revenues between $1 million and under $5 million, and Class III carriers are those with less than $1 in annual gross operating revenues.[11]

Territory Served
Local carriers operate primarily within a single service area, are partially regulated by the ICC, and may be subject to local regulations. Intercity carriers are those that derive the majority of their revenues from intercity haulage. These firms may operate as either interstate or intrastate carriers, with the primary regulatory authority resting with either the ICC or state authorities.

Type of Commodity Carried
Carriers are also categorized by the type of cargo carried. The primary classification include general freight, building materials, bulk commodities, household goods, heavy machinery, motor vehicles, package and courier services, refrigerated loads and tank truck carriage. General freight is also divided into truckload (TL) and less-than-truckload (LTL) carriage. Freight is classified as LTL if the shipment weighs less than 4535 kilograms (10,000 pounds).

A problem in interpreting transportation freight data is that data sources are frequently limited in the scope of the freight transportation market reported. Specifically, private, local, exempt, and frequently Class III carriers are often excluded from the analysis, and classifications based on territory served and commodity carried frequently aggregate all carrier operations under the primary type of service. These limitations are usually based on the reporting requirements for the regulatory agency, and create some difficulty in interpreting freight transportation data. A more detailed description of limitations of the data is provided in section 5.4.

5.3 Current Status of Freight Transportation

5.3.1 Total System Activity

A. Modal Distribution of Freight.

The highway transportation system accounted for approximately 20 percent of the freight moved in the United States in 1988 (table 29). Freight traffic has grown at a faster rate than both the general traffic and the Gross Domestic Product (table 30), and truck transportation continues to capture a growing share of this traffic. Surface freight transportation is projected to grow at a rate of 1.54 faster than the general traffic.[12]

Table 29. Modal distribution of inland freight - 1988.[14]

	Highway	Rail	Inland Waterway	Pipeline[1]
Tons (%)[2]	36	29	18	17
Ton/miles (%)[3]	22	38	16	24

[1] Oil pipelines only.

[2] Although there continues to be movement toward use of metric units, industry sources continue to report in English units, including miles and tons. This report will continue to use this conversation.

[3] Ton x 0.9 = tonne
Mile x 1.602 = kilometer

Table 30.[1] Annual average growth of inland freight.[12]

	1970-1974	1975-1980	1970-1980
Freight Traffic Growth	+3.84	+4.28	+2.51
GDP Growth	+3.83	+4.32	+2.19

[1] Measured in ton/miles and excluding services from Gross Domestic Product.

B. Number of Trucks.

Commercial vehicles represent a relatively small percentage of the United States vehicle fleet (table 31). There are differences among different sources on the exact number of vehicles. The number of heavy trucks, semi's and trailers is estimated between 3.1 to 4.9 million vehicles, and constitutes about five percent of the registered vehicles. This figure understates the actual number of commercial vehicles. There are approximately 37 million registered light trucks and vans, many serving as commercial vehicles for small business. It is impossible to determine, however, the extent to which these small trucks and vans are used for private transportation.[12,13]

Table 31. Registered vehicles - 1987.[14]

	Passenger Cars	Buses	Light Trucks and Vans	Heavy Trucks	Tractors and Trailers
Number (000's)	137,324	602	35,819	5,300	3,484
Percent	75.2	0.3	19.6	2.9	1.9

C. Truck Mileage.

Estimates of the total number of kilometers (miles) traveled by heavy trucks varies, based on the source used, between 129 and 214 million kilometers (80 and 133 million miles) annually.[13] The number of kilometers (miles) traveled has increased steadily, from (using the FHWA estimate) about

97 million kilometers (60 million miles) in 1982 to about 90 million in 1987,[17] although some estimates show a significant reduction in freight mileage based on the economic downturn in the mid-1980's.[15]

5.3.2 Network Operating Characteristics

A. Activity by Carrier Type.

An estimated 80% of the trucking is operated by for-hire carriers, with 20 percent owned and operated by private carriers.[12] In 1987, an estimated $134.6 billion was spent on trucking shipments, with $58.1 billion spent on ICC-authorized motor carriers and $76.5 billion on private, interstate and exempt carriers.[10] A breakdown of the number and revenues for ICC carriers is presented in table 32.

Table 32. ICC authorized carrier activity - 1987.[10]

	Number (approximate)	Revenues ($/billion)
Class I	1,000	39.3
Class II	3,000	7.8
Class III	33,000	11.0

The distribution of revenues among the different type of Class I and Class II carriers is provided in Figure 4. Nearly half of the commodities shipped were general freight, followed by household goods, bulk commodities, and refrigerated cargos.[11]

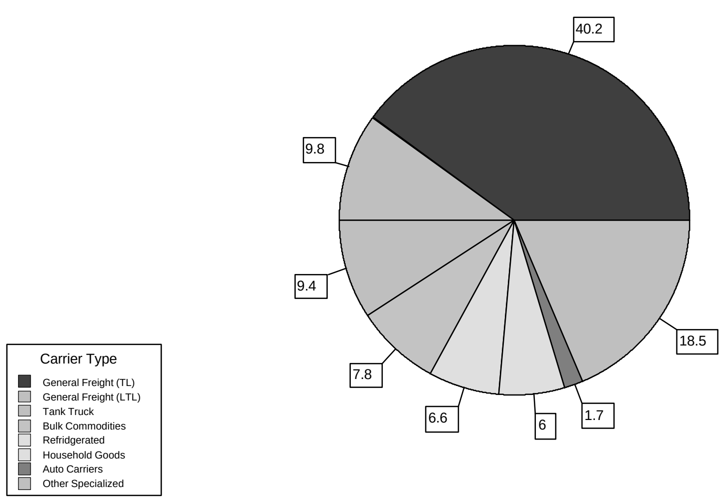

Figure 4. Distribution of freight types.[11]

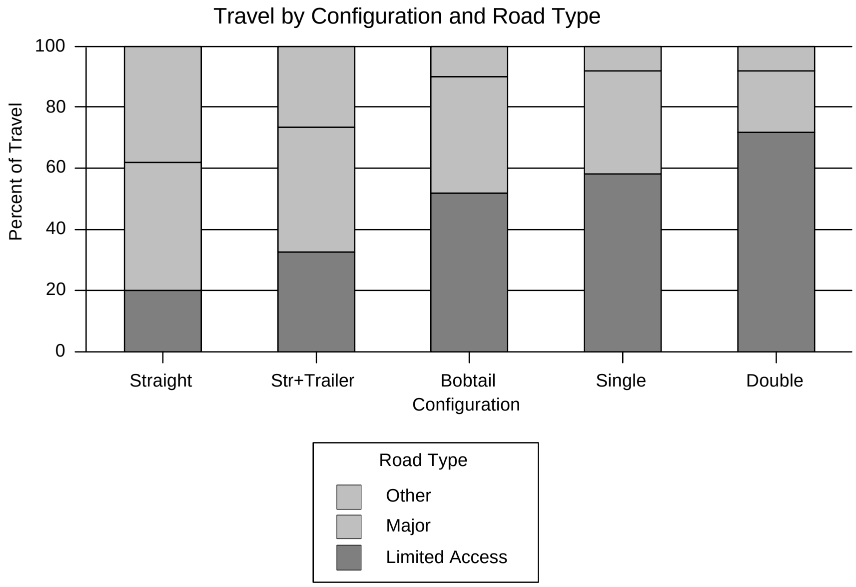

Figure 5. Travel by configuration and road type.[13]

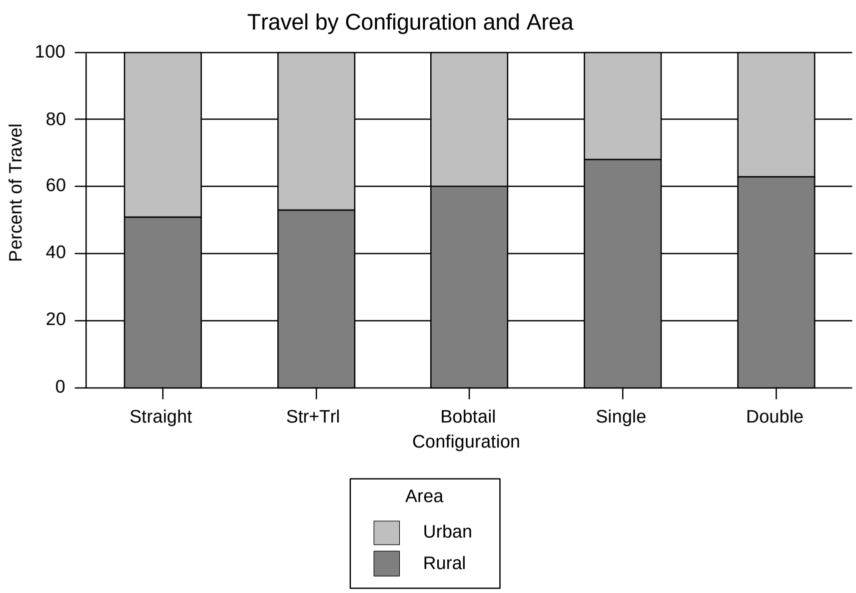

Figure 6. Travel by configuration and area.[13]

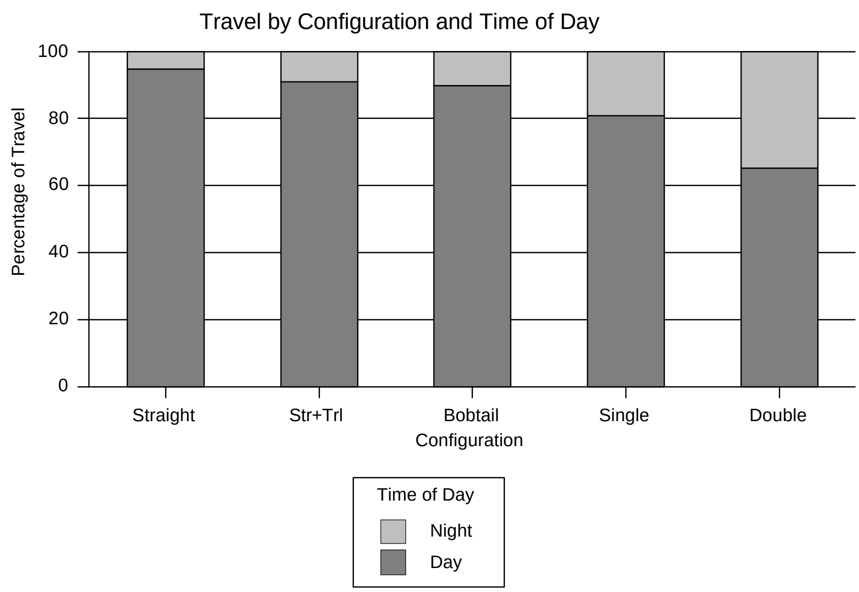

Figure 7. Travel by configuration and time of day.

B. Trip Distribution on the Highway Network.

Figures five, six and seven show the distribution of trips based on road type, area, and time of day.

The average percentage of trucks in traffic varies significantly based on the location, type of road, and time of day. This can range from 2 percent in urban areas to 19 percent on rural freeways.[12]

5.3.3 Financial and Economic Characteristics

A. Operating Costs

Operating costs for trucking firms include a combination of fixed and variable costs. Fixed costs include opportunity costs of capital, vehicle and goods insurance, and facilities. Variable costs include fuel and oil consumption, travel expenses, and vehicle maintenance.
Cost items that are split between fixed and variable costs include plant and vehicle depreciation, wages and benefits, maintenance, and taxes. Typically, variable costs represent between 40 and 50 percent of costs, and wages representing 30 to 40 percent of the operating costs.[14]

A breakdown of operating costs is presented in table 33. There are significant variations, based on the sources used, in the per kilometer (mile) cost of freight transportation. In 1992, Class I and II carriers averaged $0.240 revenue per tonne kilometer ($0.166 revenue per ton mile), with costs averaging 95.3 percent of revenues.[11]

Table 33. 1992 Operating costs for class I and II carriers[1] ($=millions).[11]

	All Carriers	
Wages and Benefits	$ 25,560	% 49.5
Operating Supplies (Fuel, oil, tires, etc.)	5,628	10.9
General Supplies	2,281	4.4
Tax and Licenses	1,659	3.2
Insurance	1,421	2.8
Utilities	661	1.3
Depreciation	2,232	4.3
Equipment[2]	8,090	15.7
Building and Office Equipment	647	1.3
Misc. Expense	1,043	2
Profit	2,411	4.6
Total	51,633	100

[1] Excludes household goods carriers.
[2] Includes disposal of operating assets (salvage) and revenue equipment rents and purchases.

There are significant differences in trucking operating costs based on the type of services provided. Table 34 shows the differences in the labor costs for alternative service type.

Table 34. 1992 Labor and benefits costs as a percentage of revenues.[11]

All Carriers	% 49.5
Revenue of $25 Million or More (Class I Carrier)	52.3
Revenue of $5 to $25 Million (Class I)	33.7
Class II Carriers	38.2
Intercity Carriers	49.5
Local Carriers	44.9
General Freight (TL)	31.5
- TL Haul Greater Than 500 Miles	29.5
- TL Haul Under 250 Miles	38.3
General Freight (LTL)	61.5
- LTL Greater Than 500 Miles	63.7
- LTL Less Than 250 Miles	52.7
Bulk Commodities	31
Automobile Transporters	38.8
Tank Trucks	33.5
Refrigerated	23.9
Other Specialized Commodities	58.4

A summary of operating and revenue characteristics is provided in table 35. As with operating costs, there are significant variations among different types of carriers and services.

Table 35. Aggregate revenue and operating characteristics - 1992.[11]

Revenue per Mile ($)	1.69
Revenue per Ton/Mile ($0.00)	0.166
Revenue per Ton ($)	51.01
Average Load (Tons)	10.17
Average Haul (Miles)	307.56

5.4 The Impacts of the AHS on CVO Operations

In previous parts of this section, we have discussed the basic structure of freight transportation. In this section we will provide an overview of the key impacts that may be associated within the development of the AHS, with particular emphasis on the restructuring of freight transportation costs and the resulting changes in the freight transportation industry. Many of the impacts of the AHS on CVO operations will result from the concurrent development of advanced logistics systems. These systems will allow for improved tracking and management of freight movements. While these logistic systems are not required for the function of the AHS per se, the information and communication systems deployed as part of the AHS will provide a basis for greater diffusion of these advanced logistic systems.

5.4.1 Operating Costs

A. Wages and Benefits

As shown in table 33, wages and benefits constitute the largest single component of operating costs. The adoption of the AHS should result in a measurable reduction in supervisor, driver and cargo handler labor per tonne kilometer (ton mile) of freight moved. Much of this reduction is based on reduced "dead-head" and turn-around time, more efficient cargo handling, improved routing and scheduling, avoidance of delay, and reduced compliance costs. A smaller reduction in clerical and administrative costs could result from improved internal efficiencies.

It is unlikely that trucks would operate without drivers; it is necessary to get on and off the AHS. Although theoretically possible under some possible configurations (i.e., staging terminals where the vehicles are manned after completing their portion of the journey on the AHS guideway), most implementations will still have drivers assigned to vehicles. What would be possible, however, is that drivers could count the time operating on the AHS as "downtime," thereby significantly reducing long haul labor costs. While there may be institutional opposition from labor groups for this action, it is possible with the AHS.

It is difficult to anticipate the impact on vehicle repair and service labor costs. Many of the cost items in this category are variable costs, and should see a reduction in service requirements per tonne kilometer (ton mile) shipped as more efficient shipping reduces the number of kilometers (miles) traveled on each shipment. The AHS equipment itself, however, will require servicing and repair. These skills are frequently very different from the maintenance capabilities now in use for most freight transportation firms, and establishing and operating maintenance and repair facilities (or outsourcing to vendors) could provide a significant additional cost. These two tendencies may serve to largely cancel each other out.

The overall effect will likely be a reduction in direct labor costs for freight transportation. A reduction in wages should result in a near proportional reduction in fringe benefits.

B. Fuel and Related Expenses

Fuel, oil, tires and other materials consumed in truck operations currently make-up about 11 percent of operating costs. Reductions in travel per tonne kilometer (ton mile) of freight moved will result in a corresponding reduction in these expenses.

C. Equipment Costs

The most significant impact of the AHS on equipment costs will be the necessity of installing vehicle and office systems to work with the AHS. Some of these costs, like roadway costs, may be spread among both CVO and passenger transportation users. Much of the equipment, however, will need to be purchased by the freight transportation firms.

The cost per vehicle can vary significantly, based on the selected AHS, production economies of scale, and type of carrier. Even assuming that vehicle electronics and control device costs are in the thousands of dollars, they will likely represent a much smaller proportion of vehicle cost for CVO applications than for passenger transportation. Any AHS that can be marketed for passenger cars will not represent a major investment problem for significantly more expensive commercial vehicles, even with the required scaling up to accommodate the operations of larger vehicles, but higher durability needs will raise costs further.

A greater problem, however, is the conversion of the existing CVO fleet. With between (depending on estimates used) 80 and 120 million heavy trucks, tractors and trailers in the existing vehicle fleet, staging the conversion of the existing fleet will be a major cost item. The nature of this cost will largely depend on the implementation strategy used.

D. Insurance

Improved freight handling, safety and reduced travel per tonne kilometer (ton mile) should result in a reduction of insurance costs.

E. Tax and Permit Fees

The development of the AHS infrastructure will require significant contributions from users. It is anticipated that freight transportation service providers would see this reflected in significant tax increases. Use of the AHS may require specific permit fees, and would directly increase the cost for freight movement using the system.

5.4.2 Other Cost Issues

There are many elements of the AHS that have the potential to affect the cost of freight transportation. These include the cost of delay, compliance costs, logistics, and safety costs.

A. Costs of Delay

If the implementation of the AHS results in a significant reduction in delay, there will be a major cost reduction for CVO firms. The Association of State and Highway Transportation Officials (ASHTO) estimates that the net cost of commercial vehicle delay is about 7.6 billion dollars per year.[16] Significant reduction of delay will reduce the per tonne/kilometer (ton/mile) cost of freight transportation.

B. Compliance Costs

There are a number of costs associated with monitoring and regulating truck traffic. These costs, commonly referred to as compliance costs, include those costs associated with toll collection, permitting, weigh limit enforcement, vehicle and driver safety checks and enforcement, and vehicle licensing and registration. The cost for these activities has been estimated, in 1990 dollars, to be between 1.1 and 3.3 billion dollars annually.[16] The AHS will significantly reduce these compliance costs, since daily operations will require more precise monitoring. On the regulation side however, we could have the opposite effect of higher costs due to more complex regulation/certification procedures.

C. Logistics and Freight Operations

The greatest potential economic gain from the AHS will probably be in the overall improvement in logistics and material movement. This may result in lower transportation costs through reductions in the labor associated with tracking documentation and more efficient services. Of greater importance will be the improvement of service variables, such as reduced shipping time, reductions in lost or delayed freight, and greater reliability in scheduled deliveries. This improvement in service will enable other innovations in manufacturing, such as just-in-time (JIT) deliveries to function more efficiently. These gains may have broad impacts on overall production costs beyond their impact on freight transportation.

D. Safety

AHS can have significant impacts on trucking safety. Approximately 20 percent of all truck accidents occur entering or exiting freeways.[12] These accidents, along with others associated with mainline freeway operations, could be expected to be significantly reduced through the use of the AHS. AHS operations could also be expected to increase the ability of transportation agencies to monitor and enforce vehicle and driver regulations. This would reduce the number of unsafe trucks operating and could be expected to improve overall system safety.

E. Social benefits

Along with any reduction in congestion and improved utilization of the freeway network, there will be a reduction in air pollution, decreased use of fossil fuels, and other social benefits. These will be similar to those developed for passenger vehicles through the use of the AHS.

5.4.3 Estimated Impact of AHS on Freight Costs

An estimate of the potential impacts on freight operating costs is provided in table 36. The low estimate is based on a minimum level of efficiency; the high estimate is based on more effective and efficient implementation. In addition to the specific cost items, the AHS would be expected to provide an overall reduction in travel for moving the same quantity of freight. This reduction is based on improved routing and scheduling, more efficient packing, and possibly larger loads. An estimate of this overall travel reduction would be 10 percent for the low efficiency scenario and 20 percent for the high.

Table 36. Estimated impact of the AHS on CVO operation expense.

	Current %	Change (%)	
		Low	High
Wages and Benefits	49.5	-2.0	-15.0
Operating Supplies (Fuel, oil, tires, etc.)	10.9	2.0	-10.0
General Supplies	4.4	1.0	-2.0
Tax and Licenses	3.2	200.0	30.0
Insurance	2.8	-1.0	-25.0
Utilities and Communication	1.3	200.0	100.0
Depreciation	4.3	100.0	0.0
Equipment	15.7	100.0	20.0
Building and Office Equipment	1.3	10.0	-10.0
Misc. Expense	2	100.0	10.0
Profit	4.6	-	-
Total	100	710.00	98.00

Based on these estimates, the impact of the AHS on CVO operations could range from a negligible reduction of costs in the low efficiency scenario (-0.01percent) to a major reduction (-28.4 percent) if implemented in a highly efficient fashion. Using the volume of Class I and Class II freight in 1992, this would translate to an annual reduction in freight costs of up to eight billion dollars.

This savings represents the direct reduction in operating costs, and does not fully account for the economic impacts of improved logistics or social benefits discussed above. This estimate is only meant to provided a point of discussion on the potential impacts of the AHS on CVO operations. There are a number of assumptions and limitations that restrict the applicability of the data produced. Some of the more significant restrictions are discussed below.

5.4.4 Estimated Impacts on Network Structure

The most obvious impact on CVO applications on the AHS would be the requirement for designing the AHS infrastructure to accommodate CVO vehicles and loads. With increased automation and control, it is anticipated that carriers would move to increase the size of vehicles and vehicle combinations that operate on the roadway.

Excluding trucks from the AHS would allow designers to significantly reduce construction and maintenance costs. Specific design reductions would include narrower lanes, weaker road structures, lower overbridges, tighter curves, steeper grades, shorter acceleration/deceleration lanes, weaker guardrail and smaller noise barriers.[14] Historically, roadway design has built out to truck standards due to the need to accommodate buses, emergency and maintenance vehicles, many of which have design characteristics similar to trucks.

Freight transportation operations also require more development of the AHS in rural areas. For passenger transportation, the initial implementation of AHS would likely occur in congested urban areas. As shown in figures 2 through 4, long haul and larger trucking operations make significant use of the rural, interstate routes. While there would be benefits for commercial firms to reduce delays in congested urban settings, the design of the AHS for CVO would need to include major sections of the rural interstate network.

5.4.5 Estimated Impacts on Types of Goods Transported

Figure 4 presents a breakdown on the current composition of goods moved by Class I and Class II trucking firms. Assuming that the AHS implementation results in a significant reduction of costs, the following impacts could be anticipated:

Increased volume of time dependent shipping. Trucking already has significant advantages over rail and water shipping on service variables such as time. The implementation of the AHS, combined with a concurrent improvement of logistic systems, would be expected to increase the volume of time-critical shipping. Some of this would be generated by capturing air freight shipments, but most would result from increased demand (i.e., Just-in-Time delivery systems) based on the improved capabilities of the system.
Increased capture of market share from rail and water modes. Trucking has a significant advantage in service and distribution over both rail and water transportation. With a significant reduction in cost for freight movement, these modes would be expected to lose market share to trucking.

5.4.6 CVO and AHS Operating Modes

Alternative operating modes will provide different relative costs and benefits to CVO activities. This section will analyze the likely impacts of each of the four major alternative modes. It will also review the basic characteristics of the alternative modes; examine the operating, economic, and industry structure characteristics; and look at the implications of implementation. These include issues associated with staging, institutional change, and sources for support and opposition to inclusion of trucks in the AHS traffic stream. This discussion is limited to the alternatives that operate with mixed truck and passenger traffic

A. Alternative Group I_1

A detailed description of the alternative modes is contained in other sections of this report. In summary, the key characteristics of Group I_1 include:

Some automated, vehicle based longitudinal control.
Low level collision avoidance systems.
Basic routing advice.
Some emergency support.

This operating mode represents the least variation from the current highway system.

A.1 Operational Characteristics

Automated lateral control, if capable of reducing headways, may reduce travel time for freight movements for vehicles using the AHS. The physical tasks of the driver, however, will not be significantly restructured based on this basic lateral control. The operators will still need to maintain full attention to vehicle maneuvering, both for the steering functions and for sudden deceleration.

More important than the impacts on drivers will be the necessary design changes if trucks are included in the Group I_1 design criteria. Braking performance for commercial vehicles, and particularly heavy trucks, will require special consideration in the design of operating headway distances. A two-tiered system, with greater headways for larger vehicles or an increase in truck braking performance will be required.

A.2 Economic Characteristics

The lateral control may provide some marginal increases in productivity resulting from reduced travel times through congested urban areas. This increase, however, may be largely offset by any costs associated with equipping vehicles for traveling on the AHS, additional fees and permit required for operating on the system.

A greater increase in productivity may result from the improvement in emergency notification and the basic navigation assistance elements in this operating mode. Again, this may be offset by both the equipment cost. There are also a number of existing notification and guidance support systems (e.g., Qualcomm) that may be less expensive and of higher utility that provided under Group I_1.

A.3 Industry Structure

There will not likely be any major changes in the trucking industry resulting from adoption of the technologies associate with Group I_1. Firms that use the AHS will have some benefits over non-users mainly in the area of safety, and there will be some logistics related improvements in operations for larger firms.

B. Alternative Group I_2

Group I_2 includes all of the elements of Group I_1, with the addition of:

Passive support for lateral guidance
More advisory information
Increased TMC activities such as monitoring the roadway.

B.1 Operational Characteristics

The combination of lateral and longitudinal control will alter the basic operation functions of trucking. Although it is anticipated that AHS vehicles would share the guideway with manual vehicles, many of the tasks would be automated and the driving environment would be changed.

Specific changes would include the reduction of driver demands, with possible changes in work rules to allow longer shifts. Improved roadside communications and emergency notification would also change the basic driver operation.

The impacts of trucks on the operational characteristics of the Group I_2 alternative will be significantly greater than those in Group I_1, with the added difficulty of incorporating large trucks into lateral control tasks.

B.2 Economic Characteristics

Group I_2 will have significant economic impacts on both participating and non-participating trucking firms. With revision in work rules, there is significant potential for labor savings. More efficient movement of vehicles through the traffic stream will provide a strong economic incentive to adopt AHS technology. Increase safety through vehicle control and improved monitoring and emergency response will result in cost savings, and these technologies may allow for increasing trailer loads.

Equipping and retrofitting vehicles for both lateral and longitudinal guidance will result in significant vehicle costs. While these costs are not likely to require separate vehicle systems for AHS and non-AHS trucking, there will begin to be differentiation in the system. A key issue in whether the systems begin to separate at this time will be the amount of instrumentation required for the trailers. There is a higher marginal cost (based on the lower initial cost) to make "smart" trailers, and there will be economic incentives to keep these higher cost vehicles out of the general trailer fleet.

B.3 Industry Structure

Group I_2 technologies begin to restructure the trucking industry. The cost of equipping vehicles, will lead to a separation of equipped and non-equipped vehicles. Participation will be more feasible for larger, more heavily capitalized firms. As stated above, market differentiation and specialization should begin with this option.

C. Alternative Group I_3

Alternative Group I_3 includes all of the technologies described in Group I_2, with the addition of:

Integration of lateral and longitudinal vehicle control.
Complicated vehicle maneuvers like lane changes, merging and weaving.
Traffic flow management.

Increased automation of the driving environment.
Increased motion coordination and traffic management.

C.1 Operational Characteristics

The increased automation of the driving function begins to significantly transform the driving task. It is anticipated that there will be a separated guideway, with hands-off driving not only possible, but necessary to use the system.

The implications of including trucks in the Group I_3 strategies will require inclusion of the maximum size truck as the "design vehicle" for construction of the physically separated guideway. This design vehicle may be larger and heavier than the existing double or triple trailer, since one motivation for participating in the AHS will be to maximize truck capacity. Given the diversity of commercial vehicles, it will also be more difficult to incorporate trucks into the physical operations required for this option.

C.2 Economic Characteristics

The major trends identified above continue. Efficiency and safety user savings are greater, and there are increased system efficiencies. The cost for implementing the control technologies are also greater, and these cost include the design and retrofit of systems for both the tractor and trailers. These trailer instrumentation costs will significantly raise the cost for participation.

C.3 Industry Structure

The implementation of Group I_3 technology will increase the separation of AHS compatible trucks from non-AHS trucking. The cost of instrumentation and the application on specialized routes will limit participation in the program to those firms that can integrate these operation with larger freight movements or are specialty players.

D. Alternative Group I_4

This group represents the "built out" AHS, with all of the features described above and:

Platooning, with integrated entry and exit.
A high level of automation.
Extensive guideway instrumentation.

This level of development is predicated on high demand, and is likely to be utilized only in congested urban settings.

D.1 Operational Characteristics

This alternative represents a complete restructuring of the driving function, with much of the heavy vehicle operation task being automated and "hands-off." In spite of the overall reduction in demands on the driver, it is likely that operating this type of vehicle will become an increasingly specialized occupation. In addition to needing the skills required for operating the vehicle in a non-AHS mode, drivers will be required to understand monitoring requirements to operate in the AHS environment.

As in the previous scenario, the inclusion of trucks in the mix will have significant operational implications for this scenario. Exit and entry maneuvers, headways, and stopping characteristics will all require significant restructuring if trucks are included.

D.2 Economic Characteristics

As stated in the description of Group $I_{3,}$ the more advanced AHS concepts involve a shift toward more capitalized, large firm basis. The cost of equipping these vehicles will be high, and participation will be limited to those firms that can effectively utilize the increased performance, greater capacity and labor savings. These will be either large firms that can effectively parse freight traffic to the more specialized service, or niche players that can integrate with other trucking operations.

Labor saving will represent a significant portion of the anticipated cost savings. As the task of operating the AHS equipped truck becomes more specialized, the savings in labor may be partially offset by the increase hourly rate of operators. If the driver is required to perform any kind of routine checks or even basic system debugging on simple failure cases, this will have an impact on hourly rates and certification processes. In rural areas such driver capabilities would be very desirable. With revision of existing work rules, greater haul capacity and more efficient freight movement, significant labor savings are possible even with increasing labor rates.

D.3 Industry Structure

As stated above, the movement to Group I_4 will primarily serve firms that have the financial and operational capability to take advantage of these systems. With the increased specialization of this type of truck transport, AHS freight movement could become an entirely separate mode, with terminal transfers required for integration with standard trucking, or in later stages influencing the trucking industry as a whole towards the AHS standard.

E. Other Operating Mode Issues

A critical issue facing AHS designer is whether to include commercial vehicles and trucking in the system. There are strong reasons for both the inclusion and exclusions of trucks from the system.

E.1 Inclusion of CVO in AHS Development

There are strong reasons for inclusion of trucks in any of the scenarios. These reasons include easier implementation of new technologies in commercial systems, cost sharing for development, and systems benefits.

Commercial vehicles represent a significantly easier market for the introduction of AHS technologies than the passenger vehicle system. The marginal cost of equipping vehicles for the AHS is much lower for commercial vehicles, and the benefits are both greater and more easily recognized. These reasons have resulted in the trucking industry being in the forefront for many new technologies, including navigation assistance, AVI/AVL, and road pricing.

Commercial operations will also be strong contributors to the overall cost of the program. There are well established methods of charging firms for their participation in the system, and relatively little opposition from participating firms. As demonstrated in the above section on potential benefits, there is an available pool of resources that could be partially tapped to support system development.

E.2 Exclusion of Trucking From AHS Options

There are equally powerful reasons for excluding trucks from the AHS program. Inclusion will require the acceptance of the largest anticipated truck as the design vehicle, and greatly increasing the cost for guideway construction.

Inclusion of trucks will also present major operational difficulties. Designing integrating larger vehicles in lateral and longitudinal control will likely degrade overall system performance. Acceleration, braking and turning characteristics of large trucks require some design level compromises.

The greatest problem, however, may be in the area of public acceptance. The reduction of headways and hands-off driving will be a more difficult process to sell to the general public with the inclusion of trucks in the vehicle stream.

All of the identified problem will likely be greater for Group I_3 and Group I_4. The separated guideway, automation of the system, significantly reduced headways and automated merging will increase the design, operation, and public acceptance problems for commercial vehicles.

F. Urban/Rural Issues in Commercial Vehicle Operations

Much of the concentration of effort in both the IVHS and AHS work programs have centered on urban needs. These programs have the potential to significantly reduce congestion and improve mobility and accessibility to transportation services in high volume, congested urban settings. These same technologies, however, may also meet specific rural transportation needs.

It is critical to identify what issues are fundamental to the development of advanced rural transportation systems, which may be supported in the development of the AHS. This review will center on those issues associated with CVO, but many are applicable to a wider range of AHS issues.

F.1 Rural Needs

Rural transportation systems are not immune to the problems facing many urban highway systems. Many recreational and interstate routes face periods of congestion during peak times, and issues of safety and service parallel those in urban areas. The logistics and layout of rural networks, however, have many distinct differences, and a different set of needs. Two specific rural needs that could be addressed through the implementation of the AHS include the need for emergency assistance and increasing the carrying capacity of long haul trucking.

F.2 Emergency Assistance

The need for real-time emergency assistance system on rural roadways has been repeatedly demonstrated. Major, multi-vehicle incidents occur regularly, often resulting in catastrophic loss of life and property. Often compounded by poor visibility from fog, dust, snow or other environmental factors, these incidents are characterized by the repeated collision of vehicles at near freeway speed with stopped and disabled vehicles.

These type of accidents can occur in either rural or urban settings. In the rural settings, however, there are specific characteristics of the rural highway system that can exacerbate this problem. These characteristics include:

The high speed of free flow vehicles.
The high mix of trucks in the traffic stream.
Inattention and acclimation of drivers to traveling in reduced visibility conditions.
Length of time required to notify agencies of the incident.
Length of time required for emergency and field vehicles to reach the incident location.

Based on the scenario developed, the AHS would be able to address this specific problem. Even the most basic operating mode would provide longitudinal control to prevent collision with the stopped vehicles. In a configuration with separated trucks and passenger vehicles, control on the passenger section would provide a method of alerting truck of potential problems, and likely slow vehicle speeds even in the non-controlled portion of the guideway.

F.3 Freight Capacity and Consolidation

As shown in the above statistics on truck travel, rural freight transportation is more likely to be characterized by long-haul, truckload (TL) carriage. The AHS would provide the potential for more efficient freight movement, including an increased number of trailers per tractor and an added capacity for the trailers. These "road trains" would provide significant efficiency gains for rural truck transportation, and could be combined with other freight initiatives (e.g. multimodal regional freight hubs).

F.4 Critical Urban/Rural Issues

There are several key issues that impact rural/urban AHS development. Specific issues that need to be considered include:

Guideway instrumentation.
Congestion and capacity.
Traffic management centers.
Road pricing.

The primary problems associated with extending the AHS to rural areas center on guideway instrumentation. The long distances, combined with the relatively low traffic volumes, may make inclusion of the rural network prohibitively expensive. Some low cost alternatives may represent only a marginal cost increase over existing road construction costs, but the retrofitting of long sections will be a major cost element.

Rural networks experience problems with congestion and capacity. These problems are different from urban congestion, and frequently the congestion is of shorter duration, limited to certain key links, and occurring on alternative cycles (e.g., weekend recreational travel versus recurrent congestion in urban areas).

One possible approach to integrating rural and urban operations is the inclusion of rural areas in TMC's. TMC's, integrated with AHS and IVHS communication systems, can reach to meet many needs identified above. A more detailed discussion is presented in section four.

A critical problem of including the rural network in any AHS scenario is pricing for the service. The relatively low volumes preclude the development of any roadway intelligence with a significant charge. Freight transportation, with the greater use of the system and higher value to freight movement, could be a large contributor to any pricing policy to pay for rural AHS.

F.5 Summary of Rural/Urban Issues

The development of the AHS in rural areas will present unique problems and opportunities for system planners. Prior to development, several issue need to be resolved, including the more detailed identification of rural needs, and the analysis of the rural cost structure.

Implementation of AHS strategies in rural setting will likely require a layered approach, with different levels of automation for alternative stretches of roadway. This layer approach may also apply to Traffic Management Centers. In a system somewhat analogous to the air traffic control system, rural TMC's may provide a lower level of control and intelligence, "handing off" traffic to urban centers with more strategic control over vehicle movements.

5.5 Conclusions and Implications for Urban/Rural Comparison

In the previous sections, we have examined the current state of the freight transportation industry and the likely effects of implementation of the AHS. This section will provide an overview of the broad impacts of the AHS on the trucking industry, discuss some limitations in this review, and suggest areas for future work.

5.5.1 Impacts on the Trucking Industry

The adoption and implementation of the AHS would have other effects on the trucking industry. Three specific impacts would include increased intermodalism, vertical integration and consolidation of firms.

Intermodalism is one of the current trends in freight transportation. The key principle to intermodal freight transportation is that different modes have different operating efficiencies, and the optimal shipping of a given element of freight may involve different modes for different segments of the trip. The problem with intermodal shipments is the discontinuity of shifting modes, and the problems in transferring the goods from one mode to another.

Part of this problem involves the physical handling of the freight. A greater part, however, is logistical. Coordinating the arrival, transfer and departure of shipments has outweighed the benefits of maximizing mode use. The adoption of AHS would work to reduce some of these logistic barriers, through the implementation of system standards. Firms that were able to benefit from the adoption of AHS technologies would be able to adapt these same technologies, with relatively little effort, to advanced logistic systems. These systems would work toward reducing the problems with intermodal transfers, and increase the potential uses of intermodal freight transportation.

Vertical integration refers to the consolidation of other related functions in an industry. In freight transportation, this would occur when, for example, a trucking firm integrated other functions of the freight transportation system, such as warehousing, broker and consolidator services, and operated other modes of shipping. The adoption of the AHS will provide users with the information capability to do more than just ship. It is expected that those organizations that can fully use the AHS will also provide other services as well.

Another anticipated result of the AHS would be a reduction in the number of firms operating, and an increase industry concentration in the trucking field. The AHS, and the related logistics and information systems associated with the AHS, will benefit larger firms that can consolidate and maximize operations, and can produce the capital necessary to move to the system. Increased accountability of drivers and vehicles will also shake out some marginal operators who currently remain competitive by operating outside of required safety regulations.

Commercial transportation firms have traditionally played a leadership role in the application of new technologies. These groups have the potential to make significant contributions in the development of the AHS. Those responsible for the design of the emerging AHS should undertake to understand how to best use and integrate with commercial vehicle operations.

5.5.2. Limitations of the Study

This review has been designed as a preliminary, conceptual overview on the potential impacts of the AHS on freight transportation. As such, there are a number of limitations that restrict the interpretation of the data.

A. Incompatible source data.

A wide range of primary and secondary data sources have been presented in this report and used to estimate the impact of the AHS on the tonne kilometer (ton mile) cost of freight. There are significant problems in the definitions used for the data collected, the time period the data was collected for, and in the accuracy of secondary data sources.

B. Definitions.

There are problems in both the definitions of AHS and CVO that affect the interpretation of this study. The concept of AHS can be implemented in significantly different configurations, each of which will result in significantly different impacts on transportation costs. Due to data availability, this examination of CVO activity has been largely limited to Class I and II truck and freight movement. Much CVO activity is excluded from this definition, and is therefore ignored in the analysis.

C. Aggregation of Freight Transportation.

There are considerable differences between the operating characteristics of different segments of the freight transportation industry, including LTL, specialty carriers, and local shippers. Using an aggregate analysis of cost impacts does not account for very different impacts on different sectors.

5.5.3 Alternative Freight Vehicle Scenarios

The above section described potential safety and economic gains associated with the adoption of CVO systems within the AHS. These gains have largely been through improved logistics, improved vehicle load factors and economies of scale. An alternative approach, however, may involve the development of smaller, modular freight vehicles. In size and weight such vehicles could resemble todays full size vans.

The development of these systems would be somewhat analogous to the "lean machine" concept for personal vehicle transportation. The smaller, lighter vehicles would have significantly less freight handling capacity, but would be capable of using guideways and system designed for "light duty" AHS vehicles, and restricted to regular heavy vehicles. While individual vehicle capacity would lower, it may be possible to provided increased system efficiency with these freight vehicles. Specific areas where efficiency gains could be realized include:

More efficient routing.
Multimodal transfer and carriage, including increased "piggy-back" service.
Linking of vehicles in "road train" configurations.
Reduction of less-than-truckload hauls.
Improved pickup and delivery service.
Quicker loading and unloading.

In order to utilize this type of freight configuration, there would need to be major changes in the freight transportation system. These changes include the development of the new vehicles, with the required maintenance and repair systems; construction and operation of terminals and modal transfer points to use the system; and an information and distribution infrastructure to support smaller, modular freight vehicle transportation. Smaller lighter containers, similar to the ones used in the air transportation industry would probably enhance such an operation as well as the interfaces of this mode to other freight modes. Other AHS related system changes such as conversion to guideway powering and roadway instrumentation would work synergistically with the move to smaller freight vehicles.

In order to assess the exact savings either from the improved logistics mentioned earlier in this section or the potential for the "smaller"-"lighter" freight vehicle described above, case studies with specific (possibly even carrier specific) existing carrier network structure and costs need to be performed. Assumptions will need to be made on the evolution of such networks and costs through the next twenty years and outputs compared to an AHS based solution. Institutional changes (specific to CVOs) needed for such a transition will also need to be examined.

5.5.4 Future Directions

This initial review of the potential impacts of the AHS on the freight transportation system point to several directions for future work. Future efforts in this direction should include:

Analysis of the primary source transportation data. The scope of this report limited the review to published primary and secondary data on trucking and transportation. There are a growing number of direct data sources, many of them on line, that could be used directly in determining the impacts of the AHS.

Specification of AHS alternatives. Again, as a preliminary overview of the AHS, this work effort is necessarily vague about the specific implementation of these new technologies. As there is movement toward developing more specific work in this area, more detailed assessments of the impacts on CVO operations can be developed.

Examination of market shifts resulting from AHS. The analysis presented is a static, ceteris paribus look at the impacts of the AHS. It does not take into account how these systems will change the basic nature of the market, or how shifting costs will impact the volume of freight and freight costs.

Investigation on non-trucking CVO. Most CVO analyses, including this report, discuss CVO issues primarily as related to Class I and II trucking (heavy trucks). While important, there is a large area of CVO activity, including local delivery, dispatch and other commercial operations that are not considered. This is primarily due to a lack of information on these groups, but additional research is warranted on these sectors of the CVO market.

Disaggregate analysis of freight. The operating characteristics of the freight transportation market differ widely based on both the type of freight hauled (LTL vs. TL; specialty carrier vs. common freight) and the type of service provided (intercity, local). A disaggregate look at the impacts of the services help identify specific impacts and service options that will benefit the developing AHS.

Integration of CVO operations with other modal efforts in advanced logistics. The movement toward AHS will increase the availability of data to freight transportation firms. The overall impact of this needs to be assessed, particular as it relates to the development of increased intermodal use.

6. DESIGN EFFECTS OF ENCOMPASSING HEAVY VEHICLES IN AHS

6.1 Introduction

This chapter examines the design effects of encompassing heavy vehicles in an Automated Highway System (AHS). For purposes of this study, heavy vehicles (HV) include transit and commercial vehicles. It is not yet certain if commercial and transit vehicles will be permitted to use an Automated Highway System on urban and/or rural highways. Urban and rural highways may have different solutions to the problem of dealing with HVs. If heavy vehicles are encompassed in AHS, its implementation will greatly facilitate Commercial and Transit Vehicle Operations. An Automated Highway System will decrease travel time, increase safety, and facilitate the adoption of electronic regulation of commercial and transit vehicles.[19] Even though heavy vehicles are only a small percentage of the vehicles on the road, encompassing heavy vehicles will affect the design of AHS in many ways due to the slower acceleration, slower top speed on grades, heavier weight, and wider body of HVs. The four design impacts that will be examined are the acceleration distance, maximum allowable grade, pavement and structural strength costs, and lane width. In addition, the significance of these impacts on urban versus rural highways will be discussed.

These effects will apply to the overall design if AHS encompasses commercial and transit vehicles in the same lanes with passenger cars. If HVs are given dedicated lanes, these design parameters will only apply to the separate Commercial and Transit Vehicle lanes.

6.2 Background

The traffic composition of 1987 is shown on the following page in table 37. There are seven buses or trucks for every 100 vehicles on U.S. urban and rural highways. Thus, there are 93 passenger cars for every seven heavy vehicles. On rural highways there are 11 heavy vehicles for every 89 passenger cars, while on urban highways there are five buses or trucks for every 95 passenger cars. Therefore, there is approximately one heavy vehicle for every eight passenger cars on rural highways, while there is approximately one heavy vehicle for every 19 passenger cars on urban highways. The increased density of heavy vehicles on rural highways emphasizes the importance of a heavy vehicle compatible AHS on those roadways. Vehicle density differences by class underscore the possibility of operational and/or design differences between urban and rural AHS.

Table 37. Traffic composition on US highways.[17]

Highway Type	Passenger Cars[1]	Buses	Single-Unit Trucks	Combination Trucks	All Trucks
Rural Interstate	80.6	0.3	3.1	16	19.1
Other Rural Arterials	89.9	0.3	3.4	6.4	9.8
Other Rural Highways	92.7	0.5	3.8	3	6.8
All Rural Highways	88.9	0.4	3.5	7.2	10.7
Other Urban Highways	96.2	0.2	1.9	1.7	3.6
All Urban Highways	95.2	0.2	2	2.6	4.6
Total Rural & Urban	92.7	0.3	2.6	4.5	7.1

[1] Including light trucks and vans

It has not yet been determined if vehicle check-in to AHS at on-ramps will be performed while vehicles are stopped or "on the fly." "On the fly" check-in is more desirable due to its efficiency. However, it has not been determined if the technology will be available to accomplish "on the fly" check-in. If "on the fly" check-in is not implemented, the on-ramp length will increase since a queuing area will be necessary and vehicles will be accelerating from a standing start.

6.3 Acceleration Distance

The on-ramp lengths of AHS will be longer when heavy vehicles are included due to the slower acceleration rates of HVs. Ramp lengths are much more forgiving today than they can be for AHS. The on-ramp lengths will be a combination of the acceleration distance and the distance needed for check-in. Since the configuration of check-in is not known, only the acceleration distance will be determined. The distance needed to accelerate from 0 to 89, 32 to 89, and 56 to 89 kph (0 to 55, 20 to 55, and 35 to 55 mph) will be determined. Although vehicles on AHS may be traveling at speeds greater than 89 kph (55 mph), the present data only covers HVs at speeds up to 89 kph (55 mph). Although tables 38 and 39 will not be used in the calculation of the acceleration distances needed, they show the slower acceleration rates of heavy vehicles.

Table 38.[1] Typical maximum acceleration rates on level roads from standing start.[18]

Vehicle Type	Weight/Power Ratio lb/hp	Typical Max. Acceleration Rate on Level Road (ft/sec^2)				
		0 to 10 mph	0 to 20 mph	0 to 30 mph	0 to 40 mph	0 to 50 mph
Passenger Car (PC)	25	9.3	8.9	8.5	8.2	7.8
	30	7.8	7.5	7.2	6.8	1.5
	35	6.8	6.5	6.2	5.9	5.5
Tractor-Semi-Trailer (TST)	100	2.9	2.3	2.2	2	1.6
	200	1.8	1.6	1.5	1.2	1
	300	1.3	1.3	1.2	1.1	0.6
	400	1.3	1.2	1.1	0.7	--

Since maximum acceleration rates are rarely used in automobiles, the observed normal acceleration rate for passenger vehicles of 1.1 m/s^2 (3.5 ft/s^2) will be used.[18] Performance curves from the “Highway Capacity Manual” will be used in order to determine the distance required for HVs to accelerate to 89 kilometers (55 miles) per hour.

Acceleration from standing start to 89 kph (55 mph). Table 38 above shows that a heavy vehicle with

[1] Pound (lb) x 0.45 = kilogram (kg)
Horsepower (hp) x 745.7 = watt (w)
Miles (mi) x 1.602 = kilometers (km)
Feet (ft) x 30 = centimeters (cm)
Above conversions are applicable to all tables that follow.

a weight/power (w/p) ratio of .061 kg/w (100lb/hp) has a maximum acceleration rate much less than that of a passenger car. The acceleration rate of 0.5 m/s^2 (1.6 ft/s^2) for 0 - 80 kph (50 mph) is less than half of the observed normal acceleration rate of passenger vehicles. Table 39 shows the large increase in distance needed to accelerate from a standing start to 89 kph (55 mph) for each increase in weight to power ratio. A w/p ratio of .061 kg/w (100 lb/hp) requires an acceleration distance which is 2.5 times greater than that of a passenger car.

Table 39. Distance needed to accelerate from 0 to 55 mph.

Vehicle Type	Weight/Power Ratio (lb/hp)	Distance (ft)	Multiplication Factor
Passenger Car	35	930	--
Tractor-	100	2300	2.5
Semi-	200	5250	5.6
Trailer	300	10000	10.8

Acceleration from a moving start to 89 kph (55 mph). Table 40 shows the typical maximum acceleration rates for 16 kph (10 mph) increments. This table shows that the acceleration rate of heavy vehicles drops off steadily as the speed increases. A HV with a weight power ratio of .061 kg/w (100 lb/hp) can accelerate at 60 percent of the normal acceleration rate of passenger cars between 32 & 48 kph (20 & 30 mph), but only at 17 percent between 80 & 89 kph (50 & 60 mph). This predicts that a moving start will not significantly reduce the acceleration distance needed with respect to a standing start due to the greater difficulty HVs have in accelerating at high speeds.

Table 40. Typical maximum acceleration rates on level roads for 10 mph increments. [18]

Vehicle Type	Weight/Power Ratio (lb/hp)	Typical Max. Acceleration Rate on Level Road (ft/s^2)			
		20 to 30 mph	30 to 40 mph	40 to 50 mph	50 to 60 mph
Passenger Car (PC)	25	7.8	7.1	6.3	5.6
	30	6.5	5.8	5.2	4.5
	35	5.6	5	4.4	3.8
Tractor-Semi-Trailer (TST)	100	2.1	1.5	1	0.6
	200	1.3	0.8	0.5	0.4
	300	1	0.6	0.3	--
	400	0.9	0.4	--	--

Tables 41 and 42 show that "on the fly" check in does not greatly reduce the required acceleration distance.

Table 41. Distance needed to accelerate from 20 to 55 mph.

Vehicle Type	Weight/Power Ratio (lb/hp)	Standing Start (SS) Distance (ft)	Moving Start Distance (ft)	Mult. Factor w/Respect to PC	Mult. Factor w/Respect to SS
Passenger Car	35	930	810		.88
Tractor-Semi-Trailer	100	2300	2000	2.5	.87
	200	5250	5100	6.5	.98
	300	10000	9900	12.3	.99

Table 42. Distance needed to accelerate from 35 to 55 mph.

Vehicle Type	Weight/Power Ratio (lb/hp)	Standing Start (SS) Distance (ft)	Moving Start Distance (ft)	Mult. Factor w/Respect to PC	Mult. Factor w/Respect to SS
Passenger Car	35	930	650		.70
Tractor- Semi- Trailer	100	2300	1600	2.5	.70
	200	5250	4750	7.3	.90
	300	10000	9900	15.4	.90

Table 42 shows that the distance needed for a HV with a weight to power (w/p) ratio of .061 kg/w (100 lb/hp), to accelerate from 56 to 89 kph (35 to 55 mph) is approximately 70 percent of the distance needed to accelerate from 0 to 89 kph (55 mph). 488 meters (1600 feet, which is .3 of a mile), is needed for a heavy vehicle with a weight/power ratio of .061 kg/w (100 lb/hp) and an "on the fly" check-in speed of 56 kph (35 mph), while 701 meters (2300 feet) is needed for this same vehicle when accelerating from a standing start. HVs with a kg/w ratio of .122 kg/w or .182 kg/w (w/p ratio of 200 or 300) experience only a minute reduction in the distance needed to accelerate to 89 kph (55 mph) due to "on the fly" check-in. The effect of "on the fly" check-in is a 30 percent reduction in the acceleration distance for passenger cars and heavy vehicles with a weight/power ratio of .061 kg/w (100 lb/hp). However, the length of on-ramps without "on the fly" check-in will be even longer due to the necessity of a queuing area.

The acceleration distance required for a heavy vehicle is between 2.5 and 15.4 times greater than a passenger car for w/p ratios of .061 to .182 kg/w (100 to 300 lb/hp). The acceleration distance of a .122 kg/w (200 lb/hp) truck is at least twice as long as the distance for a .061 kg/w (100 lb/hp) truck. As of 1992, the median weight/power ratio was .098 kg/w (160 lb/hp) in the United States.[21]

The w/p ratio of empty trucks was found to be in the range of .034 to .049 kg/w (55 to 80 lb/hp). The lower end of the scale was for two axle six tire trucks while the higher end was for tractor semi-trailers. Therefore, empty trucks are also not able to accelerate at speeds comparable to passenger vehicles. In addition, it should be noted that the deceleration distances for unloaded trucks are often greater than that of loaded trucks.

It is easily seen that the inclusion of heavy vehicles in a system where vehicles accelerate from standing stop will require much longer acceleration distances. The cost will increase due to the land costs and the paving of longer distances. Furthermore, many locations will not have sufficient space for longer on-ramps.

The difficulty in locating sufficient on-ramp space and the increased cost will be more apparent on urban highways than on rural highways. In general, rural highways have plenty of space available at a cheaper cost and less frequent on-ramps. One possible solution for urban highways will call for the limitation of locations where heavy vehicles are permitted to enter the system. This will require major coordination with the trucking industry, but is the likely answer if an Automated Highway System is implemented on urban highways.

6.4 Maximum Allowable Grade

The ability to maintain speed on an inclined road is of great importance because in general, heavy vehicles will already be traveling at steady state speed and will only have to maintain speed while on the grade.

Table 43. Maximum acceleration on upgrades.[18]

Vehicle Type	Weight/Power Ratio (lb/hp)	Grade	Typical Max. Acceleration Rate on Level Road (ft/s^2) 10 to 20 mph	20 to 30 mph	30 to 40 mph	40 to 50 mph	50 to 60 mph
Passenger Car (PC)	30	0%	7.5	6.5	5.8	5.2	4.5
		2%	6.9	5.9	5.2	4.6	3.9
		4%	6.2	5.2	4.5	3.9	3.2
		6%	4.6	4.6	3.9	3.3	2.6
		10%	4.3	3.3	2.6	2	1.3
Tractor-Semi-Trailer (TST)	100	0%	2.3	2.1	1.5	1.0	0.6
		2%	1.7	1.5	0.9	0.4	a
		4%	1.0	0.8	0.2	a	a
		6%	0.4	0.2	a	a	a
		10%	a	a	a	a	a
Tractor Semi-Trailer (TST)	200	0%	1.6	1.3	0.8	0.5	0.4
		2%	1	0.7	0.2	a	a
		4%	0.3	a	a	a	a
		6%	a	a	a	a	a

[a] Truck unable to accelerate or maintain speed on grade.

Table 43 shows the maximum acceleration rate on upgrades for grades up to 10 percent at 16 kph (10 mph) increments from 16 to 97 kph (10 to 60 mph). It shows that a passenger car with a w/p ratio of .018 kg/w (30 lb/hp) can maintain a speed of 97 kph (60 mph) with a grade of 10 percent, while a HV with a w/p ratio of .122 kg/w (200 lb/hp) cannot maintain a speed of even 64 kph (40 mph) while on a grade of two percent or greater. Therefore, trucks with a w/p ratio of .122 kg/w (200 lb/hp) or greater cannot be allowed on inclines of 2 percent or greater. Grades less than two percent and HVs with a w/p ratio of .061 kg/w (100 lb/hp) will now be discussed.

Performance Curves from the California Department of Transportation show that a HV with a w/p ratio of .061 kg/w (100 lb/hp) is able to maintain a speed of 89 kph (55 mph) for a grade of two percent or less. The chart did not examine the effects for speeds greater than 89 kph (55 mph). These HVs were able to maintain a speed of approximately 84 kph (52 mph) while on an incline of three percent. HVs with a w/p ratio of .122 kg/w (200 lb/hp) were able to maintain a speed of 85 kph (53 mph) while on a grade of one percent. The percentage of U.S. Highways with different grades was investigated but no listing of that information was found.

This study indicates that heavy vehicles with a weight to power ratio of .061 kg/w (100 lb/hp) can maintain a speed of at least 89 kph (55 mph) on grades of two percent or less, while HVs with a w/p ratio of .122 kg/w (200 lb/hp) cannot maintain a speed of 89 kph (55 mph) on a grade of one percent or greater. The maximum speed of HVs with a w/p ratio of .061 kg/w (100 lb/hp) while on one percent grades was not found.

One possible solution would be to have a mandatory exit point at the bottom of inclines for all vehicles which cannot maintain the required speed. The steepness of grades which follow could be listed along the roadside. Vehicles would be permitted to rejoin AHS once they are able to maintain speed on the grade which follows. This would allow vehicles which cannot maintain adequate speed on grades to benefit from AHS on roadways which do not include grades.

Requiring certain vehicles to exit AHS before grades will be more difficult to accomplish on urban highways than on rural highways. The transfer of vehicles from AHS lanes to not-AHS lanes and then back again will be easier in less congested areas. In addition, it is quite possible that the non-AHS lanes on the urban highway will be traveling at much slower speeds due to congestion. This discrepancy in speed between the AHS and non-AHS lanes will make the merging of vehicles difficult.

6.5 Pavement and Structural Strength Cost

All current highways are designed to withstand the force of heavy vehicles. If heavy vehicles are not included in AHS, highway and overpass design could be affected. The decreased weight will affect the design of pavement and structural strength. However, the extent to which the design change will dramatically influence the cost is uncertain. It was difficult to find any reliable design standards pertaining to design weight for passenger vehicles only since all present highway designs include heavy vehicles.

An initial evaluation shows the design of "passenger vehicle only" lanes will not be substantially cheaper than a design that included heavy vehicles. The structural strength of sections of pavement will be reduced in a "passenger vehicle only" lane, but the overall cost of paving the lane will only slightly be reduced. The structural strength of an overpass will also not be significantly effected. The design is governed by the moment equation which is $WL^2/8$. This equation shows that the effect of heavy vehicles will be less in a larger bridge due to the squaring of the length of the bridge. In addition, the weight in consideration is a ratio of dead load to live load. The large dead load of a concrete overpass overshadows the increase in live load of HVs.

Although it will only be a small increase (if heavy vehicles are included in the AHS) in pavement and structural strength cost on both urban and rural highways, it will be greater on rural highways due to the higher density of heavy vehicles on those roadways. Lower traffic densities in these areas will further magnify that effect in a cost effectiveness calculation.

6.6 Lane Width

If heavy vehicles are excluded from AHS lanes, the width of "passenger vehicle only" lanes could be decreased to enable lanes to fit into smaller regions. Table 44 gives the vehicle characteristics of a passenger car and various heavy vehicles.

Table 44. Vehicle characteristics.[18,20]

Vehicle Type	Height (ft)	Width (ft)	Length (ft)	Weight/Power Ratio (lb/hp)	Turning Radius (ft)	Min. Inside Radius (ft))
Passenger Car	4.24	7	19	32.38	24	15.3
Bus	13.5	8.5	40		42	23.3
A-BUS	10.5	8.5	60		38	21
WB - 40	13.5	8.5	50		40	19.9
WB - 50	13.5	8.5	55		45	19.8
WB - 60	13.5	8.5	65		45	22.5

The design vehicle width will be increased from 2.1 meters to 2.59 meters (7 feet to 8.5 feet) if heavy vehicles are encompassed. The actual lane width will be increased from approx-imately 2.74 meters to 3.35 meters (9 feet to 11 feet). This will increase the width 0.61 meters (2 feet) which is an increase of 22 percent. This many come into effect when trying to squeeze lanes under an underpass or into the cost of paving a roadway while constructing new lanes. However, due to the fact that AHS lanes will most likely only be in groups of one to three lanes, the effect of the reduction in lane width will be minor. Since rural highways usually have adequate space and fewer lanes side by side, the lane width reduction will have a more significant effect on urban highways.

6.7 Conclusions and Implications for Urban/Rural Comparison

Including Commercial and Transit Vehicles in an Automated Highway System will impose many changes in the design of AHS. This initial investigation showed that incorporating heavy vehicles in an Automated Highway System will have a significant effect on the design with respect to acceleration distance and maximum allowable grade but will not have a significant effect on pavement and structural strength costs and lane width. The following results are a rough estimate of the changes that will result if heavy vehicles with weight to power ratios of .061 kg/w (100 lb/hp) are encompassed in AHS:

The acceleration distance will be 2.5 times longer.
The maximum allowable grade will be 2 percent.
The lane width will be at least 22 percent greater.
The structural strength cost of bridges will not be significantly affected.
The pavement structural strength will be affected.

If heavy vehicles with weight to power ratios of .122 kg/w (200 lb/hp) are included the list will have the following changes:

The acceleration distance will be between 5 & 7 times longer.
The maximum allowable grade will be under 1 percent.

One possible consideration would be to have a mandatory exit point at the bottom of inclines for all vehicles which cannot maintain the required speed. Those vehicles would be permitted to rejoin a platoon, on the AHS, once the climbing has ended. This would allow vehicles which cannot maintain speed on grades to benefit from AHS on the majority of the roadways which do not include grades. Another possible consideration would be to reduce the number of on-ramps that heavy vehicles are permitted to use. Further investigation needs to go into the acceleration rates of heavy vehicles with h/p ratios between 0.061 kg/w and .122 kg/w (100 and 200 lb/hp).

The design effects which have a significant effect on AHS, acceleration distance and maximum allowable grade, also have a more prominent effect on urban highways than on rural highways. This is due to the lack of space available and increased congestion in urban areas.

7. AHS EMISSIONS - A FUTURE PATH

7.1 Introduction

This study outlines some of the potential impacts of AHS on vehicle emissions. First, some vehicle emissions background. The impacts of AHS on vehicle emissions are then analyzed through an example analysis of the Los Angeles Region. Finally, we propose future steps to best deal with vehicle emissions related to AHS, and evaluate the potential impacts of emission changes on urban AHS versus rural AHS.

7.2 Vehicle Emissions-What's Involved

Vehicle emissions account for about 45% of the total national emissions. Sources include autos, trains, planes, and commercial ships. As of 1991, motor vehicles accounted for 75% of all vehicle emissions or 32.75% of the total national emissions.[22] These emissions pollute the atmosphere and affect human health as well as animals and vegetation. In light of this major concern, the CARB staff have been working very hard over the years to not only measure vehicle emissions accurately, but to also find ways to minimize their impact on the environment. EMFAC[23] is the computer model used for estimating on-road motor vehicle emissions for California's twenty million plus vehicles. The data that provide for the basis for EMFAC are obtained using extensive testing of motor vehicles conducted by the CARB and Environmental Protection Agency (EPA). Testing is performed using standardized test cycle conditions (FTP) in which average speed is the deciding factor for obtaining Composite Emission Factors (CEF's). The three most important factors affecting CEF's are cold or hot start, trip length, and hot soak. EMFAC's output is used in air quality modeling (such as Airshed), micro-scale models (such as Caline), and inventory calculations (with models such as Burden). For example, EMFAC outputs CEF's to the BURDEN program (inventory model) which measures Total Organic gases (TOG), Reactive Organic Gases (ROG), Carbon Monoxide (CO), Oxides of Nitrogen (NOx), Particulate Matter (PM), Lead (Pb), and Oxides of Sulfur (SOx) by using vehicle activity with speed ranges from 0-105 kph (65 mph) for the 13 class/technology groups available. To illustrate, let's look at Light Duty Autos equipped with Catalytic Converters (CAT) (class/technology #2), for CO, we have:

$$CO = CS + HS + RE^{5} \quad \text{(Tons/Day)} \qquad (1)$$

Where:

$$CS = CEF * \#CTRIPS / CF \quad \text{(Tons/Day)}$$
$$HS = CEF * \#HTRIPS / CF \quad \text{(Tons/Day)}$$
$$RE = CEF * VMT / CF \quad \text{(Tons/Day)}$$

CS = Cold Start
HS = Hot Start
RE = Running Exhaust
CEF = Composite Emission Factor (from EMFAC)
#CTRIPS = Number of Cold Trips
#HTRIPS = Number of Hot Trips
VMT = Vehicle Miles Traveled

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[5] Equation has inherent English measurements.

CF = Correction Factor

The Cold Start creates the highest concentration. The Hot Start creates the second highest concentration, but has gotten almost as low as the Running Exhaust concentration since the introduction of catalytic converters.

Another critical aspect of the measurement is the existing engine technology. Today's engines, equipped with catalytic converters, produce pollutants' concentrations at their lowest at speeds 48-80 kph (30-50 mph), and higher otherwise, while using unleaded gasoline fuel.

7.3 AHS Emissions and Impacts

Using the existing CARB's technology for emissions inventory (EMFAC and BURDEN), we can model the impacts of AHS on the trip length part of vehicle emissions by increasing the percent of Vehicle Miles Traveled (VMT) in the speed distribution files of the BURDEN vehicle activity. For this purpose, we selected the South Coast Air Basin. This includes the counties of Los Angeles (SC-19), Orange (SC-30), Riverside (SC-33), and San Bernardino (SC-36). Comparing the existing vehicle emissions for the well known pollutants (TOG, ROG, CO, NOx, PM, Pb, and SOx) with the emissions produced at the different levels of AHS should give us an idea about the impacts of AHS on the pollution of the environment resulting from the South Coast vehicle emissions. Since modal emissions are not available for AHS and during the first AHS stages market penetration will be low, this may be a good approximation. For later AHS stages when substantial flow changes will be experienced, savings from reduced “enrichment” powertrain activities could become dominant.

Since AHS does not exist yet, there is no information available to base our decisions on. We, therefore, entertain two different scenarios: A moderate speed increase with resulting flow influences scenario where 20%[2] of the VMT moves up to the next speed range; (speed ranges in groups of 7 kph (4.4 mph)) and a significant speed increase scenario where 50%[3] of the VMT moves up to the next speed range. We assume that speeds below 40 kph (25 mph) will not be affected by AHS since it represents mainly local and arterial traffic. Consequently, changes in percent of VMT are to occur from 40 kph (25 mph) and up. It should be noted that maximum speed is 100 kph (62.5 mph). The following methodology outlines the changes in our speed distributions:

MODERATE SCENARIO - 20% INCREASE (Compared to baseline - today)

I_1 (longitudinal control):
- Increase 20% of normal speeds ranging from 40 kph (25 mph) and up.

I_2 (lateral vehicle guidance added):
- Increase 20% of I_1 speeds ranging from 40 kph (25 mph) and up.

I_3 (fully automated highway):
- Increase 20% of I_2 speeds ranging from 40 kph (25 mph) and up.

I_4 (total instrumentation-Platooning):
- Increase 20% of I_3 speeds ranging from 40 kph (25 mph) and up.

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[2] Not a total 20% increase in speed, but rather a 15~20% increase for only 20% of "affected" VMT - (about 10% of total VMT)
[3] Again, a 15~20% increase for 25%~30% of total VMT.

SIGNIFICANT SCENARIO - 50% INCREASE (Compared to baseline - today)

I_1 (longitudinal control):
- Increase 50% of normal speeds ranging from 40 kph (25 mph) and up.

I_2 (lateral vehicle guidance added):
- Increase 50% of I_1 speeds ranging from 40 kph (25 mph) and up.

I_3 (fully automated highway):
- Increase 50% of I_2 speeds ranging from 40 kph (25 mph) and up.

I_4 (total instrumentation-Platooning):
- Increase 50% of I_3 speeds ranging from 40 kph (25 mph) and up.

The above scenarios of 20% and 50% speed increases were chosen to illustrate the changes brought about by the implementation of AHS in the South Coast Air Basin. The numbers of 20% and 50% reflect a conservative approach from our part in trying to represent the impact of AHS on the daily pollution produced by the South Coast traffic. There is no rational explanation behind the numbers' choice, beside the fact that they seem more conservative than not. We expect AHS to make much more significant changes in emissions, especially toward higher speeds. The actual average speed increases over the whole population of VMT vary from case to case. The assumptions were that part (20 or 50 percent) of the VMT with speeds between 40 kph (25 mph) and 100 kph (62 mph) will go faster (by 15 to 20 percent) and the rest of the VMT will have the same speeds.

The criteria for the speed increases are the following:

Total percent of VMT is constant throughout 0-105 kph (65 mph) range (= 100%). 5 kph (3 mph) is the typical increase, therefore the percent of VMT in a given range moves up to the next range. VMT with speeds under 40 kph (25 mph) should be excluded because it is likely to originate from arterial traffic.
Always exclude the added percent of VMT when moving to the next range.
105 kph (65 mph) is the top speed, therefore 97-105 kph (60-65 mph) is the top range.

The BURDEN program prints out a report summarizing the vehicle emissions in TOG, ROG, CO, NOx, PM, Pb, and SOx (in tons/day), and also reports the fuel consumed (in 1000 Liters/day). Using our methodology, we will end up with five separate reports for each scenario: one without AHS impact, and four reports illustrating each of the four stages of AHS for each of the two scenarios. A sensible way to present the impacts of AHS would be to show the effects of AHS at each level using bar graphs comparing the before and after amount of each pollutant. Another technique is to present the whole information in a table summarizing the percent changes to pollutants at the different levels of AHS.

Each report (I level) will require the increase of speed distributions of the four counties (Los Angeles, Orange, Riverside, and San Bernardino) for the six periods of the day (P0006, P0609, P0912, P1215, P1518, and P1824); and will require a computer run to obtain the results. The results to be compared are the totals of each pollutant over the six periods of the day with the four counties added together. Also, each pollutant is determined by adding the necessary components that comprise it (i.e., CO and NOx are made of Exhaust Emissions, while TOG are made of Exhaust and Evaporative Emissions and Pb and SOx are present in the vehicle fuel).

7.4 Analysis and Results[4]

MODERATE SCENARIO - 20% INCREASE

Pollutant	Normal SP	I_1	I_2	I_3	I_4
TOG(tons/d)	517.84	520.55	523.36	526.71	530.33
ROG(tons/d)	474.66	476.92	479.25	482.07	485.14
CO(tons/d)	3662.38	3713.62	3766.98	3824.76	3884.87
NOx(tons/d)	516.68	523.61	530.68	537.83	545.06
PM(tons/d)	88.78	88.78	88.78	88.78	88.78
Pb(tons/d)	0.00	0.00	0.00	0.00	0.00
SOx(tons/d)	28.77	28.77	28.77	27.77	27.77
Gas(1000 gal)	13971.26	13971.07	13970.84	13970.75	13970.73
Dsl(1000 gal)	1576.55	1576.55	1576.55	1576.55	1576.55

SIGNIFICANT SCENARIO - 50% INCREASE

Pollutant	Normal SP	I_1	I_2	I_3	I_4
TOG(tons/d)	517.84	524.16	533.38	541.82	554.21
ROG(tons/d)	474.66	479.87	487.69	494.89	505.55
CO(tons/d)	3662.38	3787.53	3940.67	4076.25	4259.83
NOx(tons/d)	516.68	534.02	552.17	568.41	588.45
PM(tons/d)	88.78	88.78	88.78	88.78	88.78
Pb(tons/d)	0.00	0.00	0.00	0.00	0.00
SOx(tons/d)	28.77	28.77	28.77	27.77	27.77
Gas(1000 gal)	13971.26	13970.61	13970.55	13970.74	13971.38
Dsl(1000 gal)	1576.55	1576.55	1576.55	1576.55	1576.55

SUMMARY OF CHANGES DUE TO AHS IMPACTS

MODERATE SCENARIO - 20% INCREASE

Poll\Level	I_1	I_2	I_3	I_4
TOG(%)	+0.523	+1.066	+1.713	+2.412
ROG(%)	+0.476	+0.967	+1.561	+2.208
CO(%)	+1.399	+2.856	+4.434	+6.075
NOx(%)	+1.341	+2.710	+4.093	+5.493
PM(%)	0.000	0.000	0.000	0.000
Pb(%)	0.000	0.000	0.000	0.000
SOx(%)	0.000	0.000	0.000	0.000
Gas(%)	-0.001	-0.003	-0.004	-0.004
Dsl(%)	0.000	0.000	0.000	0.000

[4] 38 gal = 1 liter.
Measurement in absolute tons/d (1 tonnes = 2240 tons). Note that percentage changes are minimal.
Applicable to all results.

SIGNIFICANT SCENARIO - 50% INCREASE

Poll\Level	I_1	I_2	I_3	I_4
TOG(%)	+1.220	+3.001	+4.631	+7.023
ROG(%)	+1.098	+2.745	+4.262	+6.508
CO(%)	+3.417	+7.599	+11.301	+16.313
NOx(%)	+3.356	+6.869	+10.012	+13.891
PM(%)	0.000	0.000	0.000	0.000
Pb(%)	0.000	0.000	0.000	0.000
SOx(%)	0.000	0.000	0.000	0.000
Gas(%)	-0.005	-0.005	-0.004	+0.001
Dsl(%)	0.000	0.000	0.000	0.000

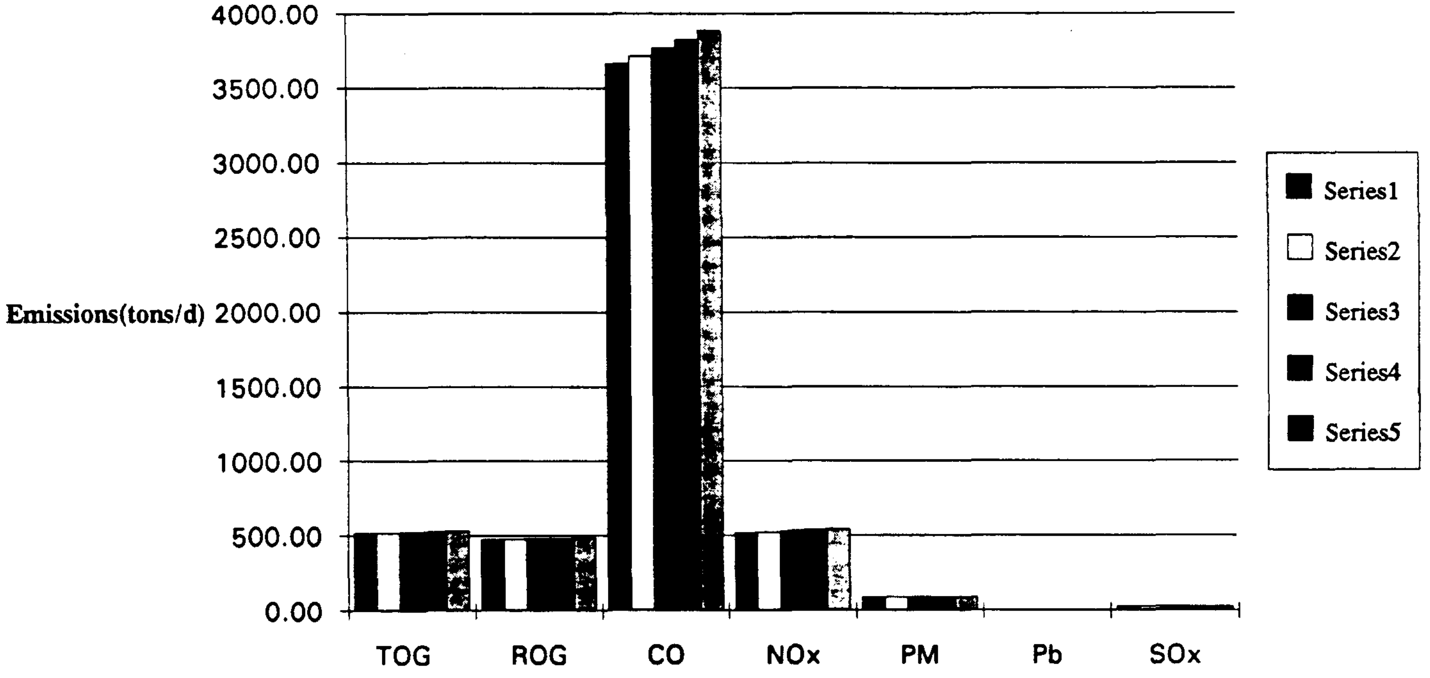

Figure 8. Moderate scenario-effects of AHS.

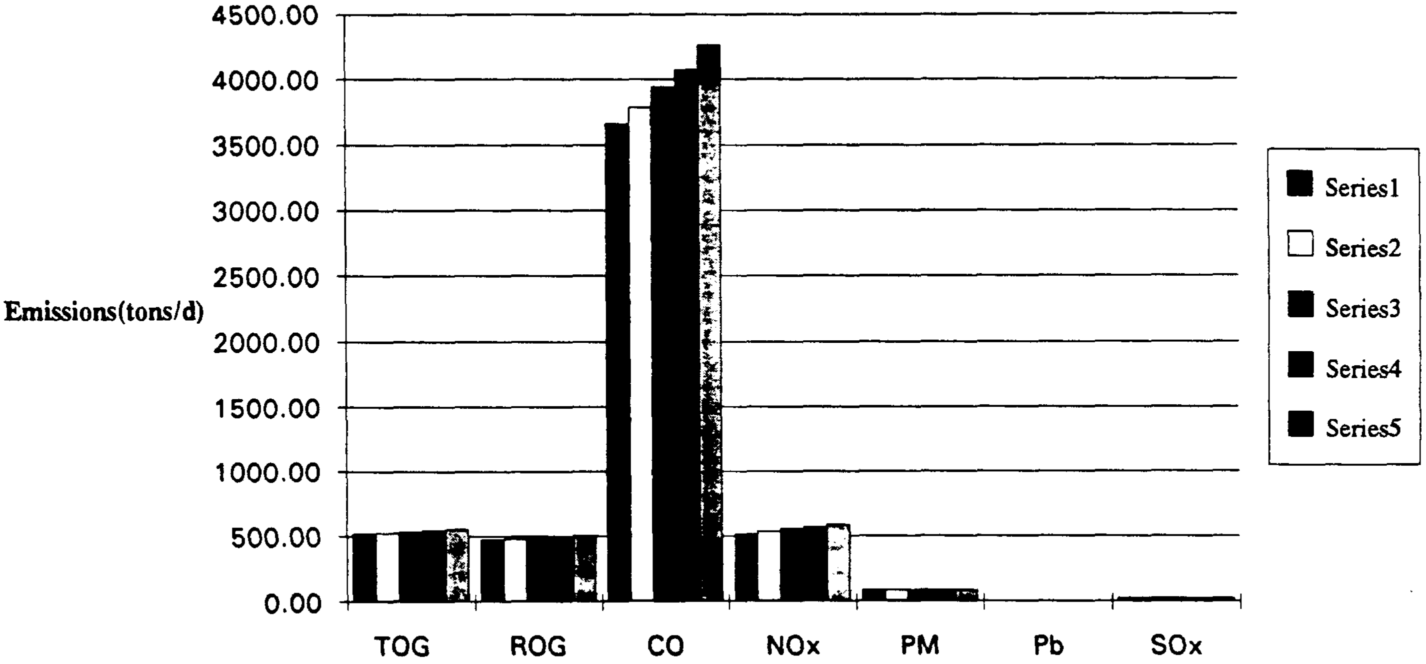

Figure 9. Significant scenario-effects of AHS.

The results above show slight increases in most pollutants. The speed increases have resulted in an increase of pollutants concentration. This is due to the fact that pollutants do not decrease with increased speed during the trip. It is not a linear function. With the existing engine technology each pollutant has an ideal speed somewhere between 48-80 kph (30-50 mph). EMFAC's Composite Emission Factors are directly affected by speed. If we go back to our illustration of CO for Light Duty Autos (LDA) - CAT, we find out from the output table that the lowest Emission Factor (0.3 grams/km) is at the speed of 48 kph (30 mph) (see EMFAC and BURDEN outputs for illustrations). Increasing the actual engine technology speeds can only have slight increases in certain pollutants (TOG, ROG, CO, & NOx), and can only have a slight decrease in gasoline consumed. It is clear that increasing the percent of VMT in the speed distributions of the BURDEN program alone will not be sufficient to represent the AHS emissions. More accuracy of measurement is required to show what happens at the different modes of driving instead of the average speed only.

7.5 Limitations of the Study

The limitations of this study are characterized by the existing vehicle technology (engine technology) and the modal speeds used in the CARB programs (EMFAC and BURDEN). While AHS deals with moderate speeds of 100 kph (62 mph) and fast speeds of 150 kph (94 mph), the CARB programs deal with speeds from 0-104 kph (0-65 mph) only. Therefore, it is impossible to model the AHS fast speeds using the existing emissions inventory programs. Also, the CARB programs are unable to represent vehicle emissions for modal speeds (idle, cruise, acceleration and deceleration). Since we expect AHS to decrease the amount of acceleration, deceleration and engine enrichment periods, it is expected that this emission reduction will at least balance the slight increase due to speed changes.

7.6 Conclusions and Implications for Urban/Rural Comparison

Increasing vehicle speeds with the existing engine technology will make it difficult to affect vehicle emissions positively if the VMT stay the same. It is vital that the engine technology be improved for better efficiency at higher speeds if AHS is to have a positive impact on vehicle emissions. Also, modal measurement is necessary to represent more accurately how AHS can decrease vehicle emissions. Skabardonis, et. al [24] shows how it is possible to obtain modal emission factors using a model that estimates time spent by driving mode percent. Such a model would draw a clearer picture, and show how AHS can lower vehicle emissions, especially by decreasing the time spent in acceleration mode. It is also worth noting that increased travel volume and longer inter-city travel will help lower emissions with the use of AHS given the same number of trips.

On the concept of differences between rural and urban systems, the following conclusions were reached:

In urban areas there is potential for emissions reductions through improved flow. Air quality impacts are also likely to be more important in these areas.

In rural areas, if higher speeds are pursued, we should expect an increase in emissions. Such an increase will not be substantial if AFVs are encouraged and/or open loop ICE operation is restricted by the design of AHS throttle controllers. The latter may have an impact towards shifting to higher rated power engines which are likely to go to open loop operation later than weaker hp/lb combinations. Air quality impacts are also likely to be less important in rural areas.

8. PRODUCT LIABILITY, NEGLIGENCE, GOVERNMENTAL IMMUNITY AND AHS

8.1 Introduction

The objective of this section is to examine how product liability and negligence may be considered with the introduction of an AHS. In addition, Government immunity, if any, will be explored. Finally, potential differences in the impacts of urban versus rural AHS will be discussed. In considering AHS, a focus on the "increasing complexity in technology and social organization has always produced a corresponding increase in the complexity of laws and litigation because '[t]here ... can be no law before a condition arises to which it can be applied. A rule of law ... cannot exist where the relations on which it is founded do not exist.'"[25]

Connecting the evolution of the law in product liability, as well as the negligence doctrine, to a representational legal group of AHS failure scenarios is important for manufacturers and Governmental agencies. Based on the Federal nature of the highway system, the need to have compatible technologies, and the need to bring a consistent legal application among states, a look at the Governmental immunity laws is undertaken in an attempt to assess Federal legal liability. A further task would be to examine policy options for future political decisions concerning AHS.

8.2 Product Liability

Product liability is a complex field, with the underlying application of strict liability. Manufacturers will want to know how the product liability law will affect development of the AHS.

8.2.1 Tracing Development

The concept of strict liability is not new to the law, although adoption by statute or common law has only become greatly accepted over the past thirty years.[1] The first case typically cited is Justice Traynor's concurrence in Escola v. Coca-Cola Bottling Co. (1944), which states:

"The cost of an injury and the loss of time or health may be an overwhelming misfortune to the person injured, and a needless one, for the risk of injury can be insured by the manufacturer, and distributed among the public as a cost of doing business .... It is to the public interest to place the responsibility for whatever injury they must cause upon the manufacturer, who, even if he is not negligent in the manufacture of the product, is responsible for its reaching the market .... It is needlessly circuitous to make negligence the basis of recovery and impose what is in reality liability without negligence. If public policy demands that a manufacturer of goods be responsible for their quality regardless of negligence there is no reason not to fix that responsibility openly."

Contractual disclaimers to liability were tossed out in Henningson v. Bloomfield Motors [as standardized contracts denote unequal bargaining power at contract formation] (1960). Combined with the previous clarification for eliminating the private defense for manufacturers in MacPhearson v. Buick Motor Co. [as injuries to foreseeable plaintiffs are compensated] (1916), the modern era of

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[1] As of late 1986, only five states and the District of Columbia had not expressly adopted strict tort liability for defective products.

product liability was "ushered in".

The general rule is found in The Restatement of Torts, section 402A (1965):

One who sells any products in a defective condition unreasonably dangerous to the user or consumer or to his property is subject to liability for physical harm thereby caused to the ultimate user or consumer, or to his property if:
the seller is engaged in the business of selling such a product, and
it is expected to and does reach the user or consumer without substantial change in the condition in which it is sold.

The rule stated in 1. applies although:
the seller has exercised all possible care in the preparation and sale of his products, and,
the user or consumer has not bought the product from or entered into any contractual relation with the seller.

8.2.2 Types of Product Liability

Three classes of product liability exist, as follows:

Construction Defect:
A construction defect is also known as a manufacturing defect. Strict liability is imposed when products come off the assembly line which are not fit for the designed use. Strict liability brings plaintiff relief similar to "no fault insurance", and the price of the product spreads the risk.[2]

Design Defect:
A design defect occurs when the product conforms to the design but the design itself is unsafe. Under this standard, two tests are usually employed:
a) Consumers' Expectations:
A product is defective if it fails to live up to consumer expectations with respect to safety. This is now the minority position among the states.[3]
b) Risk-utility:
The test is whether "on balance, the benefits of the challenged design outweigh the risk of danger inherent in such design." The process of "weighing" risk can be extremely complex. Factors to consider:

The usefulness and desirability of the product - its utility to the user and to the public as a whole.
The safety aspects of the product - the likelihood that it will cause injury.
The availability of a substitute product which will meet the same need and not be as unsafe.
The manufacturer's ability to eliminate the unsafe character of the product without impairing its usefulness or making it too expensive to maintain its utility.
The user's ability to avoid danger by the exercise of care in the use of the product.
The user's anticipated awareness of the dangers inherent in the product and their avoidability, because of general public knowledge of the obvious condition of the product, or of the existence of suitable

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[2] The Legal Realists of the 1920's and 1930's argued for "no fault", then the same as strict liability. Modernity, the two should not be confused. Strict liability has more factors to consider than no fault.
[3] Most jurisdictions that retain the consumer expectation test use it in conduction with the risk-utility test.

warnings or instructions.
The feasibility, on the part of the manufacturer, of spreading the loss by setting the price of the product or carrying liability insurance.

The factors have been altered and simplified, but otherwise remain similar among the states.

3. Failure to Warn:
When a product is known to the manufacturer to be dangerous, a label containing a warning for use has nearly no cost, and failure to provide an adequate warning has resulted in strict liability.

8.3 Negligence

"The clear standard in both law and engineering is that the Governmental entities must use reasonable care to maintain road safety features they put in, and liability will attach for negligent maintenance, even if those features did not have to be put in."

8.3.1 Basic Test

Negligence consists of a four part analysis, all of which must be proved by the plaintiff by a preponderance of the evidence:

Duty of Care: the standard is usually the reasonably prudent person, but a higher standard may be imposed under special relationships.
Breach of the Duty of Care: straightforward application of the duty of care to the situation.
Causation: both factual and legal parts. Factual causation is commonly described as the "but for" test, in that but for the breach of duty, the action creating damages would not have occurred. Legal causation is also known as proximate causation, in which the plaintiff must be foreseeable or within the zone of danger.
Damages: knowable in physical and property harm, but variable in pain and suffering or mental anguish.

8.3.2 Notice Required for Breach of Duty

"One of the crucial disputed issues in virtually every crash case, under case law or statute, is whether the defendant had sufficient notice of the defect at issue before the Plaintiff's crash to be held liable for a lapse in due care for not making timely corrections that would, more probably than not, have prevented the plaintiff's injuries. Without this notice, defendants can use the chronological defense ... that it would go bankrupt if it were required to constantly upgrade all of its road miles ...." In essence, the cost of inspection must be balanced with the degree of notice signifying the breach of the duty of care.

Types of Notice:

Two types of notice are found to exist, either of which may put the defendant on guard for a breach of duty.

A. Actual Notice

Anything that could, and should have called the defendant's attention to the need for correcting the defect at issue prior to the plaintiff's crash can constitute actual notice.

Defendant agencies in transportation are considered to be one agency. Thus, what one of the branches sees, all are supposed to see. In California, Cal. Gov. code section 835.23, public entities are held to the standard that they should know of the dangers of defects their agents have actual knowledge of, even if those agents do not realize those dangers. These open the issue of whether the agent was on-duty during the time of noticing the defect i.e. was the agent within the scope of employment.

The inspection policy is important. In some jurisdictions, defendant is relieved of liability if it can show a reasonable inspection policy which failed to detect the defect. The issue becomes whether the inspection procedure was operated with due care because it failed to detect a defect it should have noticed. Merely looking and not seeing does not, and should not, grant absolution barring a statute saying it does.

Public complaints about the facility written prior to plaintiff's injuries are evidence of notice. Also, the lack of such complaints can be evidence that it lacked notice. However, no defendant will be required in negligence law to defend against dangers it did not, in the exercise of due care, know about.

Furthermore, "recommendations to improve the facility from the defendant's own personnel may amply establish the defendant's actual notice of defects .... The final decisions implemented usually strike a balance somewhere between maximum safety and minimum cost expense." Also, the defendant's files may put the defendant on notice that the balance has swung too far away from safety considerations.

B. Constructive Notice

Constructive notice relates to defendant's notice of dangerous, unsafe, or hazardous conditions that are of such a nature that the defendant could reasonably have ascertained their existence or corrected them. Another standard is notice results from defects which have been in existence so long they could have been discovered and repaired in the exercise of reasonable care. Ultimately, a case by case analysis is required by the trier of fact, unless there is no dispute to the evidence.

2. Time to Correct

At issue is the amount of time the defendant had to correct the problem. Liability will not attach if there was not enough time (either a reasonable or a legislative determined amount) to correct the problem. But if notice is established and there was sufficient time to upgrade or correct the defect, the defendant will have great difficulty escaping liability.[4] Also, due care must be exercised by the defendant to secure the improvements within a reasonable time.

3. Timely Notice Requirement

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[4] Note that statutes may impose only one form of notice, and thus provide a defense if the wrong notice is proved.

Liability for notice must be sent often within specified time frames by the plaintiff so that defendant can investigate the accident while the facts are fresh and the evidence remains substantially intact, thus guarding against unfounded claims, promoting settling claims, and giving time for preparing for trial.[5]

8.3.3 Self Made Defects

The widely accepted law holds that the defendant needs no notice of transportation defects it has created and should therefore assume sole responsibility.

8.3.4 Ownership of the Road

In the case of an injury, determining which party will be held responsible can prove difficult. "The early factual investigation of a crash case often discloses that several Governmental and private entities have been involved with the road in question over a period of times. Thus, one Governmental body aided by various private consultants may have designed the road, another entity might have constructed it, and yet another set of public and private entities may have held maintenance jurisdiction over the road between the time it opened to traffic and the time of the crash at issue."

8.4 Defenses

Defenses to both product liability and negligence can be found in negating an element of the cause of action. Statutory relief or common law application may also bar plaintiff's claim. In lieu of such applications, standard defenses are described below. The defendant has the burden of proof to show by a preponderance of the evidence that the defense applies.

8.4.1 Contributory Negligence

Contributory negligence bars plaintiff's recovery if the plaintiff is found in any way negligent for the harm suffered. Most jurisdictions have been unwilling to take this approach under the strict liability rule, arguing it is not symmetrical. Still other jurisdictions note that it is not accepted within the meaning of Section 402 of the Restatement of Torts. Underlying the reticence for contributory negligence is that it is a complete bar on recovery for the plaintiff, even if only found a fraction of one percent negligent.

8.4.2 Comparative Negligence

Under comparative negligence, the plaintiff's award is reduced by the amount of the plaintiff's negligence. California follows a modified version of comparative negligence in that if plaintiff is more than 50 percent negligent, plaintiff receives nothing. Comparative negligence is now the majority position among the states.

8.4.3 Assumption of Risk

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[5] Note, plaintiff can lose a cause of action by not filing within legislatively determined time-frames for giving notice to the defendant. However, excuses for failing to give timely notice can be made with claims of physical or mental incapacity, or conduct by defendant’s agents which prevents plaintiff from giving timely notice.

The open and obvious rule is used as a subjective standard in measuring the assumption of risk on the plaintiff's part. The issue is whether the plaintiff subjectively knew of a defective condition in the product, a test often difficult to prove. Under modern application, the question is whether the plaintiff is allowed to assume the risk as a policy matter under public control. The reasonableness of the product design and of the plaintiff's conduct are counterbalanced.

8.4.4 Misuse of Product

Defendant's misuse of the product can bar relief. The issue is to determine what the manufacturer can expect and what he has a right to expect. This is the least likely in AHS applications to arise, and will not be discussed below.

8.5 Application to AHS Failure Scenarios

All stages of the AHS evolution will be governed by product liability law. Causation of accident to injury due to malfunctions will not be in dispute. At the later stages, the focus will include negligence as new duties arise for the Governmental agencies in charge of designing, installing, and operating the AHS.

8.5.1 Longitudinal Control

Under ICC the vehicle's acceleration and soft braking will be controlled as Stage I_1 of the AHS evolution. A failure scenario is an ICC engaged vehicle crashing into the vehicle in front in a non-emergency situation.

Under product liability law, an improperly functioning ICC would be either a construction defect or a design defect. Presuming the design is not flawed, a problem in the manufacturing will bring plaintiff relief through strict liability. These types of assembly-line errors are possible with any development of the mechanisms used in the AHS.

A second failure scenario is a crash into the vehicle in front during an emergency situation. For instance, the vehicle in front could be reacting to objects in the road or slowed traffic ahead.

The point at which a warning is given to the ICC driver to begin hard braking is an element of the design and should follow standard perception/intellection/emotion/volition (PIEV) conditions, with a safety margin installed. Otherwise known as perception reaction time, the various components of safe breaking are generally thought to be enhanced by AHS. Expert testimony on design defect could be offered at a trial. The key features of expert testimony will be dependent on the weight of the vehicle, surface condition of the road, tire traction, and ability of the vehicle to break, all to be calculated prior to design, installation and verification. The experts that design the ICC will unlikely be the experts at trial. Thus it is appropriate for any new system to have a consensus among experts, and further research through simulation would be appropriate.

8.5.2 Lateral Control

Lateral control can be performed by different types of technology. The three more likely candidates which will be discussed in comparisons of failure scenarios are vision based, magnetic pin, and millimeter radar triangulation.

1. Vision Based

A failure scenario in a vision based system would occur if the lens on the vehicle became covered with dirt, ice, or other debris and the vehicle could no longer follow the markings, or alternatively if the markings were no longer visible. The vehicle would stray from the lane, creating hazardous conditions for other drivers should the driver of the AHS equipped vehicle not realize the failure.

While lateral control by vision based technologically is feasible under ideal weather conditions, the failure rate under less than ideal conditions would come under the design defect analysis of product liability law. In the consumer's expectations test, a consumer would likely expect the lateral control to continue to function in less than ideal conditions. One could argue that an adequate warning coupled with the obvious and open danger that the vision based mechanism would fail under more extreme weather conditions presents the manufacturer or seller with an assumption of risk defense. Also, presuming the vehicle knows when it no longer is tracking the lane properly and emits a warning to the driver, the failure on the part of the driver to resume lateral control of the vehicle could be deemed negligent, either in a contributory or comparative law jurisdiction.

2. Magnetic Pins

Magnetic pins will not be impacted by weather conditions as contained under the surface of the road. On-board sensing devices will not have lens problems, as the signal will be transmitted by a magnetic field. A different type of failure scenario involves tampering by vandals. The control for vandalism is detection and law enforcement.

One issue is negligence, and in particular notice. Once installed, a duty will exist on the agency controlling the maintenance of the road to detect when the pins are no longer in the proper place. The inspection procedure will indicate notice. Also, discovery by another agency may provide notice should the agencies be considered to be branches of the same tree. Further, an off-duty employee using the AHS who notices that it is not functioning properly may properly put the agency on notice.

As urban highway systems become more sophisticated using video-image processing at the TMCs, failures in the AHS will likely be known more quickly than in rural environments.

Once the problem is known, some type of warning must be given immediately to AHS users to prevent further problems.

3. Millimeter Radar

A failure scenario is a breakdown in the communications between the roadside and vehicle. The roadside would be using triangulation to measure the correct vehicle path. If more than one lane is used in AHS, or vehicles block the path of the radar beams from the roadside, lateral control communications breakdown.

This technology has the most infrastructure development, and would therefore be less likely to be used in a rural AHS setting.

A design defect exists when the communications fail. Permitting this use of lateral control without ensuring proper functioning through rigorous testing would fall within the manufacturer's ability to eliminate the unsafe character of the product without impairing its usefulness. The risk-utility test would not be passed.

Negligence could also attach to the road maintenance agency should the equipment fail and go unnoticed or not be shut down immediately, similar to the reasoning above for the magnetic pins. Also, since the infrastructure is being put together similar to a traffic light in controlling vehicle motion actively, the self-made defect section of negligence can be used to hold the agency liable for picking millimeter radar technology.

8.5.3 General Points on Vehicle Sophistication

The following show some of the various interpretations the risk-utility factors have taken in case law which apply to AHS.

1. Feasible Alternative Design versus Cost

The fact that there were no feasible alternative designs can be a defense in selecting a technology or in choices made to implement a technology.

These also depend on whether a manufacturer can technologically improve its products and, in turn, whether the product so improved would be so expensive relative to its worth that consumers would no longer buy it.

When looking at the sophistication of the equipment which is designed to provide a driver warning of malfunction, the safety aspects of the product come into play as part of the product liability test of risk-utility. The availability of an alternative design in terms of cost is most clearly applicable in the degree of redundancy provided. Backup systems will be expensive. At what point will the cost exceed the utility?

The selection of a lateral control technology can be pitted against the others not chosen. This could be a realistic ground for expert testimony. Evidence would be available if States used different technologies and data was empirically gathered over time, but this is unlikely to occur due to the Federal nature of the AHS (as argued below).

2. State of the Art Defense

With respect to technological feasibility a manufacturer is usually allowed a "state-of-the-art" defense if the design alternative the plaintiff proposes was not possible at the "relevant time".

The relevant time varies from jurisdiction to jurisdiction. Most allow the defendant to avoid liability if he can show that the proposed alternative design was not possible at the time of distribution. The two contrasts can be seen as follows.

In Arizona, the court established in design defect cases:

Although defendant did not adopt a different type of safety device, it was not in itself sufficient

evidence to establish defective design, and
The safety features of the machine were reasonably preventative of injury, so long as the machine was properly maintained.

In California, on the other hand, the jury may consider by hindsight the gravity, the likelihood of occurrence, the mechanical feasibility, the financial cost, and the adverse consequences to the product and to the consumer that would result from an alternative design.

When faced with different interpretations of the law, the time to consider one consistent law for interstate commerce is important.

8.6 Federal Government Immunity

Federal authority may be Congressional mandated for the design, development, and implementation of the AHS. The maintenance will likely fall on state agencies. An in depth institutional review is beyond the scope of this section. Rather, the assumption is made that the Federal Government will continue to be involved, and may usurp the field.

8.6.1 Federal Powers

Congress has the power to make all laws necessary and proper for executing the powers vested in the Constitution and for improving or protecting the general welfare. Congress has exclusive legislative authority over its own spheres of Federal activities so that the United States Government is free from unwarranted state intrusion and regulation of Federal interests.
The state's product liability interest is based on the judgment that consumers need more protection from dangerous products than warranty law provides. However, should a conflict exist or the Federal interest be deemed to have completely covered the field, the notions of supremacy and pre-emption apply. State courts would not be preempted if:

The Government contracts for the purchase and installation of an item and gives only general performance standards, leaving a contractor discretion in the design and manufacturing process; or
The Government purchases from the contractor an off-the-shelf item.

The Federal power also extends into regulation of interstate commerce. In considering AHS, conflicting state applications may create an undue burden on interstate commerce. Congress may step in to ensure consistency of legal and technological application.

8.6.2 Suits Against the Federal Government

If Congress brings the Federal Government into the application of the AHS, Governmental liability will arise. The Federal Government has three defenses.

1. Traditional Defense

The traditional sovereign immunity defense provides that the Government cannot be sued without its consent. Also, public policy dictates whether Government consents to the suit. Furthermore, Congress retains the power to withdraw consent to be sued at any time.
Statutory waivers of the Government's contract and tort immunity can be found in the Tucker Act of

1887. However, the Supreme Court cannot expand the waiver of sovereign immunity more broadly than Congress directs. Thus, the addition of new legislation covering the use of AHS as an interstate matter can be drafted such that the prevailing movements toward liability limits (caps on liability) can be easily integrated.

2. Discretionary Function Defense

Discretionary functions are planning level decisions usually containing an evaluation of such factors as the political, economic, or social effects of a particular plan or policy. The discretionary function defense can be removed from the area of litigation by spelling out the scope of the Federal Government participation in the AHS. Taking the perspective that AHS will be interstate, the Federal Government can be brought into the action either by the planning decisions clearly stated or left unstated, provided the link to interstate commerce is made and the Federal courts find as such. This could be a hotly contested area if Congress does not clearly specify the Federal role. Discretionary functions are given immunity, while operational functions are not.

3. Feres-Stencel doctrine

This doctrine has been limited to lawsuits between military service persons and the Federal Government, and is not likely to be used in the AHS.

8.6.3 Suits Against the Federal Government Contractor

The Federal Government may be deemed involved sufficiently to be linked to the hiring of the contractors. Contractor defenses are as follows.

1. Government Contractor Defense

The type of specifications that the Government contract requires defines the parameters of a Government contractor's liability i.e. design and performance. Courts have consistently held in Government design specification cases that the Government bears the risk of loss associated with designs. When Government mandates performance, an underlying rationale links implied warranty to design specifications. A shared immunity based on public policy interests extends the Government's sovereign immunity defense to contractors. As implied the Government must also be immune.

In formatting the defense, the courts have generally agreed that the contractor was required to prove:

The Government established the specifications for the product and
The product conformed to those specifications in the case of equipment; and also
The contractor warned the Government of dangers it knows about.

The defense will not extend in cases of poor manufacture.

2. Contract Specification Defense

Based on ordinary negligence principles, courts have held that a contractor would not be liable for any damages, direct or consequential, that result from an employer's specifications, unless those specifications were so obviously defective and dangerous that a reasonable contractor would be put on notice that the work was dangerous and likely to cause injury.

When performance contracts contain specifications stating the desired performance characteristics for the manufactured products but do not prescribe the manner in which the specifications are to be accomplished, the contractor is given discretion to decide how to achieve the Government's design, engineering, or performance requirements.

Absent an express assumption of responsibility by the Government, the Government contractor is responsible for the method of performance and success. The distinguishing standards are where:

The Government made no representations;
Had no duty to disclose information; and
Did not improperly interfere with performance.

When these conditions are met, the contractor is liable.

3. Government Agency Defense

When a principal and agent relationship exists between the Federal Government and the contractor, the contractor is merely carrying out the Government's requests and is shielded from liability as if standing in the Government's shoes.

The agency defense is used to broaden a contractor's defense usually in public works projects. The rule is that the contractor is not liable for incidental injury or damage resulting from the performance of a Government contract, provided the contractor is not negligent.

8.6.4 Discussion of Defenses to AHS.

The role of the Government in the design, maintenance and operations of the AHS pose difficulties legally. When considering the Government as a sole entity responsible for an AHS failure, the desire to cap the amount of damages fits with limiting taxpayer exposure. When the Government contractor is held liable, the contractor may not participate in AHS unless protected to the same degree as the Government, particularly when the amounts awarded in damages exceed what can be insured against. Punitive damages produce large jury awards, in essence working like a tithe at 10% of worth which should prevent further wrongdoing. However, in the case of AHS, contractors are performing a classic Governmental function.

The case precedent for contractor immunity is Boyle v. United Technologies Corp. The escape hatch on a U.S. Marine helicopter opened out rather than in, and was ineffective when the helicopter crashed in the ocean. The co-pilot drowned. The Federal contractor was sued in state court. In a close 5-4 decision, the Supreme Court found the contractor not liable. State law was held to be in "significant conflict" with the Federal interest. The design of the helicopter was a discretionary function of the Government. If the contractor was held liable, the Government would lose out as well.

Within the meaning of the AHS, the objectives pursued should be considered Federal in nature. Increased safety and improved throughput affect the health and welfare of the country. The contractors should be protected because the function performed in making AHS realizable is in the

Federal interest.

Ultimately, the degree of applicability of the defenses to the AHS will depend on the scope of the legislation drafted at the Federal level. In setting the standards which should be uniform throughout the states (after determining the optimum technology), the degree of Federal specification will play a large role in finding Federal responsibility. The possibility of tort reform could be linked to health reform. This will be left to subsequent research.

8.7 <u>Conclusion - Urban AHS versus Rural AHS Impacts</u>

In simplifying the dominant tests for the AHS in product liability and negligence, the importance to different groups ranges from private manufacturers and contractors to State and Federal agencies. Applications to AHS through balancing tests of the "reasonableness" of a product in terms of safety can span jurisdictions. Federal standards may prove more responsive to allocating liability. Once the liability issue is determined, an accurate assessment of the risk can be made. The tort system may continue to function properly. On the issue of potential differences of impacts on rural versus urban AHS, the following conclusions can be reached:

- In the case of Governmental immunity, common standards need to apply and system benefits should be viewed for AHS as a whole.
- More vehicle based systems are likely to reduce infrastructure monitoring needs which will be extensive/expensive particularly in rural AHS.
- Issues of guideway ownership & maintenance may be different for urban/rural AHS but compromise “uniform” solutions need to be found so that consistency in the legal status is maintained.

9. CAPACITY IMPLICATIONS OF NON-CONSTANT DECELERATION MODELS ON AHS SYSTEM

9.1 Overview

This section examines the maximum theoretical capacities of AHS under different operating conditions and vehicle characteristics. Once these capacities are known, they can be compared with those currently being achieved on highway systems to determine the effectiveness of an AHS system in increasing highway capacity. The novelty of the study is the investigation of the sensitivity of the capacity to changes in operating variables including speed, weather conditions, vehicle (or system) reaction time[1], and tire and road conditions when tire-road friction coefficients are not constant. The purpose of the study was to give some insight into capacity sensitivity issues relating to pavement type and condition as well as how they can influence the design and operation of urban and rural AHS.

Capacities were determined by finding the minimum stopping distances for vehicles and the corresponding minimum spacing between vehicles. Dividing the vehicle speed by the minimum spacing between vehicles yielded the theoretical capacity.

It was determined that in highly congested areas of highway, the capacity of the system would benefit by operating at speeds lower than the highway speed limit. Also, substantial increases in capacity could be achieved by excluding vehicles with tires below grade B from the AHS system. In addition, a system requiring vehicles to have at least grade B tires could substantially increase maximum capacity by reducing vehicle reaction times. Finally, trailing vehicle reaction time appeared to have a greater impact on capacity during dry conditions than during wet conditions.

This study was limited to decelerations that were linear functions of velocity. In addition, American Association of State Highway Transportation Office (AASHTO) data was used for the friction coefficient (μ) as a function of speed (the basis for the linear deceleration functions) as a starting point with more accurate data expected in the near future.

9.2 Introduction and Background

This study examines the maximum theoretical capacities of AHS under different operating conditions and vehicle characteristics. Once these capacities are known, they can be compared with those currently being achieved on highway systems to determine the effectiveness of an AHS system in increasing highway capacity. Actual achievable capacity may vary with other factors, particularly demand and local condition-based variables.

Theoretical capacity on a highway system can be described as a function of two variables: speed and density. Thus, to determine the maximum theoretical capacity of a system, it is necessary to determine the maximum safe density that can be tolerated at different running speeds. The maximum safe density, in turn, can be found from the minimum safe distance between successive vehicles. The minimum safe distance between vehicles is defined as the minimum distance between two consecutive vehicles such that no collision would occur if the lead vehicle decelerates at its maximum

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[1] Please note that what is referred to as "reaction time" in this section of the report is different from the human factors definition of reaction time in traditional traffic engineering.

braking (or deceleration) rate. In order to determine the minimum safe spacing between vehicles on a highway system, it is essential to model the deceleration behavior of those vehicles. Upon determining the braking distances of both a lead and a trailing vehicle, it is possible to calculate the minimum distance required between the vehicles before the deceleration began for no collision to occur.

If the braking rate of a vehicle is known and is assumed to be constant, finding the minimum braking distance is simple. More realistically, however, the deceleration rate varies with the speed of the vehicle, as friction between tires and roadway has been found to change with speed.[20] Generally, the adhesion between tire and roadway (and thus maximum deceleration rate) decreases with increased vehicle speed. This study illustrates a model by which minimum vehicle braking distance, minimum safe distance between vehicles, density, and capacity can all be calculated assuming that vehicle braking rate is a function of speed.

9.3 Methodology and Calculations

The first step in this analysis was to develop an expression for minimum stopping distance for different types of vehicles.

For constant deceleration, equation (eq.) 2 (a basic equation of constantly accelerated motion) applies:

$$(v)^2 = (v_0)^2 + 2a(x - x_0) \tag{2}$$

where:

- v = final velocity
- v_o = initial velocity
- a = acceleration or deceleration
- x = final position
- x_o = initial position

To find braking distance with constant deceleration, from eq. 2, let $v_o = 0$, $x_o = 0$ and solve for x. This yields:

$$x_b = \frac{(v_0)^2}{2a} \quad (3)$$

where:

x_b = braking distance

For non-constant acceleration, however, we must begin with elementary definitions:

$$v = \frac{dx}{dt} \quad (4)$$

$$a = \frac{dv}{dt} \quad (5)$$

where

v = velocity
x = position
t = time
a = acceleration

Letting a = a function of velocity = $f(v)$ and inserting this equality into eq. 5 yields:

$$f(v) = \frac{dv}{dt} \quad (6)$$

Solving eq. 6 for dt and multiplying both sides by v yields:

$$v \ dt = \frac{v \ dv}{f(v)} \quad (7)$$

From eq. 4, v dt = dx. Inserting this equality into eq. 7 and integrating yields:

$$x = \int \frac{v \ dv}{f(v)} \quad (8)$$

If $f(v)$ is a linear function of the form A + Bu, the remaining integral can be solved using eq. 9 below:

$$\int \frac{u\ du}{f(u)} = \frac{\left(A + Bu - A\ \ln|A + Bu|\right)}{B^2} + C \qquad (9)$$

Thus, for decelerations which are linear with respect to velocity ($a = f(v) = A + Bv$), eq. 8 becomes:

$$x = \left. \frac{\left(A + Bv - A\ \ln|A + Bv|\right)}{B^2} + C \right|_{v_f}^{v_0} \qquad (10)$$

Having an equation for the distance required to change speeds, it is now possible to determine the minimum stopping distance if deceleration is a linear function of speed. In order to determine the required deceleration functions, AASHTO data on the coefficient of friction (μ) at different speeds[20] was plotted versus speed (see figure 10). Approximate linear expressions for μ as a function of speed were then determined.

Solving Newton's Second Law for acceleration (a):

$$a = \frac{F}{m} \qquad (11)$$

The maximum force due to tire friction is:

$$F = \mu N = \mu m g \qquad (12)$$

Substituting eq. 11 into eq. 12 yields:

$$a = \frac{\mu m g}{m} = \mu g \qquad (13)$$

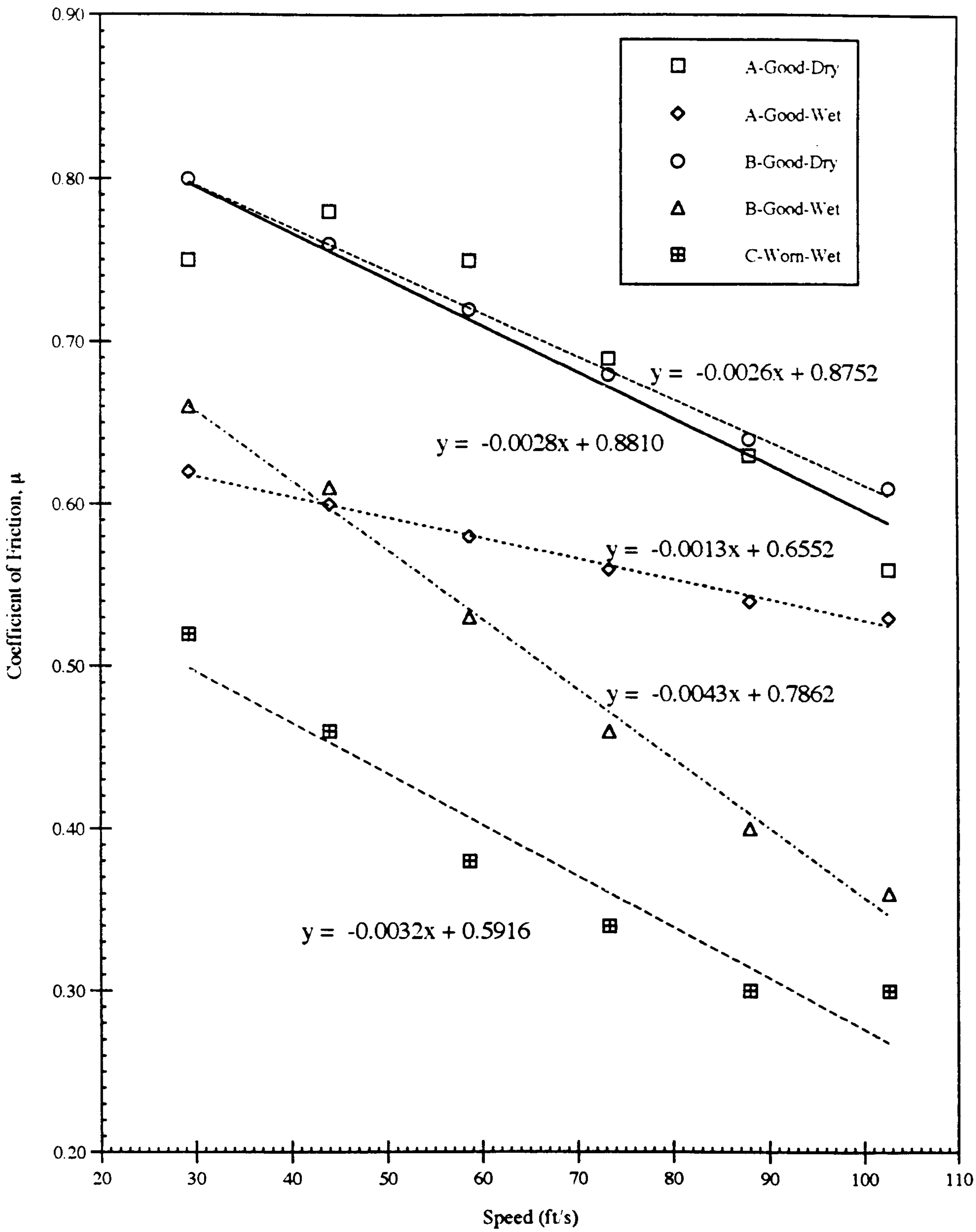


Figure 10. Coefficient of friction vs. speed.

Thus, the function for deceleration as a function of speed is the product of the g (9.81 m/s^2) (32.2 ft/s^2) and the expression for μ. Because the AASHTO data applies only to speeds of (12.4-44 kph) (29.3 to 102.3 ft/s), it was assumed that deceleration was constant at speeds outside of this range. These functions, combined with eq.10 were used to calculate minimum stopping distances. In addition, the minimum stopping distance was increased to account for the reaction time of the vehicle or system. The minimum stopping distance was increased by a distance of :

$$x = v_0 t_r \qquad (14)$$

where:

t_r = reaction time

The required minimum safe distance between vehicles was the difference between the minimum stopping distance of the lead vehicle and the minimum stopping distance of the trailing vehicle. It was assumed that the vehicles were traveling at the same speed and were 6.1 m (20 ft) long. The theoretical maximum capacity of one lane of the highway was then:

$$\text{Capacity} = (\text{Speed})(\text{Density}) = \frac{\text{Speed}}{\text{Safe Distance} + 6.1\text{m}} \qquad (15)$$

The theoretical maximum capacity and the minimum safe distance between vehicles were then determined for a variety of different scenarios. The input variables included different tire traction (A, B, and C), tread wear conditions (Good and Worn), weather conditions (Wet and Dry), vehicle speeds, (9.1-36 m/s) (30-120 ft/s), and trailing vehicle reaction times (0.1 to 1 sec).

9.4 Results and Implications for Urban/Rural Comparison

The resulting expressions for deceleration as a function of speed are summarized below in table 45.

Table 45[2] . Expression for deceleration as a function of speed.

Tire Type (traction-tread wear)	Weather	Deceleration Expression (ft/s)
A-Good	Dry	27.6 - 0.0837 v
	Wet	21.1 - 0.0419 v
B-Good	Dry	28.4 - 0.0902 v
	Wet	25.3 - 0.1385 v
C-Worn	Wet	19.0 - 0.1030 v

9.4.1 Variable Operating Speeds

With the lead vehicle having A-Good tires, capacities were determined at different operating speeds. Two different types of trailing vehicles were examined: B-Good and a worst case C-Worn. The

[2] 1 ft. = 3.3 m.

reaction time of the trailing vehicle was set at 0.3 s and the weather conditions were wet. The resulting theoretical capacity vs. speed curves for the two different types of trailing vehicles are plotted in figure 11. The safe distance gap vs. speed for the two different trailing vehicles are plotted in figure 12.

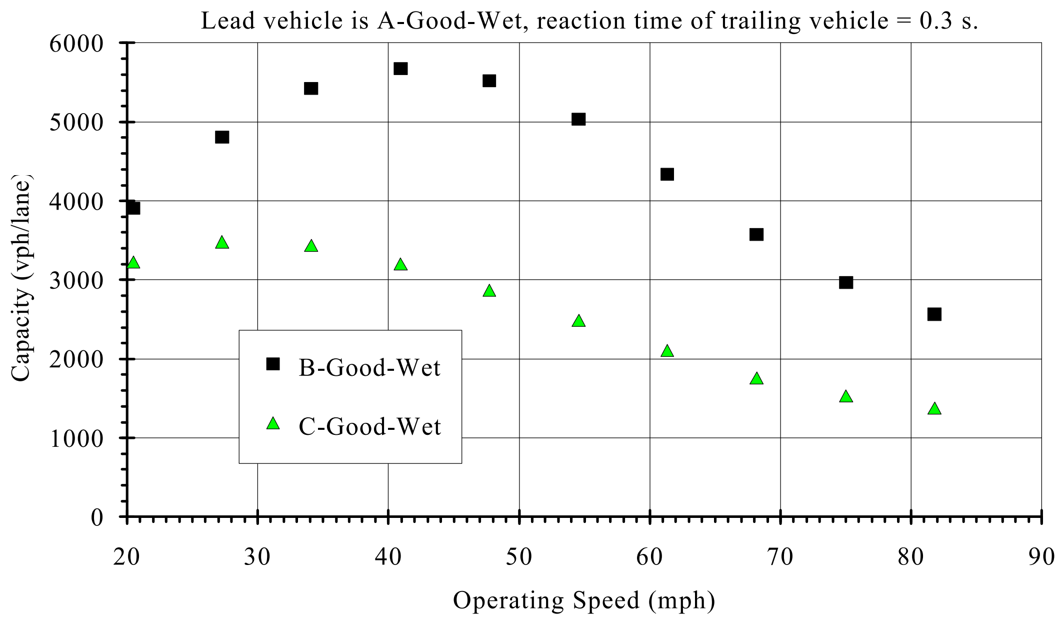
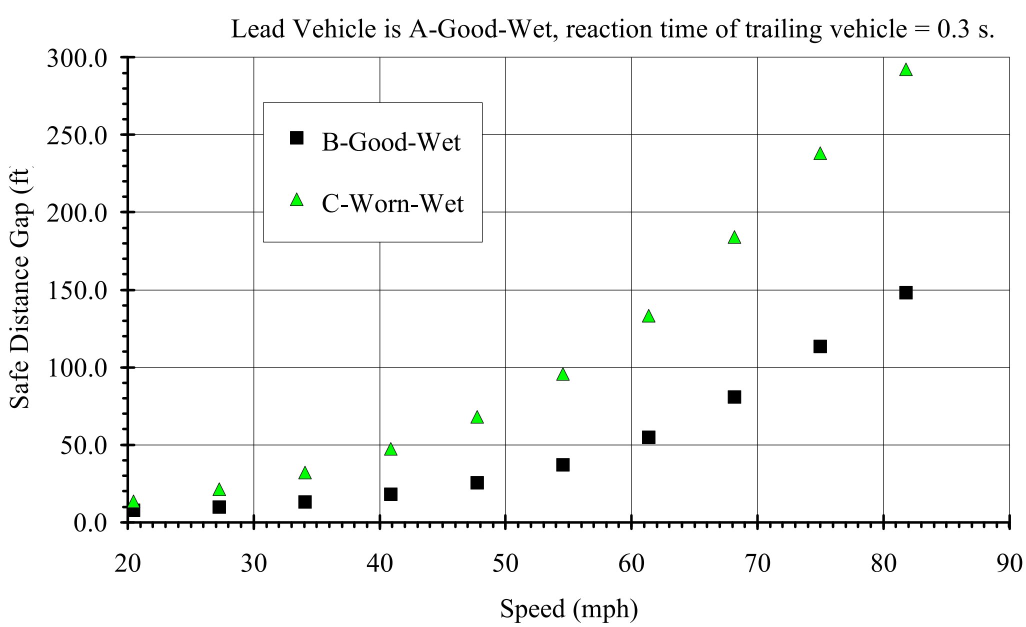


Figure 11.[3] Capacity vs. operating speed.



[3] 1 mi. = 0.6 km. Applies to following figures.

Figure 12. Minimum safe distance gap between vehicles vs. speed.

As shown in figure 12, the capacity peaked for both trailing vehicles at relatively low speeds [43 kph (27 mph) for C-Worn and 66 kph (41 mph) for B-Good]. This indicates that in terms of capacity, high speeds failed to make up for the increase in safe gap length. Indeed, the marginal increase in the safe gap required for an increase in operating speed was larger at high speeds. This data suggests that in highly congested areas of highway, the capacity of the system would be maximized by operating at speeds lower than the highway speed limit. It should be noted that more diverse input assumptions are needed for definitive conclusion in this area.

Another interesting aspect of figure 11 is the substantial increases in capacity that can be achieved by excluding vehicles with tires below grade B from the system. Particularly at operating speeds over 18 m/s (60 ft/s), the maximum capacities for a B-Good trailing vehicle are about twice as large as for a C-Worn trailing vehicle.

9.4.2 Variable Trailing Vehicle Reaction Time

The speed of the vehicles was then held constant and the reaction time of the trailing vehicle was allowed to range from 0.1 s to 1.0 s. Again, the lead vehicle was A-Good and theoretical capacities were determined for both B-Good and A-Good trailing vehicles. The speed was set at 27 m/s (90 ft/s) and the weather conditions were wet. The resulting plots of capacity vs. trailing vehicle reaction time are plotted in figure 13.

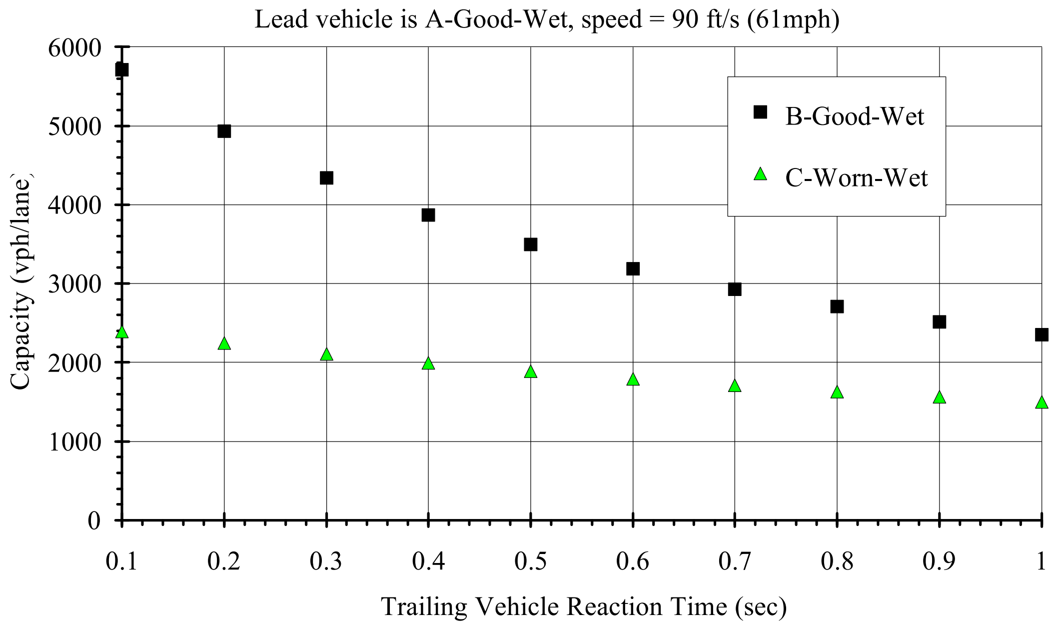


Figure 13. Capacity vs. trailing vehicle reaction time.

As shown in figure 13, increases in the reaction time of the trailing vehicle had a negative effect on capacity. The effect of increased reaction time, however, was much more dramatic when the trailing vehicle was B-Good rather than C-Worn. Because the minimum stopping distance for the B-Good vehicle was shorter than for the C-Worn vehicle, the capacity was more sensitive to changes in reaction time. Therefore, reaction time has a more significant impact on capacity when the vehicles have similar braking capabilities. On an AHS system requiring vehicles to have at least grade B tires, for example, substantial increases in capacity could be achieved by reducing vehicle reaction times.

9.4.3 Variable Weather Conditions

The sensitivity of maximum capacity to weather conditions was also examined. For this analysis, the lead vehicle was A-Good and the trailing vehicle was B-Good. Theoretical capacity was determined while varying first the operating speed and second the trailing vehicle reaction time. The results are plotted in figures 14 and 15.

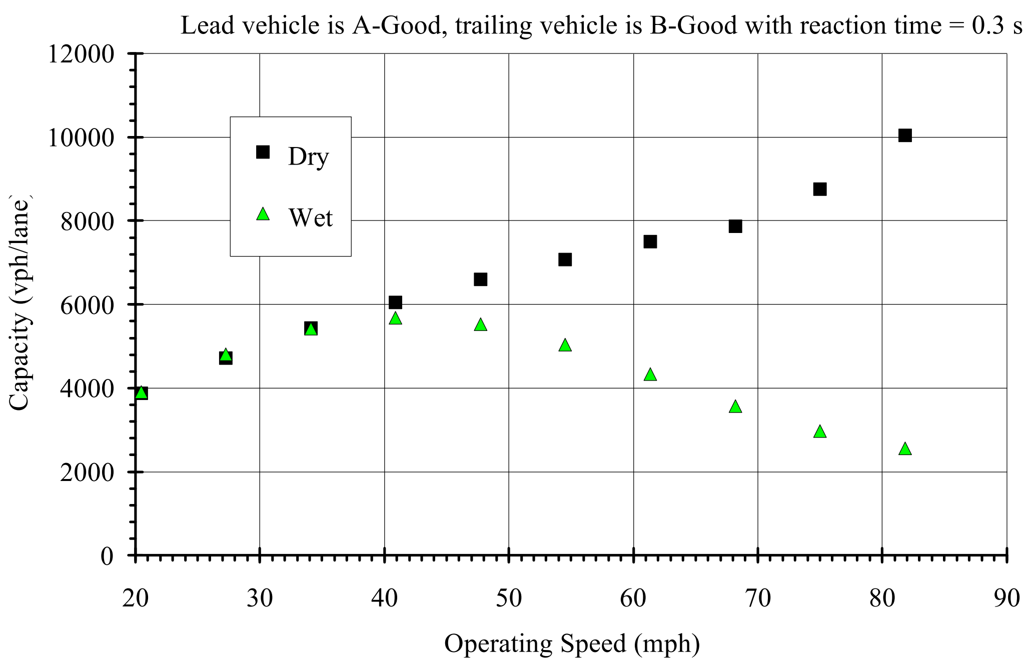


Figure 14. Capacity vs. operating speed.[4]

[4] Results in upper right corner of graph not very reliable.

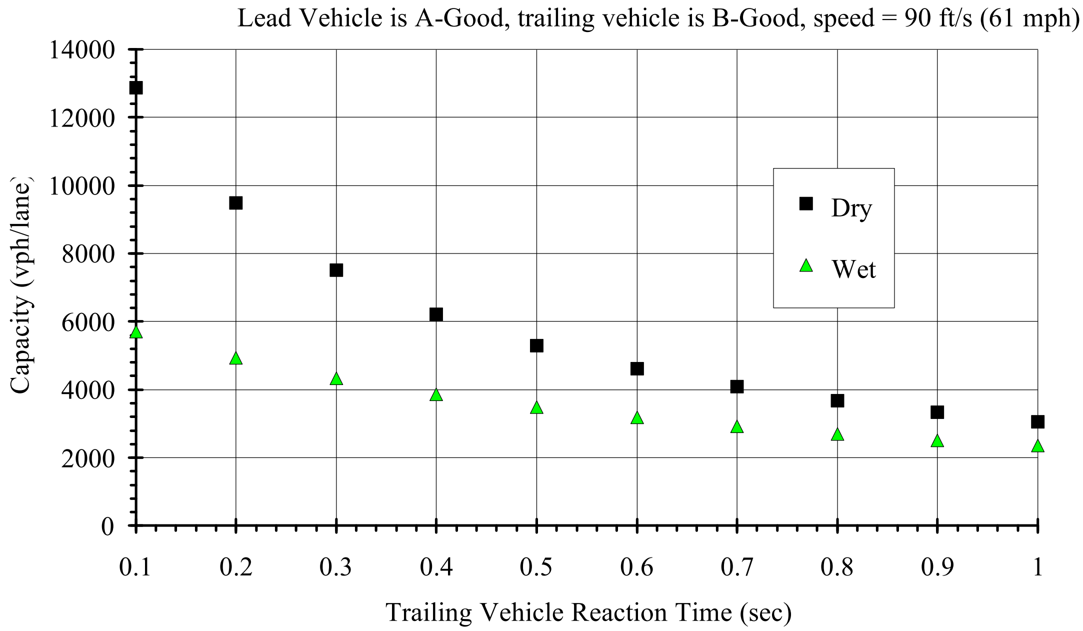


Figure 15. Capacity vs. trailing vehicle reaction time.

Figure 14 demonstrates that the capacity was sensitive to weather conditions only at higher speeds. At speeds below 18 m/s (60 ft/s), the maximum capacity appeared to be independent of vehicle speeds. At higher speeds, however, capacity for dry conditions continued to increase with increases in speed while capacity decreased for wet conditions. This occurred because the resulting linear fit of the coefficient of friction data (see figure 10) for B-Good-Dry tires had greater values for μ than for A-Good Dry tires. Clearly this pair is a special case and will probably have minor impacts on network capacity issues. However, it demonstrates the potential for major gains though requires further research.

Figure 15 shows that trailing vehicle reaction time had a greater impact on the maximum capacity during dry conditions than during wet conditions. Particularly at reaction times less than 0.5 sec, slight reductions in reaction time greatly increased the potential capacity of the system.

9.4.4 Limitations

This study was limited by several factors. If the integral (eq. 10) could be solved for non-linear expressions, (it can always be solved numerically) more accurate expressions for decelerations could be used, producing better results. This would have had the greatest impact in the case of A-Good-Dry conditions, as the data for C was clearly non-linear.

In addition, the AASHTO data for μ as a function of speed may not be the most accurate way of determining decelerations. The AASHTO data was the result of skid trials, while modern anti-lock brake systems may produce different relationships between deceleration, speed, tire types, and weather conditions. However, different expressions for deceleration as a function of speed could be entered into eq. 10 and a similar analysis could be performed.

10. PROJECT RESULTS AND CONCLUSIONS

The present section of the report will initially summarize results of the analyses on a section by section basis. Over-arching conclusions will then be attempted on the issues of rural and/or urban AHS deployments based on the strength of individual conclusions as well as their frequency of appearance in the section by section reports.

Capacity benefits[1] are expected to be the driving force for AHS deployment in busy sectors of urban areas. Substantial gains in infrastructure utilization result from the increased AHS capacity. This is expected to be an area of favorable cost/benefit evaluations. Even older studies with lower target capacities and demands reported AHS in busy urban corridors as a provider of "cost effective highway capacity."[1] Increased AHS capacities, urban travel demand and higher land values are expected to make the cost-benefit results even more convincing. Safety, travel time and comfort benefits are expected to be high in rural areas. Lower travel demand and land values in the rural areas are expected to reduce the benefits from capacity gains through AHS. However, safety benefits due to the reduction of "improper and unsafe driving" caused accidents are expected to be important.

Higher speeds could be pursued in the absence of capacity problems, although this is likely to be at the expense of energy efficiency and air pollution if the Internal Combustion Engine is the primary AHS propulsion. After a modest effort of modeling for the Los Angeles region our team determined that <u>tailpipe emissions</u> are likely to be the same before and after AHS (with a constant demand). Conservative estimates show that the savings from a smoother flow were balanced by higher emissions due to higher average speeds. More positive impacts could result from engine “enrichment” reductions due to non-driver controlled cycles. Such benefits are difficult to estimate since exact controller designs are not available and enrichment initiation points vary on a vehicle by vehicle basis. Details on the assumptions and model runs are included in section seven of the study. The "total" air quality problem requires elaborate modeling beyond the scope of this study. However, trends in the past decade indicate that although tailpipe pollutants are still at high levels they have been reduced in <u>absolute</u> total values by a factor of three compared to the early 70s despite the huge vehicle-mile increases. Experts in the air quality field are already admitting that although tailpipe emissions remain a major target for reductions, improvements in the "total" air quality area are dependent today on controlling other factors as well. Cleaner burning fuels and engine technology are also moving forward in the area of tailpipe emission reductions. Additionally, potential for negative changes in AHS emissions is more frequent in the rural areas where air quality is less of an issue. In summary, although the AHS induced higher average speeds are likely to produce similar emissions, the travel time savings and several other factors should tip the scale towards AHS deployment.

The impact of heavy vehicles on the AHS is mixed. On the one hand it was shown that some savings in operating cost for heavy vehicles may be realized through AHS. Improvements are expected in the area of more effective logistics, inter-modalism as well as industry vertical integration. As mentioned in the special section on CVOs, it is not clear that the benefits will necessarily come from more and/or faster miles on the highway. Improvements could very well stem mainly from the improved logistics, with reduced VMT on the highways for some origin destination pairs and/or areas. The total number of highway ton-miles may be reduced compared to a non-AHS future. Basically, AHS

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[1] Ranging from 5% (early I_1) to 500% (I_4) as shown in section nine of the study.

would reinforce the trend of shipping by rail or long haul freight with improved inter-modal coordination at the rail-yards. Substantial safety improvements are also expected from the use of AHS due to fewer human driving errors and more “on time” system performance. These impacts are expected to reduce unit costs and improve system efficiency. On the other hand capital will be needed for new technologies that will make AHS feasible for heavy vehicles. Additionally, substantial design and operating constraints will have to be met in order to accommodate heavy vehicles in the AHS. Constraints include infrastructure width, height and above all grades. Such design constraints will sometimes be very costly, particularly in the rural areas due to the need for retro-fitting many highway miles with low traffic volumes. In the areas of pavement design, changes may be required to ensure more predictable/uniform vehicle braking ability. AHS pavements will probably have to be maintained according to higher standards. This is expected to result in higher costs but safety benefits as well. Common standards will also need to be applied for rural and urban areas. According to pavement related publications, different deterioration limits and maintenance priority schemes are applied to urban as opposed to rural pavements today. Pavement design procedures and standards will also have to be developed around the concept of a more predictable, possibly more concentrated, loading of pavements. This area has potential for savings, but more detailed studies are required to justify more specific claims.

In the area of interactions between AHS and the legal system, the investigation concentrated on three major concepts : product liability, negligence and Governmental immunity. Findings show that although problems faced by the AHS initially look unique and threatening for the survival of the system, there are several legal options that would strengthen its position. However, the basic legal background needs to be set well before implementation efforts begin. Another finding was that for changes in the operation of the existing highway system significant legislative efforts were required which can be used as guides for the AHS legal support. Finally the concept of Governmental immunity provides the capability of shielding the system from unreasonable claims, but does so at the expense of requiring heavier Governmental involvement in the design and implementation of AHS. The Air Traffic Control system is a model that can be examined in this context. In the area of negligence, the AHS is likely to face more problems in the cases of any non-vehicle based systems. Both vandalism and/or maintenance activities will be challenging, particularly in rural areas. This could be one of the reasons impeding progress of the rural systems beyond stage I_2. In any case the legal issues will be vastly simplified if there is uniformity between urban and rural AHS.

After creating a framework for the evaluation, the group responsible for estimation of the impacts to users concluded on the following findings:

- Overall, AHS seems more desirable/acceptable to users for urban trips rather than rural area trips. The differences are more pronounced in the I_1 & I_3 stages of AHS deployment.
- The highest grades for the urban system, as well as AHS as a whole, are achieved during the I_3 stage with trucks separated from passenger vehicles. Passenger vehicles, in the case of rural trips, stage I_4 gets slightly higher grades than I_3 but still consistently lower than urban trips.
- The concept of perceived versus actual safety was considered a very important one that needs to be addressed early by any implementation effort. Quantitative differences of the two measurements cannot be reported at this time due to unavailability of “actual” and “perceived” data. However, conclusions on system design can be drawn both from expected (by user) actual safety statistics, as well as factors that influence “perceived” safety without necessarily having an impact on accident rates. Users will be very sensitive to information about system status and

performance. System rider-ship and market share will depend greatly on user acceptance of the system safety performance.

The users expectations are likely to revolve around actual safety which for a "hands off" system should be compatible with the rail and air transportation modes. Equipment that is interchangeable between vehicles was also desirable to users.

A delphi type analysis by the team responsible for the evaluation of impacts to society resulted in the following findings:

- Overall, the AHS stage I_3 was rated highest with cells #22 separate from heavy traffic/ moderate speed, long spacing (see operating mode input matrix) and #46 getting the highest grades. (Same as #22 but with moderate spacing)
- The environmental impacts were thought to be neutral (some positive some negative). Proper system design could result in more positive impacts (enrichment elimination etc.), but this depends on the priority this goal receives.
- A very positive impact is expected for the economy particularly at the more advanced stages.
- Based on the evolution assumptions made by the group, AHS deployment was found to be negative for equity issues.
- Slightly negative scores were also received in the area of technical feasibility given the financial constraints.
- Positive scores were received for system acceptability.

Additional variables were introduced to analyze form and function of the Transportation Management Centers (TMC's). The variables can be grouped as following:

- Control activities (vehicle control, inter-vehicle coordination, vehicle management, traffic flow management and incident management).
- Location of activity (on-board, at the zone level, and /or regional level control center).

The analysis on the role of the (TMC's) at the different AHS stages yielded the following findings:

- Early stages of the system will be purely vehicle based but zone and regional controllers will assume more responsibility as we move to more advanced stages.
- It is likely that urban AHS development will diverge from rural AHS development during stage I_3 with convergence in later stages. It is necessary that the two systems be fully compatible during the diverging period.

The study of the impacts of vehicle braking capabilities on AHS capacities resulted in the following findings:

- In highly congested areas (urban situation), and for average tires and pavement conditions, the capacity of the system would benefit by operating at speeds lower than the current highway speed limit. For most of the lead-trail vehicle combinations studied the optimum speed is around 64 kph (40 mph). The capacity here with a system reaction time assumed around three tenths of a second is just under 6000 VPH/lane.
- The optimum speed will become lower for lower quality tires and wet pavement conditions [in the order of 48 kph (30 mph)]. The capacity here with the same reaction time is a little over

3000 VPH/lane. As operating speed increases we have a capacity degradation of approximately 45 VPH/lane for each KPH of speed increase (See section nine for further details).

- Capacity is more sensitive to reaction times for vehicles with good braking capabilities and for changes in the low part of the reaction time scale.
- Some combinations of (good) tire qualities and (usually dry) pavement conditions which may not experience capacity degradation at higher speeds. More research and better data on braking are needed in this area since it provides promising results for the future of AHS.
- Control and monitoring of tire-pavement combinations can yield substantially higher capacities and is feasible in urban depolyments. Rural areas rarely need this additional capacity and system costs for such "control" would be prohibitive anyway.

After issues and risks for each separate environment were analyzed on an operating mode by operating mode basis, an "overall" comparison of the issues and risks in the two environments was made. This "overall" comparison was intended to detect trends in similarities or differences (in issues and risks) that are mode independent.

In the "overall" comparison category it was identified that urban AHS are likely to be more attractive/acceptable to users than rural AHS. Concerns were presented for all stages of deployment in the areas of perceived safety and equity. Commercial Vehicle Operations (CVO's) present a challenge for incorporation in the advanced AHS stages. However, they are also an important, loyal client and revenue generator. Overall, expectations of the AHS deployment as a positive impact on the national economy, were found to be very high.

On the concept of exclusive urban and/or rural AHS the following conclusions were reached:

- It is very likely that the first stages (longitudinal control) of the AHS will be purely vehicle based and operational in both urban and rural areas.
- It is also likely that the second stage (longitudinal and lateral control) of the AHS will be mainly vehicle based and operationally identical for both urban and rural areas. Because of the potential need for markers (any type) on/by the roadway for lateral guidance it is likely that rural areas will be much slower in getting lateral control capabilities.
- Stages I_3 and I_4 as shown by the TMC analysis are likely to be slightly more roadway based than their predecessors. Stages I_1 and I_2 will only offer modest benefits to urban areas. Capacity increases will be difficult to fully materialize and long term safety benefits may initially be overshadowed by fears of the AHS as the analysis of user impacts has shown. There will be pressures in the urban areas to move forward to the more rewarding stages of a separate AHS guideway. If certain urban areas move into these stages while most rural areas are still not be equipped for I_2, there is potential for separation of further developments of rural and urban AHS. One optimistic view expressed in both the TMC group as well as in the impacts to society group, is that eventually unit price reductions and economies of scale will force the system to eventually merge back again towards the mature AHS design.

The concept of a separate guideway is also likely to stir up the equity issues which according to the views presented by the impacts to society group, may be one of the big issues for AHS. Every roadway (public funds) investment, including lateral control markers, may face public opposition on equity grounds. The outcry may also be amplified by the fact that the first phases are likely to be vehicle based and rather expensive. Under this scenario the AHS will be labeled as a system for the privileged and any further refinements with public money are likely to be opposed. This is one of the dangers of a purely vehicle based system (with non-standard equipment) at the beginning. Resistance due to this phenomenon can present itself as early as at the time of installation of the lateral control markers. Another interesting point in this debate, is that eventually if the system (in its final stages) becomes as predicted more roadway based, the on-board equipment is likely to become much cheaper and may be accessible to everyone. It will just be very difficult to convince the public about the "final" stage characteristics, if it starts as an expensive vehicle based accessory. One possible solution to this problem would be to have an almost purely private system by the time we get to advanced stages. However, concerns over legal risks are likely to slow the privatization process. Furthermore, the real potential for AHS, lies in extensive implementation, covering much more ground than initial isolated sections will be able to demonstrate to investors. Even in the case of a target private system, the public sector will need to guide evolution and provide assurances for further direction to both users as well as investors. Public involvement from early stages is likely to reduce opposition in later more expensive/challenging system expansions.

In a compromise solution, it is conceivable that new highway construction projects be designed or redesigned to be AHS compatible. Along those lines, special AHS ready connectors bypassing today's urban network capacity bottlenecks could be designed and given high implementation priority on cost effectiveness grounds. Initially such connectors may be accessible to manual traffic as well. As the AHS ready network materializes and higher AHS ready vehicle market penetration is achieved, manual vehicle accessibility could be restricted on higher efficiency grounds (if applicable/necessary). This "middle ground" solution improving capacity in urban areas, (mainly through more infrastructure) while AHS is still in I_2, could preserve coordination between urban/rural deployments and could also ease opposition from manual traffic supporters.

An additional strategy could be to initially market AHS vehicles as probes (detecting and communicating conditions and abnormalities) for the "overall" highway status including local and collector streets. Probing could include (but should not be limited) to speed and congestion information, pavement condition, weather, signal and other traffic device malfunctions etc. This "probing" function of initial AHS capable vehicles could prove very helpful for operational and maintenance infrastructure upgrades, useful to all motorist/vehicles, but equally important in preparing for future AHS stages. This effect is expected to be equally beneficial to both urban and rural areas since both face significant problems in timely detection of system status and deficiency identification. Along the same lines if the AHS capable vehicles could perform some other "public good" function, (possibly even outside the narrowly defined "transportation") while moving around the network, it would have a positive effect on the public perception of the "mission" of AHS.

Apendix A

Glossary Section 7

VMT: Vehicle Miles Traveled (%).
LDA: Light Duty Autos.
CAT: Catalytic Converter.
TOG: Total Organic Gases emissions (tons/day).
ROG: Reactive Organic Gases emissions (tons/day).
CO: Carbon Monoxide emissions (tons/day).
NOx: Oxides of Nitrogen emissions (tons/day).
PM: Particulate Matter emissions (tons/day).
Pb: Lead emissions (tons/day).
SOx: Oxides of sulfur emissions(tons/day).
Fuel Command: Used to determine Pb and SOx emissions (1000 gallons/day).

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