RURAL AUTOMATED HIGHWAY SYSTEMS CASE STUDY

Greater Yellowstone Rural ITS Corridor

FINAL REPORT

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EXECUTIVE SUMMARY

Introduction

In cooperation with the National Automated Highway System Consortium (NAHSC), case studies are being conducted on existing transportation corridors to determine the feasibility of AHS. Initial activities by the NAHSC have focused on urbanized areas. However, a need exists to investigate the applicability of advanced transportation technology and AHS in rural settings. AHS applications have primarily focused on problems associated with urban traffic congestion; secondary considerations have related to safety, air quality and energy conservation. These areas are also of concern to the rural transportation provider; however, the primary focus of the rural transportation provider is improved safety.

The Greater Yellowstone Rural Intelligent Transportation Systems (GYRITS) corridor comprises a loop roadway system traversing through Wyoming, Yellowstone National Park (YNP) and Grand Teton National Park, connecting Bozeman, Montana with Idaho Falls, Idaho. The combination of varied, often undesirable driving conditions with wildlife, unfamiliar drivers, a diverse traffic stream and a lack of communication infrastructure indicates an immediate and growing need for increased focus on safety. The problems experienced in the GYRITS corridor are common to many rural environments. Hence, it is an ideal location to showcase field operational demonstrations of advanced technologies.

The intent of this study was to recommend applications and consider implications of Automated Highway Systems (AHS) in a rural environment. This study focused on developing an applicable AHS for the GYRITS corridor that would ultimately increase safety and improve operation.

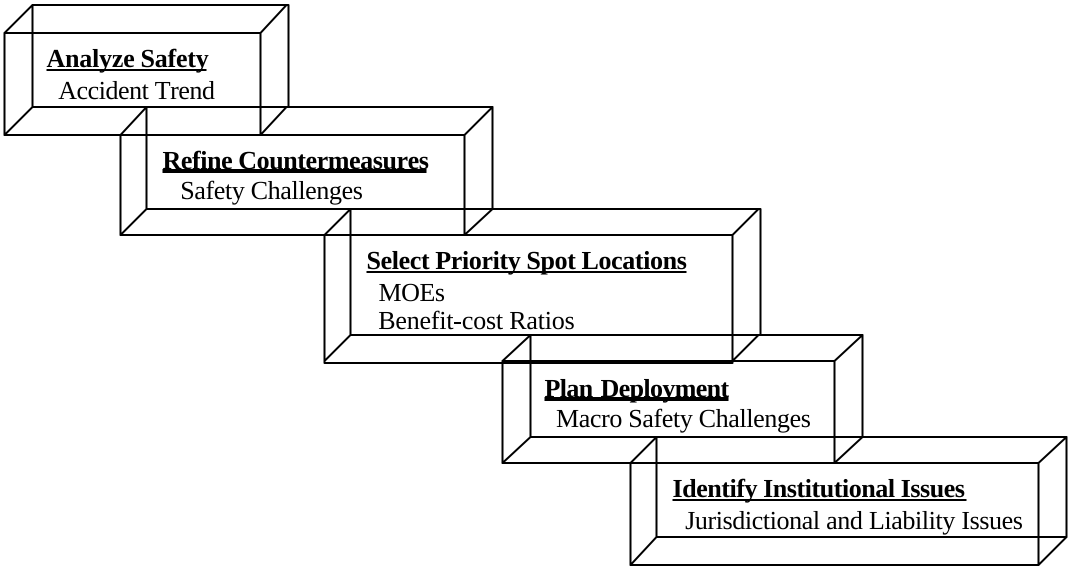

Figure i - Project Methodology

Rural AHS Vision

The system conceived for this project and used in the benefit-cost analysis assumes four incremental service levels: (1) Spot Application: locations where accidents are statistically over-represented will be implemented with technology to warning the driver of hazards via the infrastructure and dynamic messages; (2) Information Assistance: dangers warnings will be relayed to the driver via the vehicle; (3) Control Assistance: the vehicle warnings will be relayed to the driver and in the event the driver does not respond the vehicle will temporally assume control; and (4) Full Automation: in this instance the vehicle is fully autonomous.

Information Assistance, Control Assistance and Full Automation have three primary functions that assist with collision avoidance. These three functions are (1) longitudinal collision warning/guidance, (2) lateral collision warning/guidance and (3) intersection collision warning.

Institutional Issues

Challenges that may impede the deployment of AHS are institutional in nature. These include legal implications, public acceptance, procurement procedures, funding, operation and maintenance responsibility, privacy issues, environmental impacts, societal issues and jurisdictional coordination. Some public agencies are hesitant to get involved; the envisioned AHS system may be perceived as too futuristic. This is especially true in rural environments where agencies typically mitigate roadway problems using “low-tech, low-risk” solutions. Involving the rural transportation providers early in the planning, testing and evaluation phases will help promote the effectiveness of AHS, develop champions and achieve user buy-in. An incremental deployment strategy will help demonstrate early, visible, quantifiable safety benefits for potential users.

Accident Analysis

Accident rates were determined for each half-mile segment using a floating referencing system. Specifically, rates were determined on a half-mile basis, advancing along the route every tenth-mile. Additionally, severity rates were determined for each floating half-mile segment. Based on these rates, potential atypical accident locations were chosen for further study. These locations were analyzed to determine what, if any, accident trend(s) existed. Segments exhibiting trends were thought to have the best chance of maximizing benefits from AHS applications (see Table i).

Accident data, collected from Idaho, Montana, Wyoming and Yellowstone National Park, was standardized and assimilated to allow for spatial representation using Geographic Information Systems (GIS). Accident data was depicted both at spot locations and continuously along the roadway depending on the frequency and characteristics of the accidents. Before examining the accidents to determine geographic areas of focus, the corridor was separated into 18 major segments based on: changes in geometric alignment, city limits, mountainous areas, and state lines. Although state lines were assumed to be transparent, segments were broken along state lines for ease of analysis. The segment types included rural-flat, rural-mountainous, urban

Table i - Atypical Spot Locations

Milepost Range	Total Accidents	Total Trend	Milepost Range	Total Accidents	Total Trend
Montana U.S. Highway 191					
9.900-10.011	18	13	10.000-11.000	20	17
28.000-28.900	13	9	59.000-60.000	11	8
61.000-61.400	12	7			
Montana U.S. Highway 20					
1.000-2.000	10	6	8.619-8.946	11	7
Idaho U.S. Highway 20					
311.000-312.000	22	14	317.000-318.000	42	29
328.000-329.000	14	6	338.000-339.000	17	11
326.000	12	4	405.000-406.000	8	6
Idaho U.S. Highway 26					
335.000-336.000	23	12	336.000-337.000	34	24
338.000-339.000	16	11			
Wyoming U.S. Highway 89					
160.000-161.000	11	8	167.000-168.000	12	5
185.000-186.000	18	11	189.000-190.000	12	6
184.400-184.600	8	8	188.000-188.690	6	6
127.000-128.000	22	16			
Yellowstone National Park Highway 89					
21.034-21.834	18	9	21.334-21.834	5	5
43.122-43.672	9	5	66.180-67.780	20	9

(within city limits), suburban (directly outside city limits until change in cross section), and semi-mountainous (only in Yellowstone National Park). The number of accidents for each accident trend, identified previously for half-mile locations, was determined for each of the 18 major segments. A geographic area was identified for focus if the area possessed two of the three following criteria: (1) a high percentage of the accidents in the area had a common trend; (2) a high number of the accidents in the area had the same common trend; and/or (3) half-mile atypical locations existed with the same trend (see Table ii).

In addition to considering spot and regional locations for the entire accident sample, two smaller groups were separated out for further analysis: (1) commercial vehicles and (2) in-state/out-of-

Table ii – Atypical Regional Segments

Milepost Range	Road Type	Total Accidents
Yellowstone Park U.S. Highway 89		
0.000-93.446	Park	426
Wyoming U.S. Highway 26		
0.000-2.370	Mountainous	7
Montana and Yellowstone Park U.S. Highway 191		
0.000-10.835	Level	88
10.836-66.826	Mountainous	276
66.827-81.903	Level	98
Idaho U.S. Highway 20		
308.717-353.050	Level Suburban	271
353.051-401.300	Level	117
401.301-406.300	Mountainous	18
Montana U.S. Highway 20		
0.000-3.000	Level	27
3.001-9.397	Mountainous	39
Idaho U.S. Highway 26		
335.255-338.069	Level Suburban	64
338.070-375.538	Level	134
375.539-402.500	Mountainous	63
Montana U.S. Highway 89		
0.000-51.812	Level	112
51.813-53.068	Level Suburban	44
Wyoming U.S. Highway 89		
118.32-152.090	Mountainous	304
155.211-165.000	Level	86
165.001-211.620	Mountainous	245

Table iii - Heavy Vehicle Accident Rates

Accident Type	Total Accidents	Accident Rate (R/MVMT)	National Average	Difference
Property Damage Only	54	97.39	75.00	+22.39
Injury Accidents	69	40.73	47.00	-6.27
Fatal Accidents	8	4.72	2.50	+2.22

state drivers. Targeting smaller groups within this sample may actually help to accelerate NAHSC's near-term deployment goals.

Heavy vehicles were involved in approximately 10 percent of all accidents within the corridor, resulting in 28 percent of the fatality accidents and five percent of injury and property damage only accidents (see Table iii). Nationally, heavy vehicles accounted for 12 percent of all traffic fatalities and three percent of all accidents resulting in injury and property damage only. [10] The aforementioned statistics, which indicate that heavy vehicle accidents in the GYRITS corridor exceed the national averages, support the notion that a safety problem exists related to commercial vehicles in the corridor. However, the low frequency of accidents made it statistically difficult to sort heavy vehicle related accidents into trends. Instead, heavy vehicle accident rates appeared to be distributed randomly through mountainous and flat regions; indicating driver error may be the primary problem, while alignment and terrain are secondary contributors.

Traveler origin information was examined to determine if accidents within the corridor were a product of unfamiliar out-of-state travelers or local residents. It was hypothesized that this information would be helpful in determining target groups for early operational testing and evaluation. Tables iv and v describe the differences among in-state and out-of-state crash involvement rates for each geographic area of focus. The accident data from Idaho and Wyoming allowed for the determination of the causing party. Hence, each accident could be traced to a single in-state or out-of-state party; the proportion of in-state travelers and out-of-state travelers involved in an accident summed to one. Montana's accident data did not reflect causing party information but rather accident involvement. Hence, the proportion of in-state travelers and out-of-state travelers summed to greater than one.

Benefit-cost Analysis

Table vi presents realistic benefit-cost ratios based on predicted vehicle fleet market penetration as indicated in the deployment vision. Note the importance of vehicle fleet penetration and AHS service level on benefit-cost ratios for full-scale regional deployment. Many regions were deemed inappropriate for the installation of AHS infrastructure due to low benefit-cost ratios, likely resulting from the relatively low vehicle fleet market penetration. Lower accident

Table iv - Origin of Vehicle Causing Accident

State	Route	Segment	% In-state	% Out-of-state
Wyoming	89	total corridor section	51	49
	89	158.82 to 204.85	41	59
Idaho	20	total corridor section	68	32
	20	308.717 to 353.05	84	16
	20	353.06 to 406.30	37	63
	26	total corridor section	73	27

Table v - Origin of Vehicles Involved in Accident

State	Route	Segment	% In-state	% Out-of-state
Montana	20	total corridor section	65	94
	89	total corridor section	123	36
	191	total corridor section	71	48
	191	0 to 10.493	49	56
	191	10.494 to 81.903	60	36

reduction factors also resulted in lower benefit-cost ratios for the Information Assistance service level.

Next Steps

This section recommends several areas for possible early field operational testing (FOT)with low-level AHS technology. The intent of the recommended FOTs is to provide the driver with more information and more time to react. It is hypothesized that this additional information and time will help the driver avoid many collisions. Through the benefit-cost analysis, sites with the greatest potential were selected for AHS technology deployment in continuing efforts. The candidate sites include:

Friction/Ice Detection and Warning System

- Montana U.S. Highway 191, milepost 9.900 to 10.011 and 10.000 to 11.000;

Table vi - Benefit-cost Ratio Based on Deployment Vision

	Benefit-cost Ratios	
Location	**Information Assistance** 20% penetration after 10 years	**Control Assistance** 50% penetration after 20 years
Montana U.S. Highway 191		
MP 0.000 – 10.835	3:1	23:1
MP 10.836 – 66.826	2:1	17:1
MP 66.827 – 81.903	4:1	34:1
Montana U.S. Highway 89		
MP 0.000 – 51.812	0.007:1	0.07:1
MP 51.813 – 53.068	5:1	37:1
Montana U.S. Highway 20		
MP 0.000 – 3.000	2:1	14:1
MP 3.001 – 9.397	0.02:1	0.2:1
Idaho U.S. Highway 20		
MP 308.717 – 353.050	7:1	36:1
MP 353.051 – 401.300	3:1	32:1
MP 401.301 – 406.300	0.7:1	5:1
Idaho U.S. Highway 26		
MP 335.255 – 338.069	20:1	137:1
MP 338.070 – 375.538	2:1	17:1
MP 375.539 – 402.500	1:1	10:1
Wyoming U.S. Highway 26		
MP 0.000 – 2.370	0.2:1	2:1
Wyoming U.S. Highway 89		
MP 118.320 – 152.090	4:1	34:1
MP 155.211 – 165.000	4:1	36:1
MP 165.000 – 211.620	1:1	9:1
Yellowstone National Park U.S. Highway 89		
MP 0.000 – 93.446	1:1	9:1

Intersection Crossing Detection

- Idaho U.S. Highway 26, milepost 336.000 to 337.000;
- Idaho U.S. Highway 20, milepost 317.000 to 318.000 and 311.000 to 312.000;

Animal-Vehicle Collision Avoidance

- Wyoming U.S. Highway 89, milepost 160.000 to 161.000 and 189.000 to 190.000;

Horizontal Curve Speed Advisory

- Wyoming U.S. Highway 89, milepost 127.000 to 128.000.

These sites were estimated to have the greatest potential for improving safety in the GYRITS corridor through the deployment of AHS. However, before any of the above sites are designated as FOTs, further investigation of the police accident records, the site, and the transportation providers' perspectives needs to occur.

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INTRODUCTION

The intent of this study was to recommend applications and consider implications of Automated Highway Systems (AHS) in a rural environment. This study focused on developing an applicable AHS for the Greater Yellowstone Rural Intelligent Transportation Systems (GYRITS) corridor (see Appendix A) that would ultimately increase safety and improve operation of the GYRITS corridor.

Initial activities by the National Automated Highway System Consortium (NAHSC) have focused on urbanized areas (see Figure 1). However, a need exists to investigate the applicability of advanced transportation technology and AHS in rural settings. AHS applications have primarily focused on problems associated with urban traffic congestion; secondary considerations have related to safety, air quality and energy conservation. These areas are also of concern to the rural transportation provider; however, the primary focus of the rural transportation provider is improved safety.

There are many safety benefits potentially realized through the application of AHS technologies to the existing transportation infrastructure, particularly through advanced driver warnings. It is estimated that if a driver were warned of an impending collision one half second earlier, 50 percent of rear-end and cross-road crashes and 30 percent of head-on crashes could be avoided. If an additional second is provided to the driver, 90 percent of all crashes could be avoided. Experts estimate that advanced transportation technologies will potentially save 11,500 lives, 442,000 injuries, and $22 billion in property damage nationally by 2010. [2]

The selected corridor represents a vital transportation link for the trucking industry, connecting the Northwest and Canada with Intermountain and Southwest markets. Approximately 20 percent of the traffic traversing the GYRITS corridor is commercial. [3] Commercial vehicles

Figure 1 – Typical AHS Environment

use this route to transport goods between the aforementioned markets and markets within the corridor (e.g., mining, forestry, and agricultural industries). Because much of the corridor is two-lane highway, many dangerous passing situations result involving large trucks, recreational vehicles, tourists and slow-moving farm machinery. Poor sight distance, limited by the winding road and canyon walls, exacerbates the danger.

The corridor presents an environment filled with unique challenges that must be confronted when developing a viable transportation system. The corridor receives about 80 to 90 inches of snow in a typical winter (see Figure 2). Temperatures can reach 65 degrees below zero (Fahrenheit) and a 40 to 50 degree temperature shift from day to night is not unusual. Winter conditions typically last about eight months. However, it has been known to snow in the higher elevations in the summer months.

Figure 2 – Typical Corridor Snowfall

Figure 3 – Potential Animal-vehicle Conflict

The corridor encompasses migration routes and habitat for deer, elk, bison and moose. Periodically, these animals can be found on the roadway, presenting a potential animal-vehicle conflict (see Figure 3). Over a recent three-year period, 367 animal-vehicle collisions were reported. Non-reported animal-vehicle collisions likely increase this number substantially.

Because much of the corridor abuts mountain ranges, many sections of the corridor are not covered by cellular phone service. The canyon walls also preclude the reception of AM or FM radio band signals throughout much of the corridor.

The combination of varied, often undesirable driving conditions with wildlife, unfamiliar drivers, a diverse traffic stream and a lack of communication infrastructure indicates an immediate and growing need for increased focus on safety. The problems experienced in the GYRITS corridor are common to many rural environments. Hence, it is an ideal location to showcase field operational demonstrations of advanced technologies.

Background

In the last couple of decades, the transportation community has seen the emergence of new transportation technologies. Many agencies across the country have implemented and demonstrated the use of advanced transportation technologies but with little or no national coordination, standards or strategic direction. The congressional enactment of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) restructured the United States Department of Transportation (USDOT) and made provisions for the development of an advanced technology program titled "Intelligent Vehicle-Highway Systems (IVHS). The USDOT was required to develop a national strategic plan and a grant program for the research, development and deployment of advanced transportation technologies. Later IVHS evolved into Intelligent Transportation Systems (ITS). This evolution presented ITS as a *transportation* consortium rather than a *highway* consortium. In 1992, the nation's first strategic plan, outlining the goals and objectives of the development of the national ITS architecture, was developed. [4]

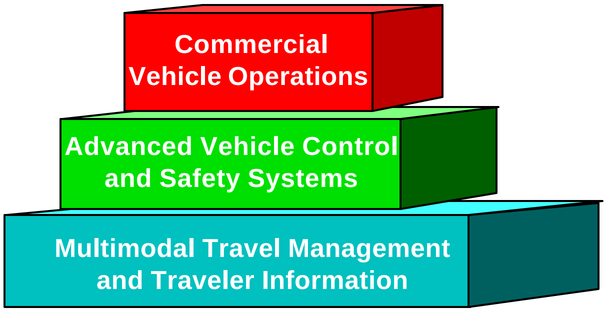


Figure 4 - ITS Areas of Focus

Automated Highway Systems (AHS) reside within one of the three major study areas of ITS. Specifically, AHS is part of the Advanced Vehicle Control and Safety Systems (AVCSS) branch. Figure 4 depicts the three primary study areas of ITS.

ISTEA allocated resources to ITS and mandated an AHS technology feasibility demonstration in 1997, now known as *Demo 97*. To meet this goal, the National Automated Highway Systems Consortium (NAHSC) was created. The National Automated Highway Systems Consortium is a government-industry-academia collaboration working to apply AHS technology to our nation's highways to enhance efficiency and safety. This group led the efforts to meet the 1997 AHS demonstration goal.

The National Automated Highway System Consortium was charged with specifying, developing and demonstrating a prototype Automated Highway System (AHS). The specifications will provide for an evolutionary deployment that can be tailored to meet regional and local transportation needs. The NAHSC evolutionary deployment will: (1) provide for early introduction of vehicle and highway automation technologies to benefit all surface transportation; (2) incorporate public and private stakeholder views; and (3) involve stakeholder decision-making organizations.

Vehicle and highway automation is not new. The concept has been in existence for the last 50 years. As the vehicle has evolved, it has been automated (i.e., electric starters). As early as the 1950s and 1960s, General Motors and RCA experimented and demonstrated automated control of vehicle steering and speed on test tracks using analog vacuum-tube electronics. From the mid-1960s to about 1980, Ohio State University continued AHS research under the sponsorship of the Bureau of Public Roads and its successor, the Federal Highway Administration (FHWA). During this same timeframe, private sector companies such as TRW, Calspan and General Motors also studied AHS issues.

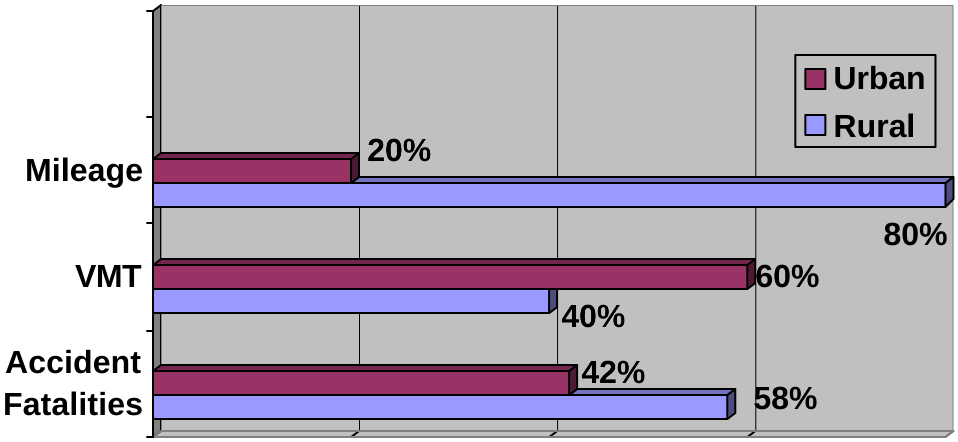
AHS was resurrected in 1986 by the California Department of Transportation (Caltrans) when they organized a conference on "Technology Options for Tomorrow's Transportation." At this time, Caltrans also founded the Partner for Advanced Transit and Highways (PATH) program. Through PATH, Caltrans was able to promote advanced transportation technologies to meet California's growing need for greater highway capacity. In 1988, an informal working coalition, called Mobility 2000, was formed. Mobility 2000 defined the framework for the national program to develop, deploy and evaluate AHS technology. Mobility 2000 helped lead the development of ITS America, which in turn coordinated, funded and solidified the nation's AHS effort. [5]

Given that much of the historical advanced transportation technology development came about in response to urban traffic congestion, it is important to understand the different characteristics of the rural and urban environment. As the transportation community is now learning, advanced transportation technologies designed for the urban setting cannot necessarily be mirrored to the rural setting.

Project Goals and Objectives

The goal of this project is to enhance the quality of life for rural residents and travelers through more safe and efficient movements of goods and people using judicious applications of advanced vehicle control technologies. An evolutionary deployment process will be followed, which allows transportation system users and providers to gradually realize the tangible benefits of deploying advanced vehicle control technologies.

The rural community is faced with many unique challenges and opportunities to develop sustainable transportation systems that address the needs of the rural traveler. Some of the rural transportation needs are in vast contrast to the urban transportation needs. Urban problems encompass congestion, mobility, air quality, noise, safety, and energy issues. While rural areas struggle with many of these same issues, they have a rural-specific focus that differs. Rural safety issues are the highest priority. Two-lane rural highways are the backbone of the rural transportation network. These roads carry local traffic as well as commercial vehicles, transit vehicles, school buses, recreational traffic and commuter traffic destined for metropolitan areas. Rural roads account for 80 percent of the nation's total mileage. Only 40 percent of the national vehicle-miles traveled occur in rural areas. However, rural areas account for 58 percent of the accidents causing fatalities (see Figure 5). [1]



Source: FHWA 1994 "Highway Statistics"

Figure 5 – Rural and Urban Travel Characteristics

Corridor Description

This section provides an overview of rural transportation problems specific to the GYRITS corridor. The focus of this report is safety as it relates to roadway alignment, human factors and weather. Figure 6 portrays the interaction of these elements in the project methodology.

Roadways

The corridor contains several roadways; a description of each roadway follows (see Appendix A). In the northern portion of the corridor, U.S. 191 originates in Bozeman, Montana and continues south for fifty miles through the Gallatin Canyon following the Gallatin River. The Gallatin Canyon hosts a wealth of industries such as logging, recreation and tourism. Big Sky Ski and Summer Resort lies 35 miles from Bozeman, Montana, north of U.S. 191, offering abundant summer and winter recreational activities. U.S. 191 also travels through the Gallatin National Forest, which is used extensively by recreational travelers and commercial vehicles supporting the timber industry. Continuing south, U.S. 191 leaves Gallatin Canyon and enters Yellowstone National Park (YNP), home to thousands of elk, deer, moose and bison. YNP is also the location of an increasing number of year-round tourists. Between 1988 and 1992, annual visitation to YNP increased 40 percent, to total more than 3 million. [6] U.S. 191 terminates at West Yellowstone, Montana.

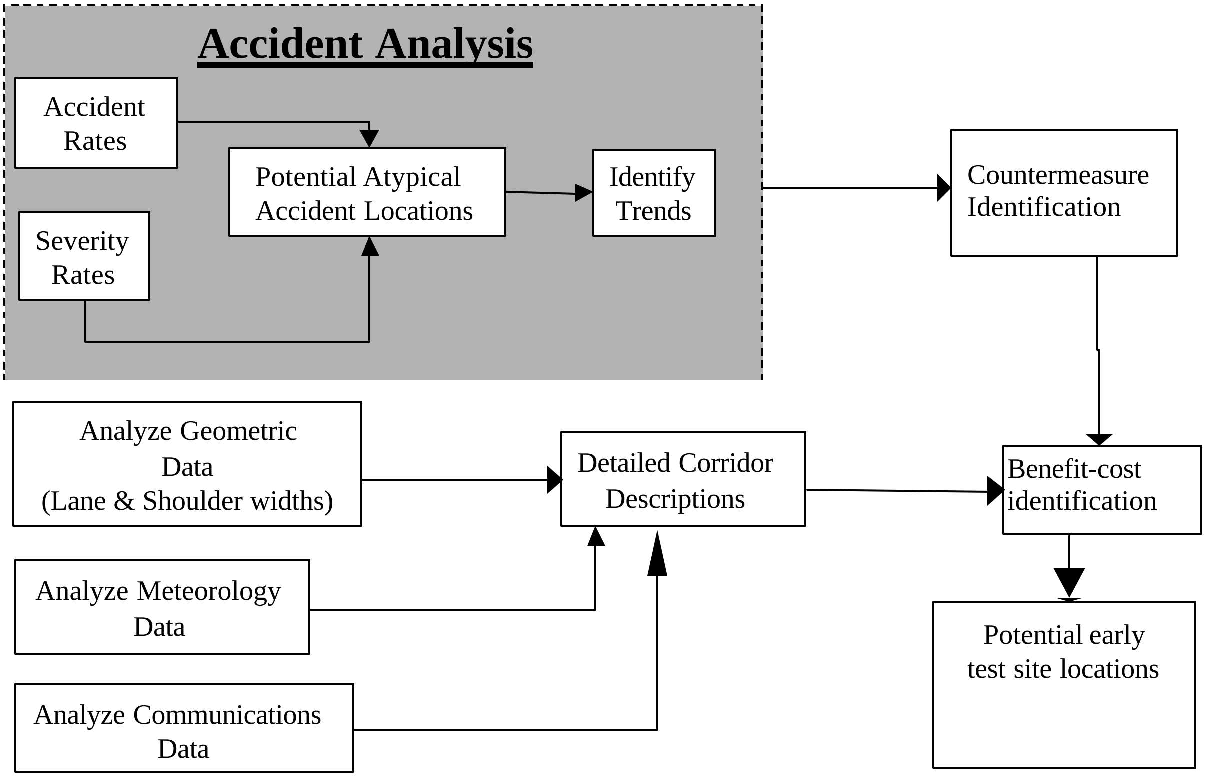


Figure 6 – Project Methodology

U.S. 20 originates at West Yellowstone, Montana and continues southwesterly to Idaho Falls, Idaho. U.S. 20 crosses Targhee Pass and the Continental Divide at an elevation of 7,072 feet. Every year, this pass delays travelers due to snow and other winter-related driving difficulties. U.S. 20 passes through Targhee National Forest, enters east central Idaho and terminates at Idaho Falls, Idaho.

U.S. 89, beginning in Livingston, Montana (for this study) presents driving conditions similar to U.S. 191. The primary difference is that U.S. 89 does not directly traverse the foothills of Paradise Valley, but rather crosses semi-flat terrain. Approximately 53 miles before U.S. 89 enters Yellowstone National Park, it passes through the Gallatin National Forest. It then continues though Yellowstone National Park and enters the Bridger-Teton National Forest in Wyoming. U.S. 89 continues through Grand Teton National Park and the recreational community of Jackson, Wyoming. U.S. 89 passes through either national park or national forest areas continually to the western Wyoming border.

Near the Wyoming border, at Alpine Junction, U.S. 26 begins. It enters Idaho and continues on to the study's final destination in Idaho Falls, Idaho.

Meteorological Conditions

The prevailing meteorological conditions throughout the corridor are varied and severe, creating problems related to both safety and maintenance. The corridor receives heavy snowfall for several months at a time, creating surface conditions that vary from wet to hard-packed ice. Drivers, unaware of these changing conditions, are in danger of running off the roadway, becoming stranded or experiencing a potentially life-threatening collision. Heavy snowfall also strains maintenance resources. Maintenance activities in themselves may pose a safety risk for motorists attempting to pass a snowplow or unaware of an oncoming snowplow.

Temperatures throughout the corridor can drop well below zero degrees (Fahrenheit) for extended periods of time, creating dangerous conditions for motorists who become stranded and are unable to obtain help in a timely manner. Temperature changes of 50 degrees in a single day are not unusual and can create unexpected changes in the road surface conditions.

Windy conditions throughout the corridor are commonplace; gusts can occur unexpectedly creating hazardous situations. Travelers may experience blinding conditions or be forced to take an unfamiliar route due to a wind-related road closure. Wind can also create maintenance concerns in the form of downed signs or debris in the roadway.

The corridor is located in an active seismic region. The seismic activity, coupled with the diverse weather conditions, can create rockslides in the mountainous regions, which can block roadways, strike vehicles or cause vehicular collisions.

Meteorological data was collected at various locations throughout the corridor. The data included average maximum and minimum monthly and yearly temperatures, average annual precipitation, average annual snowfall, design wind speed and seismic zones. Temperature, precipitation and snowfall data, from January 1, 1995 to May 31, 1996, was obtained through the Western Regional Climate Center. [7] Design wind speed and seismic zone data was obtained from the 1994 Uniform Building Code. [9] The wind speed values were based on the highest recorded velocity averaged over the time it takes for one mile of air to pass a given location. Seismic zones give a generalized representation of the seismic activity in a region. These zones were ranked from one to four, with four being the most seismically active.

Appendix B provides corridor conditions by route and city. The meteorological data is city-specific. It was assumed that average conditions existed along the route between any two cities.

Communication Infrastructure

Information related to the corridor communication infrastructure was difficult to obtain. However, some facts were determinable:

- cellular service is limited and spotty in some locations;
    - Gallatin Canyon has almost no service, service resumes near West Yellowstone, Montana and continues strongly to Idaho Falls, Idaho

    - Yellowstone National Park has no service
    - U.S. Highway 89 has spotty service throughout
- most areas in the mountainous regions are unable to receive AM or FM band radio signals; and
- most areas rely on some type of hardwire communication system for phone service and power.

Geometric Characteristics

Geometric data collected for the corridor included number of lanes, lane width, length of each segment, physical configuration of each on- and off-ramp, shoulder width, and median width. Much of the corridor consisted of two-lane highways with limited stretches of three- and four-lane highways near major cities. Lane widths were typically 12 feet, except for a 14-foot section along Idaho U.S. Highway 20 from milepost 360.3 to 360.6 (a four-lane segment of highway). In addition, 10-foot auxiliary lanes (mostly left turn lanes) existed in some areas along Wyoming U.S. Highway 89. Paved shoulders varied from zero to 14 feet in width and occasionally had additional unpaved shoulders. Most of the corridor’s highways had at-grade intersections with rural collectors and driveways. The only section of roadway that had limited access was U.S. Highway 20 from Idaho Falls, Idaho (milepost 307) to northeast of Idaho Falls, Idaho (approximately milepost 347). Along this segment of roadway, only diamond interchanges existed. Detailed geometric characteristics are provided in Appendix C by milepost.

Project Partners

This study encompassed four principal jurisdictions and numerous local jurisdictions. The four principal jurisdictions and their respective contacts were:

- Montana Department of Transportation - Dennis Hult, ITS Program Coordinator;
- Idaho Department of Transportation – Lance Holmstrom, Senior Transportation Planner;
- Wyoming Department of Transportation – Jim Gaulke, Traffic/Research Engineer; and
- Yellowstone National Park – Jack Roberts, Road Maintenance Supervisor.

These jurisdictional representatives provided the research team with relevant and timely corridor information.

RURAL AHS VISION

Automated Highway Systems (AHS), according to the National Automated Highway Systems Consortium (NAHSC), "will safely operate properly equipped vehicles under automated control on properly equipped lanes." [11] This is the long-term goal of the NAHSC. However, before this goal can be achieved, AHS will have to be incrementally deployed. For AHS to successfully evolve, the system must present clear and obvious advantages and benefits to the users. If no tangible benefits can be presented, then potential users will likely be unwilling to invest in AHS. This will be particularly true if capital costs are significant. The evolutionary approach will allow users to gradually use and accept AHS technology. With staged successes, users will be able to segmentally experience AHS and develop confidence in AHS safety and reliability.

This incremental approach will permit rural agencies the necessary time to fund and develop advanced technology applications to their transportation system. Generally, rural transportation providers operate with limited resources. Typical characteristics of rural transportation providers are:

- fewer finical resources which to operate;
- more lane-miles per capita to operate and maintain;
- smaller personnel base; and
- wider variety of weather extremes, particularly in the GYRITS corridor.

Rural highways were built to provide high-speed, long-distance travel to all vehicle types. The rural driving environment is unique from the urban driving environment in that rural highways posses the following characteristics:

- longer trips, often through unfamiliar areas;
- 78 percent of rural trips greater than 150 miles are for pleasure [12];
- areas of irregular terrain and road alignment, many times the irregular terrain dictates a less than desirable geometric road design;
- higher traffic speeds coupled with lower traffic volumes;
- longer trips, resulting in inattention, disorientation or fatigued conditions and lengthening driver reaction times;
- more motor vehicle fatalities and higher fatality rates;

- more older drivers, the average age is 45.8 and 18 percent of rural drivers are over 64 years of age [1];
- more severe effects of bad weather;
- more miles of unlit roadways;
- unexpected hazards, such as animals and slow-moving vehicles (farm machinery);
- fewer alternative routes; and
- generally more roadside obstructions and limited clear zones, particularly scenic areas.

For this rural case study, the AHS definition has been tailored to more adequately define the needs of the rural traveler and the evolutionary deployment vision. This case study has defined AHS to be “any application that assists the driver with avoiding any type of impending collision through the use of collision avoidance technology.” This includes any type of audio or visual warning that will provide the driver with a few more seconds of reaction time. This concept best suits the rural environment due to the limited right-of-way and funding. On rural two-lane, limited access highways, dedicated AHS lanes are not a feasible option.

Near-term rural strategies will consist of collision avoidance technologies applied at spot locations where a statistically high number of recurring accidents. Information will be communicated to the driver via roadside dynamic message signs or warning sign beacon mountings.

Long-term rural solutions consist of collision avoidance/driver assistance technology implemented in the vehicle. This will allow infrastructure to vehicle communication and vehicle to vehicle communication, resulting in a “smart” highway system.

The System

The system conceived for this project and used in the benefit-cost analysis assumes four incremental service levels. The service levels are:

1. **Spot Application**: locations where accidents are statistically over-represented will be implemented with technology to warning the driver of hazards via the infrastructure and dynamic messages.
2. **Information Assistance**: dangers warnings will be relayed to the driver via the vehicle.
3. **Control Assistance**: the vehicle warnings will be relayed to the driver and in the event the driver does not respond the vehicle will temporally assume control.
4. **Full Automation**: in this instance the vehicle is fully autonomous.

Information Assistance, Control Assistance and Full Automation have three primary functions that assist with collision avoidance. These three functions are (1) longitudinal collision warning/guidance, (2) lateral collision warning/guidance and (3) intersection collision warning.

Longitudinal Collision Warning/Guidance

The longitudinal warning function is designed to detect when a vehicle is traveling too fast for an oncoming roadway segment. The longitudinal warning system utilizes a vehicle's dynamic state and performance data in conjunction with current pavement condition and roadway geometric alignment data to calculate a maximum safe speed. If a vehicle is exceeding the maximum safe speed, the vehicle will alert the driver of the danger so that he/she may take appropriate action to avoid a crash. In the case of Control Assistance, a vehicle may automatically decelerate to a safe operating speed. The longitudinal warning function also detects slow-moving and fixed objects at a sufficient distance to allow the driver to stop or safely maneuver around the object. Once again, Control Assistance may intervene if a driver does not react or if the distance is to short to permit a driver adequate reaction time.

Lateral Collision Warning/Guidance

The lateral warning system is designed to detect when a vehicle is departing a travel lane. The lateral warning system utilizes data about the dynamic state of a vehicle in conjunction with information about an oncoming roadway geometric alignment to determine if a vehicle's current position and orientation will likely lead to a lane departure. If the likelihood of lane departure exceeds a particular threshold, an audio or visual alarm alerts the driver of danger to avoid an accident. In the case of Control Assistance, a limited amount of steering torque will be applied to reposition the vehicle in the center of the driving lane.

Intersection Collision Warning

The intersection warning system is designed to detect the presence of vehicles on major roadways and relay the information to vehicles waiting to cross on minor roadways. Sensors or loop detectors placed on either side of the intersection in the major road determine when crossing, left turn or right turn maneuvers are safe. The American Association of State Highway and Transportation Officials (AASHTO) provides safe distance values for all three maneuvers (i.e., crossing, left turn, right turn). Safe crossing information is relayed to the driver through stop sign-mounted beacons or through in-vehicle displays.

Deployment Vision

Limited quantification of AHS benefits and slow market penetration (i.e., vehicles equipped with advanced vehicle control systems) makes it difficult to clearly envision AHS deployment. However, it is recommended that AHS development in this corridor be incremental. Incremental deployment has been the "rule of thumb" for all AHS deployments. Most rural agencies will have to incrementally build an AHS infrastructure due to limited annual financial resources. This approach is referred to as "open architecture" - the use of incremental deployment with flexible design and regional tailorability (see Figure 7). An open architecture allows rural

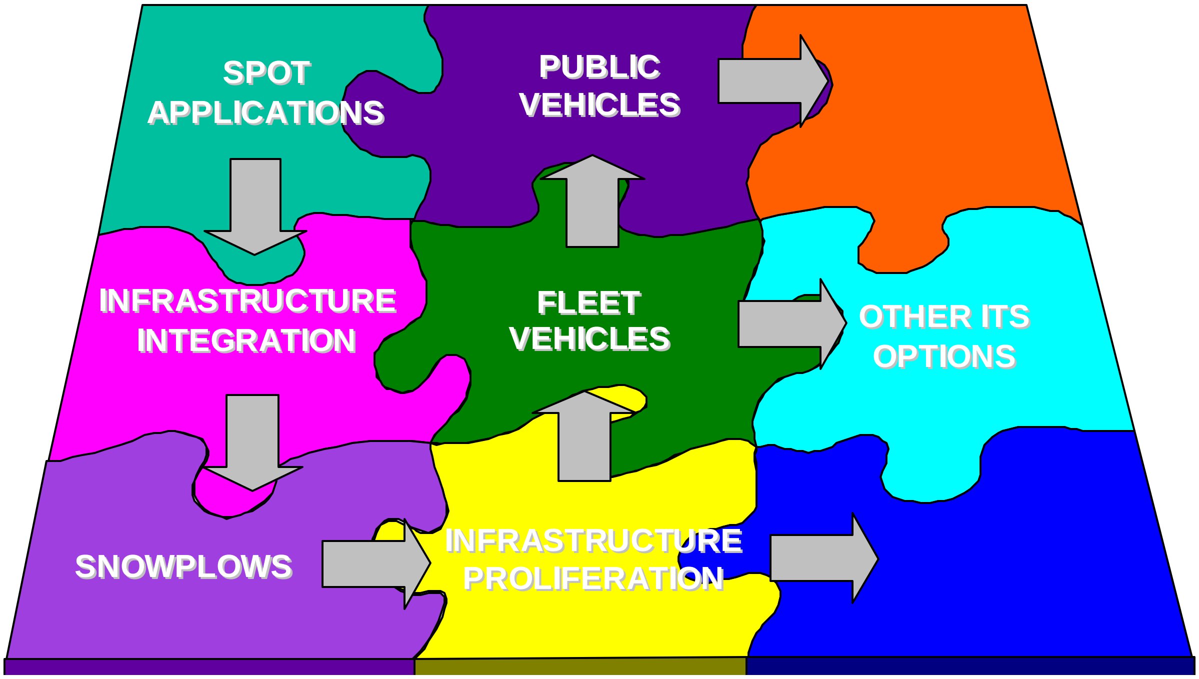


Figure 7 – Incremental AHS Deployment

transportation providers to segment installation, remaining open to adapt evolving technologies yet tailor it to their specific needs.

Unlike in urban areas, the element driving rural AHS is safety. Recurring congestion is generally not a problem in rural environments. This section does not determine the feasibility of implementing advanced vehicle control systems at the technical or institutional level, but instead proposes a near-term and long-term deployment vision.

5-year Vision

Within the next five years, field operational tests (FOTs) may begin in some of the spot locations with favorable benefit/cost ratios, assuming this effort is continued in subsequent phases. The fostering of FOTs in the next few years is important to winning AHS support from transportation users, providers and private agencies. Institutional/jurisdictional coordination between the project partners should solidify over the next few years as FOTs develop.

Lateral guidance technology will likely be installed in the infrastructure during this time period. The Montana Department of Transportation (MDT) is interested in demonstrating automated snowplow technology and may pursue this effort further in 1998. One of their target locations is within the GYRITS corridor - the Gallatin Canyon on U.S. Highway 191. If MDT partners with a private agency to develop their lateral control system, private-public partnerships may assist proliferation of AHS in the GYRITS corridor. As FOTs develop, it is important to initiate educational and informational programs to make the public aware of the benefits of advanced technology. Public outreach is the best way to obtain public support and make the public aware of the benefits of AHS by the successful use of the technology. Maintaining and increasing support for the system is the best way to attract new users.

10-year Vision

In the next ten years, AHS-Ready Vehicles (ARVs) will likely begin to penetrate the market. It is speculated that there will be approximately 20 percent fleet penetration by 2009. [13] It is assumed that rural fleet penetration will be somewhat lower. If MDT's automated snowplow demonstration comes to fruition, the lateral guidance system will exist throughout the entire Gallatin Canyon providing an advanced vehicle control foundation for the ARVs. The ARVs will likely use Information Assistance for the driver via audio and visual danger warnings. Institutional coordination will improve within this timeframe, leading to the proliferation of lateral guidance infrastructure systems to both Wyoming and Idaho.

Fleet vehicles will likely be equipped with AHS components. These vehicles will include local utility vehicles (i.e., power and telephone), emergency service vehicles, highway maintenance vehicles and commercial vehicles that use the route regularly. Little quantitative safety data will be available from equipped fleet vehicles; these vehicles are seldom involved in accidents within the corridor. Equipping fleet vehicles with advanced vehicle control systems will however provide qualitative data related to user satisfaction. As the use of AHS is augmented, public education on the emergence of new technology is particularly important.

20-year Vision and Beyond

Following a 20 year AHS effort, a greater number of vehicles will be using advanced vehicle control systems. It is predicted that by the year 2014, fleet vehicle penetration will be approximately 50 percent. [13] Once again, penetration rates in rural areas will likely be lower. In this same timeframe, ARVs will likely have advanced to Control Assistance.

On rural two-lane, uncontrolled access highways, AHS utilizing Control Assistance will likely be the pinnacle of development. Full automation is difficult to justify in the rural two-lane highway environment; the inability to dedicate a lane of travel to fully automated vehicles would result in fully automated vehicle mixing with non- or semi-automated traffic. In addition, uncontrolled access would result in many points of conflict that could have an adverse effect on fully automated AHS.

AHS Benefits

Automated Highway Systems (AHS) have the potential to address several different types of safety problems. AHS may be considered the tool of the future for engineers attempting to add to the safety and operation of a roadway where other traditional or conventional safety applications have fallen short. Unlike conventional safety applications, the goal of AHS is to achieve safety benefits through dynamic crash prevention countermeasures. Automated Highway Systems will provide dynamic warning and vehicle control information based on current roadway, traffic and environmental conditions.

Improving safety and security is the ultimate goal of this effort. As stated previously, approximately 90 percent of traffic accidents result from human error, generally related to fatigue, inattentive driving and excessive speed. [1] Automated Highway Systems will assist the driver and help reduce/eliminate human error accidents. In the GYRITS corridor, it is expected that collision avoidance systems with Information Assistance will help reduce the frequency of accidents while the advancement to Control Assistance will help reduce the rate and severity of crashes. If fully automated vehicles were provided on rural two-lane uncontrolled access highways, crashes could be eliminated. With an evolutionary deployment AHS can provide the rural traveler with:

- safer travel;
- more efficient travel;
- environmental benefits;
- additional mobility for the aging rural population; and
- reduced insurance rates due to the reduction in accident frequency and severity.

INSTITUTIONAL ISSUES

Probably the most prohibiting aspect of deploying an Automated Highway System (AHS) is the challenges presented to the state and local transportation providers. These two entities will likely inherit responsibilities related to maintaining and deploying AHS on the infrastructure within their jurisdictions. Furthermore, any testing or evaluating of AHS will likely be performed on state and local right-of-way. When the transportation network encompasses multiple jurisdictions, as this project does, the challenges are greater.

It is important that this study investigate the impacts of institutional issues as they apply to the rural community, and specifically, the GYRITS corridor. This section investigates the general issues and concerns that affect the successful development of AHS in the GYRITS corridor. Typical questions and concerns are:

- How will agencies procure AHS?
- Who will pay capital startup costs?
- Who will maintain and operate the system?
- Who will absorb possible liability claims?
- How are privacy issues dealt with?
- How will local agencies handle the technical demands?
- How is user acceptance established?
- Will the system be reliable?
- How will the new technology integrate with current state strategic plans?
- How will AHS affect the environment?
- Could public-private partnerships be successful?

Once these concerns have been isolated, they can be manageably addressed through outreach efforts to local governmental agencies and public stakeholders. Ultimately, both groups will be AHS users. Champions can be identified from each group who can help facilitate the maturation of AHS in pursuit of the AHS long-term goals and vision.

Some public agencies are hesitant to get involved; the envisioned AHS system may be perceived as too futuristic. This is especially true in rural environments where agencies typically mitigate roadway problems using “low-tech, low-risk” solutions. Involving the rural transportation providers early in the planning, testing and evaluation phases will help promote the effectiveness of AHS, develop champions and achieve user buy-in. An incremental deployment strategy will help demonstrate early, visible, quantifiable safety benefits for potential users.

General Issues

AHS is a long-term, futuristic concept with the objective of developing autonomous vehicles, particularly in urban regions. Much of the technological know-how to make this futuristic concept a reality exists today. Near-term applications can be augmented to synergistically attain the ultimate AHS goal.

Challenges that may impede the deployment of AHS are institutional in nature. These include:

- legal implications;
- public acceptance;
- procurement procedures;
- funding;
- operation and maintenance responsibility;
- privacy issues;
- environmental impacts;
- societal issues and
- jurisdictional coordination.

All of these issues are concurrent problems in the rural and urban environments. However, some of these issues pose a greater challenge in the rural environment, creating disinterest and disincentive to commit agency resources. Key differences are highlighted in Table 1.

Legal Issues

The legal concerns of the urban and rural environment are quite comparable when approaching the issue from the transportation provider perspective. The salient concerns of the transportation providers are how to mitigate the impeding legal ramifications of transferring vehicle control from the driver to the infrastructure. The goal of AHS is to assist and eventually remove the driver

Table 1 - Rural and Urban Institutional Issue Focus

Issues	**Rural**	**Urban**
Legal Issues	• Liability	• Liability
Public Acceptance	• High Tech Change • User Costs	• User Costs
Procurement Procedures	• Staffing Resources • Technical Resources • Technology Obsolescence	• Technology Obsolescence
Funding	• Low Levels of Funding	
Operation and Maintenance Responsibility	• Funding Resources • Technical Support	
Privacy Issues	• Use of Individuals Data	• Use of Individuals Data
Environmental Impacts	• Aesthetics	• Air Quality • Energy Conservation
Societal Issues	• Economy • Land Use	• Mobility • Economy • Land Use
Jurisdictional Coordination	• Agency Coordination	• Agency Coordination

from the decision making process. Consequently, some party other than the driver may be responsible if an accident occurs.

Liability

One of the principal concerns transportation providers have when installing safety hardware on their roadway is liability. The governing laws are typically known as tort liability laws. The definition of tort liability is:

- **Tort** – A civil wrong or injury committed to a person or a person's property. It is an act or a failure to act that gives rise to a legal obligation, enforceable by a civil court, to pay money damages to those who suffer damage. [18]
- **Liability** – An obligation by law to be responsible for an activity or action. A liability is a court-enforceable duty of a person or entity (city, township, state, or private corporation). [18]

There are two categories of tort law: (1) injury law and (2) damage law. Most tort laws are developed and enforced at the state level, with differing sets of governing laws. Most states have tort compensations limits. Idaho, Montana and Wyoming all have tort limits that cap the amount of compensation per claim against the state. These limits are as follows:

Montana	$750,000 per claim and $1.5 million per occurrence.
Idaho	$500,000 per occurrence.
Wyoming	$250,000 per claim and $500,000 per occurrence.

State and local transportation providers are responsible for providing “reasonably safe highways”. Most courts use the following definition of this responsibility:

> “Persons using highways, streets and sidewalks are entitled to have them maintained in a reasonably safe conditions for travel. One traveling on a highway is entitled to assume that his way is reasonably safe, and although a person is required to use reasonable care for his own safety, he is neither required nor expected to search for obstructions or dangers.” [18]

Most transportation providers are considered with areas termed “high-risk.” High-risk areas typically have a potential for high frequencies of accidents. The following items are considered high-risk:

- work zones;
- signs, signals and pavement markings;
- clear zones;
- structures;
- guard rails; and
- intersections.

AHS may be considered high-risk by transportation providers, particularly during the initial stages of demonstration and evaluation. During the initial development of AHS, much of the technology will be infrastructure based, placing much of the responsibility on the local transportation provider. As AHS matures and becomes more regional in scope, AHS technologies will shift from infrastructure based to vehicle based, reducing the responsibility of the transportation provider.

AHS is intended to enhance highway safety; thus liability claims in the aggregate should reduce. Legal issues may be mitigated at the legislative level by adjusting tort liability compensation levels or instituting individual state "sovereign immunity" laws that protect transportation providers from unreasonable liability claims.

Public Acceptance

Public acceptance may prove to be more of a barrier in the rural environment than in the urban environment. It is human nature to resist change and fear what is not fully understood. Historically, urban areas have been at the forefront, demonstrating and deploying components of advanced transportation technologies. Consequently, urban users have been exposed to new transportation technologies and may be more adaptable to the continued growth of AHS.

Rural transportation providers have been more reluctant to expand their transportation "toolbox" to include AHS applications, due to lack of financial and technical resources. The rural driver may be resistant without education and quantifiable, tangible travel and safety benefits.

Procurement Procedures

Procurement of advanced transportation technologies presents another difference between urban and rural transportation providers. Most urban transportation systems have reached or exceeded their capacity; transportation providers have been searching for ways to enhance their transportation capacity with AHS applications. These urban agencies typically have large planning and procurement departments and financial resources.

Rural agencies generally have little to no financial resources dedicated to advanced transportation technologies. Rural transportation agencies have vast transportation networks to maintain with limited economic resources. Consequently, rural agencies seek low-cost, low-tech, and low-risk near-term solutions to provide an adequate level of service to their customers.

Funding

Most rural transportation providers operate on limited budgets with little to no funds set aside for the development of AHS. Many rural agencies rely on volunteers to perform public safety functions. Rural agencies' poor economy is explained through their vast highway system coupled with their low populations and consequent small tax base. Much of the federal funding allocated to states is a reflection of the state's population.

Rural areas may be an ideal testbed for the effectiveness of public/private partnerships. The current economy may not permit rural transportation providers to deploy AHS. The private sector may supplement through both financial resources and technical sophistication unavailable in the public sector.

Operation and Maintenance Responsibility

Operation and maintenance is another issue impacting rural transportation providers more than urban transportation providers, given current funding levels and technical support. It is speculated that private or federal agencies will be the primary participants in early AHS deployment efforts, especially during testing and evaluation. State agencies would assume operation and maintenance responsibilities once the system is functional. [19] The critical question is - will rural transportation agencies have the financial and technical resources to assume operation and maintenance responsibilities? Currently, they do not possess the financial or technical means; it is doubtful that the future will bring about significant change.

Privacy Issues

Privacy issues affect rural and urban transportation providers equally. Standards and guidelines should be developed defining the control and use of motorist-related data gathered through AHS. Standards and guidelines should address individual and vehicle identification, storage and access of the information, and any secondary uses of the information. Proper standards and guidelines will help to foster public acceptance.

Environmental Impacts

Generic issues within this category that affect both the rural and urban environment include air quality, energy and resource conservation. Aesthetic issues may capture more national attention in the rural environment given that most rural areas host many national parks, national forests and recreational centers.

Aesthetic issues may provide an even greater impact to this study due to the fact that it encompasses a treasure of natural resources, two national parks, several national forests and hundreds of campgrounds.

Societal Issues

Societal issues will impact both the rural and urban sectors to different degrees. Societal issues will impact community mobility, local economy, land use, social equity and other transportation issues. The gamut of impact will vary depending on community development goals or master plans.

Jurisdictional Coordination

Jurisdictional coordination poses a hurdle for both rural and urban transportation providers. Roadway jurisdiction is fragmented between state and local agencies. Any decision making process may involve governors, mayors, state legislatures, city councils, and local transportation coordinating committees. Furthermore, rural communities do not have

Metropolitan Planning Organizations (MPO). Guidelines should be developed to mitigate jurisdictional conflicts and streamline coordination between the many agencies involved.

The roadway network for this study encompasses over 500 miles of roadway in three states and two national parks. The chore of uniting the multiple jurisdictions has thus far proven challenging. The Greater Yellowstone Steering Committee, who oversee the Greater Yellowstone Rural ITS Corridor project, may provide the multi-jurisdictional organizational structure needed to carry these initial AHS efforts to fruition. Thus, coordinating the Greater Yellowstone Rural ITS Corridor project and this study will help develop a seamless rural architecture and provide a tangible product.

Project Partner Concerns

This study facilitated an early discussion of institutional issues of concern to the project partners. Appendix M provides the survey instrument that was used to gather feedback from each partner. Surveys provided partners with a forum to voice their concerns. The findings are summarized in Table 2 and discussed below.

Montana Department of Transportation (MDT)

The Montana Department of Transportation (MDT) was unable to respond to the questionnaire. However, MDT tends to be proactive and is investigating ways to guide snowplows through the GYRITS corridor in cooperation with 3M.

Table 2 – Concerns from Project Partners

Issues	**IDT**	**WyDOT**	**YNP**
Legal Issues	No concern, now	No concern, now	No concern, now
Public Acceptance	Some concern	Some concern	Little concern
Procurement Procedures	Need more data	Need more data	Need more data
Funding	Need more data	Need more data	Need more data
Operation & Maintenance Responsibility	No concern	Would be problem	No concern
Privacy Issues	No concern, now	Some concern	No concern, now
Environmental Impacts	Need more data	Need more data	Need more data
Societal Issues	Some concern	Need more data	No concern, now
Jurisdictional Coordination	Adequate	Adequate	Adequate

* No survey was received from the Montana Department of Transportation

Idaho Department of Transportation (IDT)

The Idaho Department of Transportation (IDT) is interested in what AHS technology can do, but is hesitant to get directly involved. IDT may not completely understand the AHS concept. Further outreach and education may solicit IDT's participation.

Planning and Outreach

To implement AHS in Idaho, all state and local transportation providers need to be involved, including state and local police. IDT currently has a transportation improvement plan that includes advanced transportation systems; information related to specific applications was unavailable. The IDT planning office would monitor all AHS research-related activities on their highways. IDT favors an evolutionary approach to slowly achieve public support.

Demonstrating, Deployment and Operation

IDT's desire is that AHS deployment be simple and incremental. The effectiveness of the technology must be proven to the local transportation providers and users. The pursuit of advanced technologies such as AHS is part of Idaho's state transportation improvement plan. However, it is premature for them to begin deploying any AHS technologies. IDT is willing to train appropriate personnel to maintain and operate any AHS. If AHS deployment were made possible through the continuation of this study, IDT would be willing to operate and maintain the system.

Financing and Legal Issues

Currently, IDT is not willing to commit funds to deploy any advanced transportation technologies until the systems are thoroughly proven and cost-effective.

Wyoming Department of Transportation (WyDOT)

The Wyoming Department of Transportation (WyDOT), similar to IDT, has adopted a "wait-and-see" approach before committing to AHS. While WyDOT wants to remain an involved player in AHS and ITS activities, they are hesitant to demonstrate the benefits of AHS on their transportation system. Outreach efforts may encourage a more intimate involvement from WyDOT.

Planning and Outreach

WyDOT would be the principal agency involved in any planning and deployment of AHS. City involvement may be required if AHS is deployed within their jurisdiction.

AHS could be adapted into Wyoming's state transportation plan if WyDOT views AHS as an agency goal or objective. In other words, if the system presents tangible benefits to all users, WyDOT would be interested in incorporating the technology into their transportation "toolbox."

The Wyoming Department of Transportation (WyDOT) maintains roads in Wyoming and in Grand Teton National Park; both agencies coordinate and exchange information. However, communication between these two agencies could be improved.

Demonstrating, Deploying and Operation

WyDOT is not proactive in pursuing new and innovative technologies to solve their transportation problems. Limited financial resources may explain their hesitancy to stray from basic maintenance and familiar, conventional countermeasures. However, WyDOT does want to have some level involvement, but prefers to take a wait-and-see approach. WyDOT wants to witness tangible benefits before committing any resources.

Currently, WyDOT would not be willing to deploy AHS in their fleet vehicles. They would prefer to see the technology demonstrated first. WyDOT does not have adequate technical staffing to maintain and operate AHS. They are willing to train their employees if WyDOT deploys an AHS. WyDOT is willing to assume control of an AHS after a "successful" demonstration.

Financing and Legal Issues

WyDOT is willing to financially support AHS if tangible benefits are demonstrated and they decide to adopt the technology as part of their transportation "toolbox." WyDOT would encourage public-private partnerships that would help finance AHS. WyDOT's principal concerns involving technology are system reliability and privacy issues.

Yellowstone National Park (YNP)

Yellowstone National Park (YNP) is very proactive in seeking advanced transportation solutions. Resistance from Park management may be minimal depending on public reaction to AHS requirements and ecological impacts. YNP is ready to move forward toward developing and deploying AHS components for testing and demonstration.

Planning and Outreach

The Department of the Interior is the roadway authority; representing both Yellowstone National Park (YNP) and Grand Teton National Park. A fluent line of communication exists between the Park Managers and their staff.

A review process exists which requires both Park Managers to approve any AHS deployment initiatives. Any AHS proposals that have been accepted by Park management can readily be adapted to their transportation plans. Each of the two national parks have maintenance and planning divisions that would be responsible for monitoring the AHS planning and deployment process.

The Department of the Interior needs a better understanding of what AHS is and what it can do for them. Some of their questions may be answered in this report. However, additional outreach efforts may facilitate better user education and interest.

Demonstrating, Deploying and Operation

Yellowstone National Park would prefer to have a proactive role in the development of AHS. YNP is open to any advanced transportation technologies that will help improve the Park's visitor experience by reducing traffic congestion and reducing motor vehicle accidents.

YNP is very interested in participating in an AHS demonstration project and demonstrating the effectiveness of AHS in their fleet vehicles. They have over 700 vehicles; implementation would depend on system requirements.

If AHS can demonstrate tangible benefits and reliability, Yellowstone National Park would commit to controlling, operating and maintaining the system. Currently the Park maintains radio communication systems and numerous computer systems. With training, the Park's staff should be able to operate and maintain the advanced transportation system. It is premature to measure resistance to installing advanced transportation technologies and equipment in the right-of-way until a system is designed and elements such as location, unit size, and electrical and communication requirements are determined.

Lacking within the YNP jurisdiction is an inadequate communication and electrical infrastructure.

Financing and Legal Issues

Yellowstone National Park has no barriers restricting them from fostering private-public partnerships. However, it is too early in the preplanning stage for YNP to predict any financial amount they would be willing to channel toward deploying AHS. It would depend on system reliability and capabilities.

ACCIDENT ANALYSIS

The fundamental objective of AHS is to address the limitations of human-based vehicle systems by:

- warning the driver of potential conflict, thus increasing the time for the driver to react;
- assisting the driver in potential collision situations by partially relieving the driver of the driving task; and
- providing autonomous vehicles.

To effectively determine where AHS technologies would produce the highest level of tangible benefits; traffic accidents for the GYRITS corridor were analyzed at spot locations (microanalysis) and roadway segments (macroanalysis). Safety is of paramount concern in the rural environment. By focusing this study on the safety applications of AHS, a greater acceptance can be achieved from the rural stakeholders. This section describes the accident analysis methodology and results.

To target high benefit areas, traffic accidents for the corridor were analyzed. A total of 2,538 accidents were analyzed for a three-year period: 1993 to 1995 for Montana and Idaho and 1994 to1996 for Wyoming. These accidents resulted in an economic impact to society of $131,242,436 (see Appendix G). Accidents within the city limits of Jackson, Wyoming and Livingston, Montana were ignored to focus on typical rural environments. The accidents that occurred within the city limits of these small cities paralleled accidents typical of large urban traffic centers caused by stop/go and merge/diverge traffic.

Accident rates were determined for each mile or half-mile segment along the corridor. It should be noted that Yellowstone National Park segments varied from 0 to 6 miles because of the node/sheet data format. High accident areas (i.e., locations in the corridor with a statistical over-representation of accidents when compared to the volume of traffic traversing the road) are referred to as “atypical” locations in this report.

Severity rates were also determined for each mile or half-mile segment. Potential atypical accident locations were chosen on the basis of severity in addition to accident frequency.

High accident and severity rates were used as indicators to target areas where accidents were occurring as the result of recurring contributing circumstances (i.e., accident trends). Areas experiencing accident trends were thought to have the best chance of maximizing benefits from AHS safety countermeasures.

Micro Accident Analysis

Accident rates were determined for each half-mile segment using a floating referencing system. Specifically, rates were determined on a half-mile basis, advancing along the route every tenth-mile. Additionally, severity rates were determined for each floating half-mile segment. Based on these rates, potential atypical accident locations were chosen for further study. These locations were analyzed to determine what, if any, accident trend(s) existed. Segments exhibiting trends were thought to have the best chance of maximizing benefits from AHS applications.

Accident Rates

Accident locations were identified as "atypical" if their accident rate showed a statistical over-representation of accidents. Over-representation was defined as being two standard deviations from the mean accident rate. Accident rates were determined for each half-mile segment using a rate per million vehicle-miles traveled (R/MVMT). Average annual daily traffic (AADT) from the nearest traffic counting station was estimated by averaging the AADT over the three-year timeframe. The accident rates for all segments were compared along each route. Routes were compared by alignment (i.e., level, rolling or mountainous) (see Appendix D). The objective of this analysis was to determine the best site for further research or operational testing and to quantify corridor challenges; not necessarily to determine the most accident-prone locations in the corridor.

Severity Rates

Severity rates were calculated in the same manner as the accident rates, except that accidents were weighted based on their severity. Fatalities were weighted by a factor of eight, injuries were weighted by a factor of three, and property damage only accidents were weighted by a factor of one. These weighting factors were taken from "Traffic and Highway Engineering." [9] A factor of eight was used for fatalities instead of the suggested factor of 12 to prevent random singular fatalities from skewing the severity rates in particular half-mile segments. Severity rates did not yield significantly different results from the atypical locations identified by the accident rates.

Accident Trends

Each half-mile segment that was identified as atypical was analyzed for accident trend. For the purpose of this study, a trend was defined as an area having more than 25 percent of the same type of accident but not less than four total accidents.

The atypical accident locations identified through this microanalysis are listed in Table 3. Greater detail is provided in Appendix E. The accidents presented in Table 1 are typically a result of "speed too fast for conditions," "icy/slippery roads," "animal-vehicle collisions," "failure to yield right-of-way," and "moving vehicle collisions."

Table 3 - Atypical Spot Locations

Milepost Range	Total Accidents	Total Trend	Milepost Range	Total Accidents	Total Trend
Montana U.S. Highway 191					
9.900-10.011	18	13	10.000-11.000	20	17
28.000-28.900	13	9	59.000-60.000	11	8
61.000-61.400	12	7			
Montana U.S. Highway 20					
1.000-2.000	10	6	8.619-8.946	11	7
Idaho U.S. Highway 20					
311.000-312.000	22	14	317.000-318.000	42	29
328.000-329.000	14	6	338.000-339.000	17	11
326.000	12	4	405.000-406.000	8	6
Idaho U.S. Highway 26					
335.000-336.000	23	12	336.000-337.000	34	24
338.000-339.000	16	11			
Wyoming U.S. Highway 89					
160.000-161.000	11	8	167.000-168.000	12	5
185.000-186.000	18	11	189.000-190.000	12	6
184.400-184.600	8	8	188.000-188.690	6	6
127.000-128.000	22	16			
Yellowstone National Park Highway 89					
21.034-21.834	18	9	21.334-21.834	5	5
43.122-43.672	9	5	66.180-67.780	20	9

Macro Accident Analysis

Accident data, collected from Idaho, Montana, Wyoming and Yellowstone National Park, was standardized and assimilated to allow for spatial representation using Geographic Information Systems (GIS). Accident data was depicted both at spot locations and continuously along the roadway depending on the frequency and characteristics of the accidents.

Before examining the accidents to determine geographic areas of focus, the corridor was separated into 18 major segments based on: changes in geometric alignment, city limits, mountainous areas, and state lines (see Appendix D). Although state lines were assumed to be transparent, segments were broken along state lines for ease of analysis. The segment types included rural-flat, rural-mountainous, urban (within city limits), suburban (directly outside city limits until change in cross section), and semi-mountainous (only in Yellowstone National Park). The number of accidents for each accident trend, identified previously for half-mile locations, was determined for each of the 18 major segments. A geographic area was identified for focus if the area possessed two of the three following criteria:

- a high percentage of the accidents in the area had a common trend;
- a high number of the accidents in the area had the same common trend; and/or
- half-mile atypical locations existed with the same trend.

Table 4 presents the results of the macroanalysis. Appendix F provides a more detailed description.

Stratified Accident Analysis

The previous accident analyses considered the entire accident sample when determining potential AHS deployment locations. Targeting smaller groups within this sample may actually help to accelerate NAHSC's near-term deployment goals. Hence, two smaller groups were separated out for further analysis: (1) commercial vehicles and (2) in-state/out-of-state drivers.

Commercial Vehicles

Commercial vehicles or heavy vehicles were targeted because they provide a smaller market group and market penetration may be fostered more easily. Heavy vehicle accidents were sorted and stratified with the following objectives:

- to determine the characteristics of crashes involving heavy vehicles;
- to determine if heavy vehicles are over-represented in crashes in the corridor;
- to identify causal factors for heavy vehicles; and
- to link causal factors to trends.

With the stratified accident data, a microanalysis and macroanalysis were performed to characterize and geographically locate trends and challenges related to heavy vehicles.

Microanalysis

After careful analysis, no spot locations where heavy vehicles were over-represented in the accident trends were identified. Most heavy vehicle accidents were randomly distributed throughout the corridor. AHS near-term applications related to heavy vehicles at spot locations would be inappropriate.

Table 4 – Atypical Regional Segments

Milepost Range	Road Type	Total Accidents
Yellowstone Park U.S. Highway 89		
0.000-93.446	Park	426
Wyoming U.S. Highway 26		
0.000-2.370	Mountainous	7
Montana and Yellowstone Park U.S. Highway 191		
0.000-10.835	Level	88
10.836-66.826	Mountainous	276
66.827-81.903	Level	98
Idaho U.S. Highway 20		
308.717-353.050	Level Suburban	271
353.051-401.300	Level	117
401.301-406.300	Mountainous	18
Montana U.S. Highway 20		
0.000-3.000	Level	27
3.001-9.397	Mountainous	39
Idaho U.S. Highway 26		
335.255-338.069	Level Suburban	64
338.070-375.538	Level	134
375.539-402.500	Mountainous	63
Montana U.S. Highway 89		
0.000-51.812	Level	112
51.813-53.068	Level Suburban	44
Wyoming U.S. Highway 89		
118.32-152.090	Mountainous	304
155.211-165.000	Level	86
165.001-211.620	Mountainous	245

Table 5 - Heavy Vehicle Accident Rates

Accident Type	Total Accidents	Accident Rate (R/MVMT)	National Average	Difference
Property Damage Only	54	97.39	75.00	+22.39
Injury Accidents	69	40.73	47.00	-6.27
Fatal Accidents	8	4.72	2.50	+2.22

Macroanalysis

Heavy vehicles were involved in approximately 10 percent of all accidents within the corridor, resulting in 28 percent of the fatality accidents and five percent of injury and property damage only accidents (see Table 5). Nationally, heavy vehicles accounted for 12 percent of all traffic fatalities and three percent of all accidents resulting in injury and property damage only. [10]

The aforementioned statistics, which indicate that heavy vehicle accidents in the GYRITS corridor exceed the national averages, support the notion that a safety problem exists related to commercial vehicles in the corridor. However, the low frequency of accidents made it statistically difficult to sort heavy vehicle related accidents into trends. Heavy vehicle accident rates were stratified by road type (i.e., mountainous, rolling, level, etc.), hypothesizing that roads with mountainous alignment would have higher accident rates. This hypothesis could not be statistically verified (see Appendix H). Instead, heavy vehicle accident rates appeared to be distributed randomly through mountainous and flat regions; indicating driver error may be the primary problem, while alignment and terrain are secondary contributors.

Montana U.S. Highway 191 consistently exceeded the national average in all three severity rating categories (i.e., property damage only, injury and fatality rates). Particular segments included milepost 10.836 to milepost 66.826 (Gallatin Canyon) and milepost 66.826 to milepost 81.903 (a level section of highway between Bozeman, Montana and Gallatin Canyon). The accidents in these milepost ranges resulted in 74 total accidents with the following frequent "first harmful event":

- 28 motor vehicle in transit;
- 15 animal-vehicle conflicts;
- 11 fixed object; and
- 12 overturns.

Most frequent "first harmful event" categories for all heavy vehicle accidents in the corridor are provided in Table 6.

Table 6 - CVO Accidents: First Harmful Event

First Harmful Event	Percent Occurred
Motor Vehicle in Transit	30%
Animal-vehicle Conflict	16%
Run-Off-Road	8%
Hit Fixed Object	7%
Overturn	6%
None	6%
Other	27%

The leading categories of "contributing circumstances" for the 74 heavy vehicle accidents along Montana U.S. Highway 191 were:

- 22 driver inattentive;
- 18 speed too fast for conditions (i.e., weather conditions); and
- 13 icy surface conditions.

Most accidents were human error, and resulted in the driver leaving the appropriate travel lane. Most frequent "contributing circumstances" categories for all heavy vehicle accidents in the corridor are provided in Table 7.

In all, heavy vehicles accounted for 54 property damage only accidents, 69 injury accidents and 8 fatal accidents from 1993 to 1995. These accidents, resulting in 9 fatalities, 84 injuries and 165 property damage cases, resulted in an economic cost to society of $29,288,056. These economic costs were also stratified by road type and reduced to a cost per mile for each segment (see Appendix H). Montana U.S. Highway 191 consistently ranked the highest in this category, as did Montana U.S. Highway 20.

Table 7 - CVO Accidents: Contributing Circumstances

Contributing Circumstance	Percent Occurred
Inattentive	25%
Speed Too Fast For Conditions	19%
Icy	9%
Failure To Yield	8%
Failure To Have Vehicle Under Control	5%
Following Too Close	4%
Improper Pass	4%
Other	26%

With respect to AHS deployment, commercial vehicles will require targeting on the macro level by determining commercial carriers that consistently use the corridor as a common route to transport goods and services. Carriers that use Montana U.S. Highway 191 may be a good target group, since this highway may provide enough data to statistically quantify benefits.

Traveler Origin

Traveler origin information was examined to determine if accidents within the corridor were a product of unfamiliar out-of-state travelers or local residents. It was hypothesized that this information would be helpful in determining target groups for early operational testing and evaluation. Specifically, if the origin data indicated a statistical accident over-representation of either of the two aforementioned groups, this group could be isolated and targeted for various AHS applications.

The information presented here represents only vehicles involved in accidents within the corridor and does not represent the percent of total out-of-state/local travelers traversing the highways. The data was stratified by state and was only reduced to a macro level; the low frequency of accidents at most locations would not yield statistically valid findings in a microanalysis. The accident data from Idaho and Wyoming allowed for the determination of the causing party. Hence, each accident could be traced to a single in-state or out-of-state party; the proportion of in-state travelers and out-of-state travelers involved in an accident summed to one. Montana's accident data did not reflect causing party information but rather accident involvement. Hence, the proportion of in-state travelers and out-of-state travelers summed to greater than one.

Macroanalysis

Tables 8 and 9 summarize the proportion of in-state/out-of-state vehicles causing accidents and involved in accidents for geographic areas of focus.

Table 8 - Origin of Vehicle Causing Accident

State	Route	Segment	% In-state	% Out-of-state
Wyoming	89	total corridor section	51	49
	89	158.82 to 204.85	41	59
Idaho	20	total corridor section	68	32
	20	308.717 to 353.05	84	16
	20	353.06 to 406.30	37	63
	26	total corridor section	73	27

Table 9 - Origin of Vehicles Involved in Accident

State	Route	Segment	% In-state	% Out-of-state
Montana	20	total corridor section	65	94
	89	total corridor section	123	36
	191	total corridor section	71	48
	191	0 to 10.493	49	56
	191	10.494 to 81.903	60	36

Wyoming U.S. Highway 89

On Wyoming U.S. Highway 89, vehicles with out-of-state plates were the involved in approximately 51 percent of the accidents, while vehicles with Wyoming license plates were involved in 49 percent. Using a 95 percent confidence interval, no statistical difference was found at this location between in-state or out-of-state travelers.

The section of U.S. Highway 89 that traverses through Grand Teton National Park was examined separately to determine if out-of-state travelers influenced the number of accidents. In this 46-mile section of roadway, vehicles with out-of-state license plates were involved in 59 percent of the accidents, while vehicles with Wyoming plates were involved in 41 percent. The percent of unfamiliar drivers is likely greater than 59 percent since all Wyoming drivers may not be local to this specific route. On this 46-mile section of roadway there were 243 accidents. The first harmful event in these accidents were as follows:

- 108 animal-vehicle conflicts;
- 73 motor vehicle in transit;
- 31 vehicle overturned; and
- 31 other.

Note that 44 percent of these accidents resulted from animal-vehicle conflicts. This is an overwhelming number resulting from one causal factor.

Idaho U.S. Highway 20

On Idaho U.S. Highway 20, vehicles with Idaho license plates were involved in 68 percent of the accidents, while out-of-state vehicles accounted for 32 percent of the accidents. The accident data was stratified by roadway type to determine if driver origin characteristics were attributable to the location or type of facility. The first 44-mile section of highway leaving Idaho Falls, Idaho is a divided four-lane structure with a suburban surrounding. Vehicles with Idaho license plates were involved in 84 percent of the accidents, while the remaining 16 percent involved vehicles with out-of-state plates. The remaining 53-miles of roadway is a rural undivided two-lane structure. Vehicles with out-of-state plates were involved in 63 percent of the accidents, while vehicles with Idaho plates accounted for the remaining 37 percent. Once again, the number of unfamiliar drivers in the area is speculated to be greater than 63 percent since all vehicles with Idaho plates are likely not local to this route.

Idaho U.S. Highway 26

The accidents on Idaho U.S. Highway 26 involved vehicles with Idaho license plates 73 percent of the time and vehicles with out-of-state plates 27 percent of the time.

Montana U.S. Highway 20

The accidents on Montana U.S. Highway 20 involved out-of-state vehicles 94 percent of the time and vehicles with Montana plates 65 percent of the time.

Montana U.S. Highway 89

The accidents on Montana U.S. Highway 89 involved out-of-state vehicles 36 percent of the time and vehicles with Montana plates 123 percent of the time. It was hypothesized that Montana U.S. Highway 89 hosted a high level of local travelers, since many people living in Gardiner, Montana travel to Livingston, Montana (the two cities at each end of this route) for work and shopping.

Montana U.S. Highway 191

The accidents on Montana U.S. Highway 191 comprised 71 percent vehicles with Montana plates and 48 percent out-of-state vehicles. Highway 191 was split into two segments: (1) milepost zero to 10.493 and (2) milepost 10.494 to 81.903. Milepost zero to 10.493 had an accident involvement rate of 49 percent for vehicles with Montana plates and an accident involvement rate of 56 percent for vehicles with out-of-state plates. Statistically, there was no difference between in-state and out-of-state involvement rates. Milepost 10.494 to 81.903 had an accident involvement rate of 60 percent for vehicles with Montana plates and an accident involvement rate of 36 percent for out-of-state vehicles.

With respect to AHS applications, accidents involving out-of-state travelers likely occur because of their lack of familiarity with the road they are traveling. For this reason, unfamiliar travelers need extra information or guidance. The extra information or guidance could be provided as safe speed warnings and slippery condition warnings via dynamic message signs or by partial vehicle automation. Early operational testing of vehicle automation can target out-of-state travelers through vehicle-rental agencies. Further, investigation should take place to determine accident involvement rates for rental vehicles.

Atypical accident areas involving in-state travelers may result because local commuters become familiar with a section of commonly traveled roadway and begin to overdrive. In a sense, they become inattentive; not concentrating on driving as much as someone would on an unfamiliar section of roadway. The same countermeasures could be applied in this situation, however local commuters present a much larger, varied target group. The quantification of benefits may be challenged without sizeable market penetration.

POTENTIAL AHS COUNTERMEASURES

This section briefly discusses the AHS requirements in the Greater Yellowstone Rural ITS (GYRITS) corridor. Many of the system-related requirements are a direct result of the adverse weather conditions in this corridor. A discussion of potential AHS countermeasures is provided below which includes a description of the equipment, system justification, predicted benefits and estimated costs.

Spot Location Countermeasures

This section presents technology applications appropriate for spot locations (i.e., roadway segments of one mile or less). The intent of these applications is to communicate potentially dangerous situations to the driver. Both advanced technology applications and traditional countermeasures are reviewed.

Road Surface Conditions Monitoring

Systems presented here are intended for unsafe situations resulting from icy road conditions. Typically, drivers are unaware of the slipperiness of the road or are inattentive and driving too fast for conditions.

New Technology: Friction/Ice Detection and Warning Systems

Tire-to-road friction is an important factor in vehicle control; adequate frictional forces are required to keep a vehicle on the road. Drivers must reduce their speed when friction levels are low to have adequate stopping distance. The envisioned friction/ice detection warning system would calculate a safe advisory speed and display the speed on a roadside mounted changeable message sign (CMS) (see Figure 8). The CMS would be placed far enough in advance of the problem area to allow the driver time to adjust their speed. The system would determine a coefficient of friction through measured weather conditions, road surface characteristics, and road grade. A processor would calculate an advisory speed based on the coefficient of friction and display the speed on the CMS, hence creating a dynamic operational system.

Justification:	• This technology is to be applied to locations where the numbers of accidents due to icy conditions are statistically over-represented.
Benefits:	• Drivers are warned of areas with icy conditions in advance. Dynamic signs placed sufficiently in advance of recurring slippery areas would allow drivers adequate deceleration distance before entering slippery areas. “Too fast for condition” accidents should be reduced.
Costs:	• The estimated cost for this system is $111,620 which includes estimated installation costs, a four-point detection system with weather station and processing, and one changeable message sign.

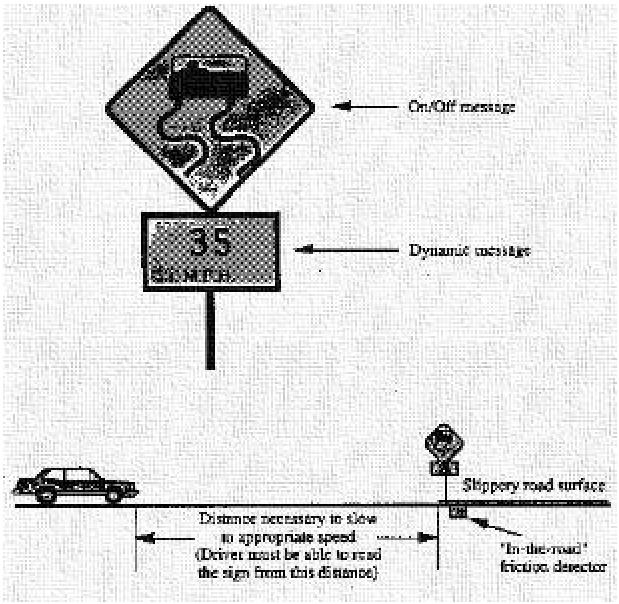


Figure 8 - Ice Detection Schematic

Traditional Countermeasure: Static Ice Warning Sign

The traditional method of informing motorists of recurring icy conditions is with a static ice warning sign (see Figure 9). Static signs have typically been over used. Many state agencies place these signs on every bridge and other areas where ice may form. Thus, many times these signs inform the driver of nonexistent icy conditions. This violates driver expectancy and over time, drivers begin to ignore warning signs, making them ineffective. Nonetheless, this countermeasure is attractive because of its low cost.

Justification:	• This technology is to be applied to locations where the numbers of accidents due to icy conditions are statistically over-represented.
Benefits:	• Initially, static signs may affect the speed of local drivers, but over time static signs may lose their effectiveness.
Costs:	• The total cost of the sign is approximately $108 including material and installation.

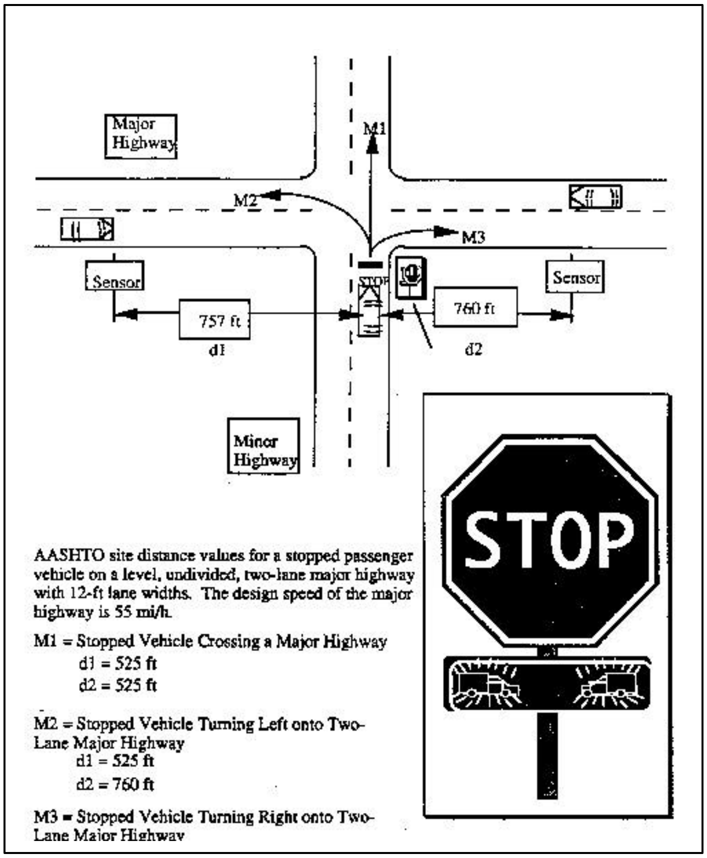
Figure 9 - Slippery Warning Sign

Intersection Warnings

An intersection warning system is designed to detect the presence of vehicles on major roadways and relay information to vehicles waiting to cross on minor roadways. Sensors or loop detectors placed on either side of the intersection in the major roadway determine the safest time for crossing or turning. The American Association of State Highway and Transportation Officials (AASHTO) provides safe distance values for three maneuvers (i.e., crossing, turning left, turning right). Safe crossing information is relayed to motorists with beacons mounted on stop signs or through in-vehicle displays.

New Technology: Crossing Detection

An intersection crossing detection system is intended to enhance the driver's ability to safely enter the intersection of a major road from a minor approach. The system is intended to address crossing-path accidents at intersections controlled by stop signs on the minor road (see Figure 10). Stop signs on the minor roads would be equipped with displays indicating the presence of vehicles on the major road. The indicator would inform the driver if the vehicles on the major road are approaching from the left or right. Sensors or loop detector would be placed on either side of the intersection in the major road. The time required for a maneuver depends on design speeds, geometric alignment of the intersection and vehicle type factors.



AASHTO site distance values for a stopped passenger vehicle on a level, undivided, two-lane major highway with 12-ft lane widths. The design speed of the major highway is 55 mi/h.

M1 = Stopped Vehicle Crossing a Major Highway
d1 = 525 ft
d2 = 525 ft

M2 = Stopped Vehicle Turning Left onto Two-Lane Major Highway
d1 = 525 ft
d2 = 760 ft

M3 = Stopped Vehicle Turning Right onto Two-Lane Major Highway

Figure 10 - Crossing-Path Detection Schematic

Justification:

- This technology is to be applied along rural high-speed highways where intersection control consists of two-way stop signs on the minor approach, there is a statistically high number of crossing-path accidents and traditional countermeasure are unable to mitigate the problem.

Benefits:

- At the stop sign, drivers are warned that vehicles on the major roadway are close enough to the intersection that any maneuver the driver wants to make from the minor approach is unsafe. However, the driver ultimately makes the final decision on when to proceed and may not heed the warning. Hence, total accident elimination is unlikely.

Costs:

- The estimated cost for this system is $34,590, which includes two inductive loop detectors, two sign controllers, two signs with illuminated vehicle icons and estimated installation costs.

Traditional Countermeasure: None

After making site visits and examining intersection crossing-path accident records, no notable traditional countermeasures were discovered.

Animal-vehicle Collision Avoidance

Animal-vehicle collisions are numerous in the rural environment. While rarely resulting in human fatality, animal-vehicle collisions result in extensive property damage and almost always result in the death of the animal. Most animal-vehicle collision avoidance systems rely on object recognition and warning.

New Technology: Radar Detection Activation

Radar detection activation is intended to inform the driver of in-road objects that the driver is unable to see because of low visibility or poor geometric alignment. This system would activate any current, commercially available radar detector to warn the driver of a hazard. A transmitter is placed along the roadway where there are a high number of animal-vehicle accidents. The transmitter has a detection range of one mile in each direction. If an animal is detected, the transmitter would send a signal to an in-vehicle radar detector commonly used to identify police. On older detectors, the K-band alert will sound. New detectors under development will transmit variable text. Fixed messages would be stored in the newer detectors that would provide the driver with more details about the hazard. One drawback of this spot location application is that it is only effective for vehicles equipped with radar detectors.

Justification:

- This system is intended for use in areas where animal-vehicle collisions are statistically over-represented.

Benefits:

- Drivers are warned in advance of animals or objects on the roadway, providing drivers with the necessary time to slow down and make the appropriate maneuver to avoid a collision. This technology may be very useful in the GYRITS corridor national parks where there are many animal-vehicle collisions. Radar detectors could be loaned or leased to tourists as they travel inside the park boundaries.

Costs:

- The estimated cost for this system is $3,800, which includes one transmitter, one solar pack and estimated installation costs.

Traditional Countermeasure: Fences, Reflectors, Repellents, Etc.

There are many traditional treatments for animal-vehicle collisions including wildlife fences, wildlife reflectors, repellents, increased hunting, reduced vehicle speeds, public education, vegetation clearance and improved vehicle lighting. Most traditional countermeasures focus on preventing the animal from crossing or accessing the roadway, which is either not feasible, ineffective or disturbs the natural aesthetics of the area.

Horizontal Curve Speed Advisory

Horizontal curve speed advisory systems are intended to provide the driver with real-time information about their ability to safely negotiate a roadway curve given their travel speed and the roadway surface conditions.

New Technology: Dynamic Variable Message Sign

The objective of this application is to help drivers negotiate horizontal curves at speeds safe for the design radius of curvature, the super-elevation and the frictional characteristics of the roadway. A dynamic message sign would display the calculated safe speed to the driver far enough in advance for the driver to react and decelerate to the appropriate speed (see Figure 11). Pavement monitoring sensors and processors may be added to monitor icy/slippery conditions.

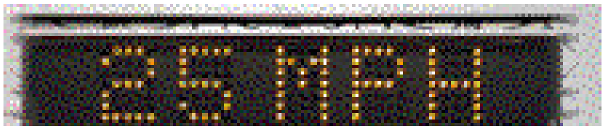


Figure 11 - Variable Message Sign

Justification:

- This system is intended for use at spot locations where run-off-the-road accidents due to horizontal alignment are statistically over-represented.

Benefits:

- Drivers are warned in advance of a horizontal curve and provided with a recommended speed to safely negotiate the curve.

Costs:

- The estimated cost for this system is $4,000 for the sign and installation; a power source was assumed to exist.

Traditional Countermeasures: Static Curve Warning Signs

Two of the most common traditional countermeasures for horizontal curve accidents are “curve ahead” advisory signs and chevrons. As with the static ice warning sign, this traditional countermeasure is appealing because of its low cost. The combination of a static curve ahead sign and chevrons may be the most feasible application at this time. Chevrons cost approximately $27 for each sign and approximately $75 for installation. Six signs would total $615.

Regional Countermeasures

This section of the report briefly discusses regional countermeasures for the Greater Yellowstone Rural ITS (GYRITS) corridor AHS. Regional countermeasures were considered from a rural transportation provider perspective. Namely, what would the local and state transportation departments be responsible for? It was hypothesized that transportation providers would be responsible for providing the in-pavement lateral sensing technology. Specifically, it is assumed by the time AHS vehicles penetrate the market, most of the necessary components (i.e., sensors, processors, and longitudinal guidance systems) will be in the vehicles.

These countermeasures consider the adverse weather conditions presented in this corridor. If during typical winter, the lateral sensors can no longer locate the lateral position of the vehicle, or the longitudinal headway control can no longer measure headway and obstacles, serious safety problems will result.

Longitudinal Sensing

The most effective technology for longitudinal guidance was investigated for the GYRITS corridor. Many sensors are capable of longitudinal detection using: vision, ultrasonic, Laser Radar (LIDAR) and radar. The advantages and disadvantages of some of the systems are presented in Table 10.

Given the severe weather encountered in this region, system-related literature recommended radar as the best alternative for the GYRITS corridor. The accuracy of radar systems is sufficiently accurate for collision detection and warning. The system has a reported accuracy of ± 1 meter for ranges between 15 and 100 meters (49.21 and 328.08 feet).

Lateral Sensing

Factors affecting sensor selection include their capabilities in addressing poor road delineating, low temperatures, obscure pavement, reduced visibility conditions and mountainous road conditions. Several technologies are available for lateral guidance, which use vision, roadway referencing, radio wave signals, magnetic sensors and roadway magnetic markers and global positioning. Hybrids of these systems also exist. The advantages and disadvantages of some of the systems are presented in Table 11.

Due to the severe winter conditions and the mountainous environment, magnetic pavement markers currently seem to be the best technology for lateral sensing. Two magnetic systems were reviewed for this project: (1) PATH's magnetic nails and (2) 3M's magnetic tape. One concern with using magnetic nails is their effect on flexible pavements. How will inserting a rigid nail into a flexible pavement affect the properties of the pavement? Flexible pavements tend to distort with temperature variations and loading, causing cracking and rutting. Will the nails cause additional cracking? In colder climates, where frequent freeze-thaw cycles occur throughout the winter months, there are concerns that the rigid nails will be the nuclei for surface cracking. Conversely, how will the "flexing" of the pavement affect the performance of the nails? The 3M magnetic tape seems more suitable for colder climates, but is more expensive to install. The PATH magnetic nails have yet to be tested in cold climate flexible pavements.

Table 10 - Longitudinal Sensing Technology

Sensor Technology	Advantages	Disadvantages
Radar	• Accurate range and range rate (for Doppler radar) when performing optimally • Low susceptibility to poor weather conditions • Longer range sensing capability than infrared or vision systems	• Problems with very short range • Susceptible to multi-path and clutter • For high accuracy may require cooperative target (e.g., reflectors on vehicle bumpers) • Higher cost sensor, and larger size • Frequency allocation uncertainties • Interference from other radar-equipped vehicles • Potential health concerns from electromagnetic emissions exposure
Laser Radar	• Significantly lower sensor cost than radar, and smaller size • Accurate range measurements at short range. Maximum detection range ~ 100 m in good conditions with target retro-reflector • More focused beam than radar	• Sensitive to rain and very limited in fog • Lower accuracy at longer range (for acceptable power levels) • At longer ranges, requires cooperative target (retro-reflector) • Difficulty detecting mud-covered vehicles • Requires target reflectors for reliable performance • Positioning of source and target must be “favorable” • Power output limited by safety concerns
Vision systems	• Passive sensor • Can potentially provide both lateral and longitudinal control information • Interference not a problem • Can detect obstacles • Can differentiate between lanes	• Degraded performance in poor weather and low lighting conditions • Processing intensive • Very high relative cost • Much further development required

Source: [14]

Table 11 - Lateral Sensing Technology

Sensor Technology	Advantages	Disadvantages
Magnetic roadway sensors and markers	• Precise lateral control technology • Low-cost, passive sensor • Very low data rate transfer of roadway turn information via magnetic marker polarity • Low susceptibility to poor environmental conditions	• Susceptible to electromagnetic interference from vehicle an other sources
GPS	• Provides highly accurate, 3-D absolute position and velocity for both lateral and longitudinal control from single sensor • Extremely accurate time • Passive sensor • Absolute position enables direct mapping to upcoming roadway characteristics in stored roadway database • Most processing for information needed by control system performed by the sensor • Commercially available, receiver costs decreasing rapidly	• Differential correction network required • Requires augmentation with other sensors or pseudolites in areas where satellites are obstructed • Initialization period required to achieve high accuracy • Susceptible to multi-path errors

Source: [14]

New Technology: Magnetic Nails

The discrete magnetic nails developed by PATH are passive requiring no power, extremely durable, and will provide guidance in all weather conditions (see Figure 12). The sensors are installed along the centerline of the travel lane and are sensed by a magnetometer aboard the vehicle. The vehicle sensors detect the magnetic field; a processor determines the vehicle's deviation from the centerline. The polarity of the magnetic nails can be varied and encoded to provide the vehicle with limited amounts of information on the upcoming roadway alignment and characteristics. This technology was demonstrated in San Diego at *Demo 97*. The magnetic nails are proven, inexpensive and low cost to install. The cost for the magnetic nails is approximately $17,000 per lane per mile. This cost includes 20 percent for magnets, 40 percent for surveying and 40 percent for installation. The magnetic nails are provided by All Magnetics, Incorporated from Placentia, California.

Figure 12 - Magnetic Nail

New Technology: Magnetic Tape

3M offers a continuous magnetic tape with a permanent magnetic field. The magnetic tape is also very durable, passive and relatively low cost. The magnetic tape functions similarly to the PATH's nails. The advantage of the tape over the nails is that the tape has been proven successful in cold climates, having been used and tested on several projects in Minnesota. The tape is a little more expensive than the nails. For a tape quantity between 5 to 10 miles, the cost is $26,400 per lineal lane mile; for a tape quantity greater than 10 miles, the cost is $23,760 per lineal lane mile.

Both systems require minimal maintenance. Presently, the principal maintenance consideration is highway overlays. If highways are directly overlain, the magnetic sensors may have to be raised if the pavement depth above the magnetic sensors exceeds a predetermined threshold. If milling operations are performed the sensors may have to be removed and reinstalled. The magnetic sensors life cycle greatly exceeds the life cycle of the pavement and maintenance on the magnetic sensors is negligible.

BENEFIT-COST ANALYSIS

Benefit-cost analysis is a monetary valuation of the impact of deploying projects. This technique is used by many public and private sector organizations to justify a project or to rank projects. In transportation engineering, benefit-cost analysis involves analyzing the advantages, benefits and cost reductions associated with a proposed transportation system enhancement as they apply to the system providers and users. The costs associated with the benefits of the enhancement are then directly compared to the capital expenditures required for providing the proposed transportation enhancement. Enhancements are generally safety-related or capacity-related with the goal of saving lives and/or increasing levels of service (LOS).

This analysis considered system costs to local transportation providers; it was assumed that the costs for vehicle upgrades would be distributed to the consumer. Specifically, this analysis assumed transportation providers would only be responsible for the purchase and installation of the magnetic lateral warning and guidance systems discussed previously.

The benefit-cost analysis was performed on a regional basis to better determine the magnitude of AHS impacts in the GYRITS corridor. The benefit-cost analysis was also performed separately on each corridor section (see Appendix D), where the roadway segments were separated and categorized by roadway type. The benefit-cost analysis consequently indicated the relative magnitude of benefits experienced along particular sections of roadway. The identification of relative impacts among corridor segments was intended to assist in the ranking of projects for field operational tests. The sites were analyzed and ranked only if a feasible countermeasure existed – either advanced or traditional.

Assumptions

The objective of this analysis was not to determine the performance of AHS at the technical or institutional level. The analysis assumes that the technologies perform as anticipated and as indicated in the literature.

Safety benefits resulting from AHS were difficult to predict for two reasons: (1) system reliability is unproven and (2) success relies often on driver response. Accident reduction factors (ARFs) were adopted from previous research or were assumed by hypothesizing that a certain percentage, less than 100 percent, of human error accidents could be reduced.

For the regional analysis, it was assumed that AHS technologies would be helpful in mitigating the following types of accidents, categorized by longitudinal assistance, lateral assistance, intersection assistance and other.

Longitudinal Assistance

- rear ends
- animal-vehicle conflicts

- following too close
- motor vehicle parked along roadside

Lateral Assistance

- head on collisions
- sideswipes
- overturned (after leaving the roadway)
- ran off road
- struck another motor vehicle in transit
- struck fixed object
- struck guard rail
- struck ditch
- struck cut slope
- struck tree
- struck sign
- struck fill slope
- not in right lane
-

Intersection Assistance

- disregard traffic control
- failure too yield

Other

- inattentive
- traveling too fast for conditions
- fell asleep
- illegal lane change
- illegal backing maneuver
- fail to signal
- over corrected
- improper pass

The appropriate ARFs were applied to each functional classification to determine the reduction in accidents and ultimately the resulting benefits. The ARFs used in this analysis were adopted from Yokota, Tokuyama and Ueda. [15] It is important to remember that the ARFs and consequent benefits from AHS are theoretical values. Field operational testing is required to confirm the accuracy of the theoretical ARFs. The ARFs applied regionally by each evolutionary stage are summarized in Table 12. The ARFs applied at spot locations are summarized in Table 13. In each case, the ARF value represents the proportion that accidents are reduced. For example, an ARF of 0.20 indicates that accidents are predicted to reduce by 20 percent.

Table 12 – Regional Accident Reduction Factors

System	Accident Reduction Factors		
	Information Assistance	Control Assistance	Full Automation
Longitudinal Assistance	0.65	1.0*	1.0
Lateral Assistance	0.30	0.85	1.0
Intersection Assistance	0.75	0.90	1.0
Other	0.30	0.85	1.0

* 0.90 used for Animal-vehicle Collisions

Table 13 - Spot Location Accident Reduction Factors

System	Accident Reduction Factors
Friction/ice detection and warning systems	0.45
Static ice warning sign	0.23 [16]
Intersection crossing detection	0.50 [17]
Animal-vehicle collision warning system	0.20
Dynamic variable message sign (speed advisory)	0.75
Chevrons	0.25

The friction/ice detection and warning system accident reduction factor (0.45) was derived by assuming that half of the 90 percent human error accidents would be eliminated. [1] With this system, it is still largely to the driver to decide on an appropriate response. The intersection crossing detection system ARF (0.50) was adopted from an FHWA report 93-080. [17] The animal-vehicle collision warning system ARF (0.20) was assumed to be low; many vehicles may not be equipped with radar detection devices and the driver is once again responsible for the final response. The dynamic variable message sign (speed advisory) ARF (0.75) was assumed to be high; the system is proving very successful in field applications (i.e., Roosevelt Tunnel in Colorado). The ARFs for the traditional applications - warning signs (0.23) and chevrons (0.25) - were taken from Agent, Stamatiadis and Jones. [16]

Spot Location Benefit-cost Analysis

Spot location benefits, costs and benefit-cost ratios are estimated below.

Benefits

Tables 14-19 approximate the financial benefits to be gained at site-specific locations through countermeasure deployment. A detailed description of the benefit estimation process using FHWA's economic costs is provided in Appendix I. Accidents likely mitigated by the countermeasures were separated from unrelated accidents. For example, this analysis assumed that AHS would have negligible effects on drivers who are chemically intoxicated. These "target" accidents were then multiplied by the appropriate ARF. Costs were assigned to the accident reduction. All benefits are expressed in annual terms.

Table 14 - Annual Benefits With Friction/Ice Detection

Location	Annual Cost Contributed By Trend	Annual Benefit
Montana U.S. Highway 191		
MP 9.900 – 10.011	$910,133	$409,560
MP 10.000 – 11.000	$903,666	$406,650
MP 59.000 – 60.000	$138,600	$62,370
MP 61.000 – 61.400	$6,733	$3,030
MP 1.000 – 2.000	$12,666	$5,700
Idaho U.S. Highway 20		
MP 405.000 – 406.000	$47,393	$21,326

Table 15 -Annual Benefits with Static Ice Warning Sign

Location	Annual Cost Contributed By Trend	Annual Benefit
Montana U.S. Highway 191		
MP 9.900 – 10.011	$910,133	$209,330
MP 10.000 – 11.000	$903,666	$207,843
MP 59.000 – 60.000	$138,600	$31,878
MP 61.000 – 61.400	$6,733	$1,548
MP 1.000 – 2.000	$12,666	$2,913
Idaho U.S. Highway 20		
MP 405.000 – 406.000	$47,393	$10,900

Table 16 - Annual Benefits with Intersection Crossing Detection

Location	Annual Cost Contributed By Trend	Annual Benefit
Idaho U.S. Highway 20		
MP 311.000 – 312.000	$411,203.67	$205,601.83
MP 317.000 – 318.000	$713,591.67	$356,795.83
MP 328.000 – 329.000	$184,238.67	$92,119.33
MP 338.000 – 339.000	$232,965.00	$116,482.50
Idaho U.S. Highway 26		
MP 335.000 – 336.000	$144,845.67	$72,422.83
MP 336.000 – 337.000	$1,329,263.33	$664,631.67
MP 338.000 – 339.000	$320,417.67	$160,208.83

Table 17 - Annual Benefits with Animal-Vehicle Collision Warning

Location	Annual Cost Contributed By Trend	Annual Benefit
Montana U.S. Highway 191		
MP 28.000 – 28.900	$600.00	$120.00
Wyoming U.S. Highway 89		
MP 160.000 – 161.000	$27,363.33	$5,472.66
MP 167.000 – 168.000	$4,000	$800
MP 185.000 – 186.000	$7,333.33	$1,466.67
MP 189.000 – 190.000	$26,030.00	$5,206
Yellowstone National Park U.S. Highway 89		
MP 21.034 – 21.834	$5,333.33	$1,066.67

Table 18 - Annual Benefits with Dynamic Variable Message Sign

Location	Annual Cost Contributed By Trend	Annual Benefit
Wyoming U.S. Highway 89		
MP 127.000 – 128.000	$502.656.33	$376,992.25

Table 19 - Annual Benefits with Chevrons

Location	Annual Cost Contributed By Trend	Annual Benefit
Wyoming U.S. Highway 89		
MP 127.000 – 128.000	$614	$125,664

Costs

Table 20 provides the approximate capital cost for each system considered for spot location deployment. Each cost was developed assuming the existance of a power source, if needed. These costs, in combination with the aforementioned monetary benefits, were used to estimate benefit-cost ratios.

Benefit-cost Ratios

Tables 21 through 26 present the benefit-cost ratios for each of the spot location countermeasures. The benefit-cost ratios were developed by dividing the projected annual benefits by the projected annual cost (see Appendix K). The spot locations with the highest benefit-cost ratio should be targeted as early deployment locations.

The traditional, low-tech countermeasures had high benefit-cost ratios, skewed primarily by their extreme relative low cost of materials and installation and their long cycle life. Most of the more advanced countermeasures have favorable benefit-cost ratios, but not as high as the traditional countermeasures. The ARFs used for estimating advanced technology benefits were conservative; higher accident reductions may be realized when the technology is deployed and evaluated.

Table 20 - Estimated Spot Location System Costs

System	Cost
Friction/ice detection and warning systems	$111,620
Traditional “icy warning sign”	$107
Intersection crossing detection	$34,589
Animal-vehicle safety warning system	$3,800
Dynamic variable message sign (speed advisory)	$4,000
Chevrons	$614

Table 21 - Benefit-cost with Friction/Ice Detection System

Location	Benefit-cost Ratio
Montana U.S. Highway 191	
MP 9.900 – 10.011	25:1
MP 10.000 – 11.000	24:1
MP 59.000 – 60.000	4:1
MP 61.000 – 61.400	0.18:1
MP 1.000 – 2.000	0.34:1
Idaho U.S. Highway 20	
MP 405.000 – 406.000	1:1

Table 22 - Benefit-cost with Static Ice Warning Sign

Location	Benefit-cost Ratio
Montana U.S. Highway 191	
MP 9.900 – 10.011	14,659:1
MP 10.000 – 11.000	14,554:1
MP 59.000 – 60.000	2,232:1
MP 61.000 – 61.400	108:1
MP 1.000 – 2.000	204:1
Idaho U.S. Highway 20	
MP 405.000 – 406.000	763:1

Table 23 - Benefit-cost with Intersection Crossing Detection

Location	Benefit-cost Ratio
Idaho U.S. Highway 20	
MP 311.000 – 312.000	40:1
MP 317.000 – 318.000	69:1
MP 328.000 – 329.000	17:1
MP 338.000 – 339.000	23:1
Idaho U.S. Highway 26	
MP 335.000 – 336.000	14:1
MP 336.000 – 337.000	129:1
MP 338.000 – 339.000	31:1

Table 24 - Benefit-cost with Animal-Vehicle Collision Warning

Location	Benefit-cost Ratio
Montana U.S. Highway 191	
MP 28.000 – 28.900	0.21:1
Wyoming U.S. Highway 89	
MP 160.000 – 161.000	10:1
MP 167.000 – 168.000	1.4:1
MP 185.000 – 186.000	3:1
MP 189.000 – 190.000	9:1
Yellowstone National Park U.S. Highway 89	
MP 21.034 – 21.834	2:1

Table 25 - Benefit-cost with Dynamic Variable Message Sign

Location	Benefit-cost Ratio
Wyoming U.S. Highway 89	
MP 127.000 – 128.000	632:1

Table 26 - Benefit-cost with Chevrons

Location	Benefit-cost Ratio
Wyoming U.S. Highway 89	
MP 127.000 – 128.000	1540:1

Regional Analysis

Regional benefits, costs and benefit-cost ratios are estimated below.

Benefits

Table 27 approximates the financial benefit for each regional section of highway. Benefits vary depending upon the service level of AHS (i.e., information assistance, control assistance, full automation). The benefit data presented here assumes 100 percent market penetration at each service level. The benefits were estimated using the same methodology used for the spot location applications, but a broader subset of accidents were assumed to be mitigated. Appendix J provides a more detailed breakdown of benefits by accident causal factor. Again, all benefits are expressed in annual terms.

Costs

Table 28 approximates the capital cost for the infrastructure installation of lateral magnetic guidance and warning systems, under consideration for deployment at regional sections. These costs were combined with the aforementioned monetary system benefits to produce benefit-cost ratios.

Benefit-cost Ratios

Table 29 presents the benefit-cost ratios for each of the regional highway segments. These calculations assume 100 percent vehicle fleet market penetration.

AHS, with lateral warning and assistance systems, are attractive countermeasures for improving safety within the GYRITS corridor due to their ability to mitigate a wide range of accidents. The collision avoidance systems can help reduce the severity and frequency of accidents within the corridor, saving both money and lives.

Table 27 - Annual Regional Benefits with AHS

	Annual Financial Benefit		
Location	**Information Assistance**	**Control Assistance**	**Full Automation**
Montana U.S. Highway 191			
MP 0.000 – 10.835	$ 482,716	$1,154,983	$1,345,000
MP 10.836 – 66.826	$ 1,647,950	$4,448,683	$5,198,000
MP 66.827 – 81.903	$1,124,166	$2,339,500	$2,581,333
Montana U.S. Highway 89			
MP 0.000 – 51.812	$643,683	$1,576,183	$1,828,666
MP 51.813 – 53.068	$ 113,700	$212,600	$227,333
Montana U.S. Highway 20			
MP 0.000 – 3.000	$98,416	$193,800	$220,333
MP 3.001 – 9.397	$312,516	$874,183	$1,027,333
Idaho U.S. Highway 20			
MP 308.717 – 353.050	$ 5,205,932	$7,340,406	$8,197,450
MP 353.051 – 401.300	$ 2,765,106	$7,090,389	$8,237,174
MP 401.301 – 406.300	$60,570	$108,483	$120,871
Idaho U.S. Highway 26			
MP 335.255 – 338.069	$992,358	$1,778,401	$2,026,710
MP 338.070 – 375.538	$1,349,893	$2,876,419	$3,268,250
MP 375.539 – 402.500	$498,579	$1,241,874	$1,433,647
Wyoming U.S. Highway 26			
MP 0.000 – 2.370	$8,712	$22,801	$26,707
Wyoming U.S. Highway 89			
MP 118.320 – 152.090	$2,179,625	$5,324,161	$6,124,796
MP 155.211 – 165.000	$672,246	$1,637,940	$1,873,090
MP 165.000 – 211.620	$962,665	$2,033,252	$2,310,630
Yellowstone National Park U.S. Highway 89			
MP 0.000 – 93.446	$2,055,447	$4,016,507	$4,500,617

Table 29 - Infrastructure Costs for Lateral Guidance

System	Cost
PATH magnetic nails	$17,000 per lane per mile
3M magnetic tape	$26,000 per lane per mile for 5-10 miles $23,760 per lane per mile for 10.1 miles or more

Table 29 - Benefit-cost Ratio with Regional Deployment

	Benefit-cost Ratios		
Location	**Information Assistance**	**Control Assistance**	**Full Automation**
Montana U.S. Highway 191			
MP 0.000 – 10.835	9:1	21:1	25:1
MP 10.836 – 66.826	6:1	16:1	18:1
MP 66.827 – 81.903	15:1	31:1	34:1
Montana U.S. Highway 89			
MP 0.000 – 51.812	2:1	6:1	7:1
MP 51.813 – 53.068	18:1	33:1	36:1
Montana U.S. Highway 20			
MP 0.000 – 3.000	6:1	13:1	15:1
MP 3.001 – 9.397	10:1	27:1	32:1
Idaho U.S. Highway 20			
MP 308.717 – 353.050	23:1	33:1	37:1
MP 353.051 – 401.300	11:1	29:1	34:1
MP 401.301 – 406.300	2:1	4:1	5:1
Idaho U.S. Highway 26			
MP 335.255 – 338.069	70:1	125:1	142:1
MP 338.070 – 375.538	7:1	15:1	17:1
MP 375.539 – 402.500	4:1	9:1	11:1
Wyoming U.S. Highway 26			
MP 0.000 – 2.370	1:1	2:1	2:1
Wyoming U.S. Highway 89			
MP 118.320 – 152.090	13:1	31:1	36:1
MP 155.211 – 165.000	14:1	33:1	38:1
MP 165.000 – 211.620	4:1	9:1	10:1
Yellowstone National Park U.S. Highway 89			
MP 0.000 – 93.446	4:1	8:1	10:1

Deployment Vision Benefit-cost Analysis

Benefit-cost ratios on the basis of the deployment vision are estimated below.

Benefits

In an effort to more accurately project AHS impacts, assumptions from the deployment vision were included in the analysis. The Information Assistance service level is projected out 10 years assuming a four-percent inflation rate and a 20 percent vehicle fleet penetration (see Table 30). The Control Assistance service level is projected out 20 years assuming a four-percent inflation rate and a 50 percent vehicle fleet penetration. The Full Automation service level was omitted; it was assumed inappropriate for rural two-lane highways.

Costs

The capital costs previously estimated for the regional benefit-cost analysis (i.e., the infrastructure installation of the lateral magnetic guidance and warning system) were used here. These costs were combined with the aforementioned deployment vision monetary benefits to produce benefit-cost ratios.

Benefit-cost Ratios

Table 31 presents more realistic benefit-cost ratios based on predicted vehicle fleet market penetration as indicated in the deployment vision.

Note the importance of vehicle fleet penetration and AHS service level on benefit-cost ratios for full-scale regional deployment. Many regions were deemed inappropriate for the installation of AHS infrastructure due to low benefit-cost ratios, likely resulting from the relatively low vehicle fleet market penetration. Lower ARFs also resulted in lower benefit-cost ratios for the Information Assistance service level.

Table 30 - AHS Benefits with Deployment Vision

	Annual Financial Benefit	
Location	**Information Assistance** 20% penetration after 10 years	**Control Assistance** 50% penetration after 20 years
Montana U.S. Highway 191		
MP 0.000 – 10.835	$142,907	$1,265,353
MP 10.836 – 66.826	$487,872	$4,873,799
MP 66.827 – 81.903	$332,807	$2,563,062
Montana U.S. Highway 89		
MP 0.000 – 51.812	$190,561	$1,726,803
MP 51.813 – 53.068	$33,660	$232,916
Montana U.S. Highway 20		
MP 0.000 – 3.000	$29,136	$212,319
MP 3.001 – 9.397	$92,519	$957,720
Idaho U.S. Highway 20		
MP 308.717 – 353.050	$1,541,205	$8,041,856
MP 353.051 – 401.300	$818,604	$7,767,946
MP 401.301 – 406.300	$17,931	$118,850
Idaho U.S. Highway 26		
MP 335.255 – 338.069	$293,785	$1,948,345
MP 338.070 – 375.538	$399,633	$3,151,290
MP 375.539 – 402.500	$147,603	$1,360,548
Wyoming U.S. Highway 26		
MP 0.000 – 2.370	$2,579	$24,980
Wyoming U.S. Highway 89		
MP 118.320 – 152.090	$645,273	$5,832,938
MP 155.211 – 165.000	$199,017	$1,794,461
MP 165.000 – 211.620	$284,995	$2,227,550
Yellowstone National Park U.S. Highway 89		
MP 0.000 – 93.446	$608,511	$4,400,325

Table 31 - Benefit-cost Ratio Based on Deployment Vision

	Benefit-cost Ratios	
Location	**Information Assistance** 20% penetration after 10 years	**Control Assistance** 50% penetration after 20 years
Montana U.S. Highway 191		
MP 0.000 – 10.835	3:1	23:1
MP 10.836 – 66.826	2:1	17:1
MP 66.827 – 81.903	4:1	34:1
Montana U.S. Highway 89		
MP 0.000 – 51.812	0.007:1	0.07:1
MP 51.813 – 53.068	5:1	37:1
Montana U.S. Highway 20		
MP 0.000 – 3.000	2:1	14:1
MP 3.001 – 9.397	0.02:1	0.2:1
Idaho U.S. Highway 20		
MP 308.717 – 353.050	7:1	36:1
MP 353.051 – 401.300	3:1	32:1
MP 401.301 – 406.300	0.7:1	5:1
Idaho U.S. Highway 26		
MP 335.255 – 338.069	20:1	137:1
MP 338.070 – 375.538	2:1	17:1
MP 375.539 – 402.500	1:1	10:1
Wyoming U.S. Highway 26		
MP 0.000 – 2.370	0.2:1	2:1
Wyoming U.S. Highway 89		
MP 118.320 – 152.090	4:1	34:1
MP 155.211 – 165.000	4:1	36:1
MP 165.000 – 211.620	1:1	9:1
Yellowstone National Park U.S. Highway 89		
MP 0.000 – 93.446	1:1	9:1

NEXT STEPS

Candidate Field Operational Tests

Field operational tests (FOTs) encourage support for the deployment of advanced transportation technologies. Through field operational tests, “proof of technology” can be demonstrated. The proliferation of AHS will not emerge until components of AHS are successfully demonstrated. Through the successful demonstration of “showcase” projects, AHS can win the support of both transportation providers and users. Automated Highway Systems must demonstrate tangible safety benefits to support the theoretical accident reduction claims made by researchers.

This section recommends several areas for possible early field operational testing with low-level AHS technology. The intent of the recommended FOTs is to provide the driver with more information and more time to react. It is hypothesized that this additional information and time will help the driver avoid many collisions. Through the benefit-cost analysis, sites with the greatest potential were selected for AHS technology deployment in continuing efforts. The candidate sites include:

Friction/Ice Detection and Warning System

- Montana U.S. Highway 191, milepost 9.900 to 10.011 and 10.000 to 11.000;

Intersection Crossing Detection

- Idaho U.S. Highway 26, milepost 336.000 to 337.000;
- Idaho U.S. Highway 20, milepost 317.000 to 318.000 and 311.000 to 312.000;

Animal-Vehicle Collision Avoidance

- Wyoming U.S. Highway 89, milepost 160.000 to 161.000 and 189.000 to 190.000;

Horizontal Curve Speed Advisory

- Wyoming U.S. Highway 89, milepost 127.000 to 128.000.

These sites were estimated to have the greatest potential for improving safety in the GYRITS corridor through the deployment of AHS. However, before any of the above sites are designated as FOTs, further investigation of the police accident records, the site, and the transportation providers’ perspectives needs to occur.

Measures of Effectiveness

As stated earlier in the deployment vision, the objective of this effort is to make travel within the GYRITS corridor safer. This objective will predictably be attained through the systematic application of advanced transportation technologies. Specific measures of effectiveness (MOEs) should be developed to gage the attainment of the longer-term objective. Specifically, MOEs serve to:

- assess the system improvements;
- quantify associated benefits and costs; and
- communicate deployment results to technical and non-technical audiences.

For this study, system effectiveness centers on improving safety, including reducing accidents and reducing vehicle speeds. Selection of the MOEs is critical in determining system effectiveness. For the GYRITS corridor, there were four spot location advanced technologies considered for deployment. At these four locations, the following MOEs are recommended to determine system performance.

Goals:

- Increase safety

Objectives:

- Assess accident causal factors
- Assess driver/roadway operation characteristics
- Assess impact of weather on accidents
- Assess impact of vehicle mix on safety

MOEs:

- Accident rates per million vehicle-miles traveled
- Total accident reduction
- Speed reductions

Each of these MOEs should be evaluated with statistically valid before-after analyses (see Appendix L).

Similar MOEs can be developed for the regional deployment sections. Because regional deployment measures affect a broader range of accident types, a broader base of MOEs should be used to evaluate system performance. Regional MOEs may include:

- number of annual crashes
- number of annual fatalities
- annual fatality rates
- annual number of injuries

- annual injury rates
- annual injury rate
- injury severity index
- accident rates per million miles traveled (kilometer miles traveled)
- annual cost of injuries
- infrastructure damage

The MOEs presented above provide a method to quantify the safety improvements resulting from AHS deployments in the GYRITS corridor. Quantitative analysis considers system performance from an equipment-related perspective, as well. Did the system operate within the guidelines and specifications that were intended? Qualitative methods may also be used to evaluate system performance from a human factor perspective. The qualitative evaluation is non-technical but evaluates any possible improvements in quality of life for the transportation users and/or providers.

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APPENDICES