# Cost-Benefit Analysis of a Rural Advanced Traveler Information System

KAZI ULLAH, WENDE A. O'NEILL, AND A. BRUCE BISHOP

A life-cycle cost model is developed to evaluate a proposed rural Advanced Traveler Information System (ATIS). Costs used in this model include capital investment (in equipment and facilities as well as installation), operation, and maintenance costs. A cost-benefit analysis is reported. System benefits are equated to potential reduction in the number of accidents that occur while the ATIS is in place. Sensitivity analysis is performed on both its costs and benefits. The approach is useful for evaluating Intelligent Vehicle Highway System applications as well as for exploring trade-offs among proposed technologies for the application.

The Advanced Traveler Information System (ATIS) is one component of the Intelligent Vehicle Highway System (IVHS) applications currently sweeping the nation. The IVHS program's goal is to improve the efficiency and safety of surface transportation (*1*). ATISs are information-based applications designed to provide roadway users with accurate and timely information on travel conditions. A major assumption underlying these systems is that this information affects a person's decisions as to where, when, and how to travel. The purpose of ATIS is to mitigate traffic congestion problems by either (*a*) informing an en route driver of traffic incidents ahead and suggesting alternative routes or (*b*) allowing pretrip travel information to prompt someone to delay trip starts or to choose alternative routes or modes of transportation. ATIS applications have been made primarily in urban areas, where congestion and traffic delays are major cost factors. Rural applications of ATIS, on the other hand, focus on single corridors of travel (usually a section of Interstate) that have high accident rates or other operational problems.

Design of ATIS incorporates several technologies that (*a*) collect data on current traffic conditions, (*b*) interpret the information, and (*c*) communicate it to the public. The most common technologies for these applications include video, satellite, radio, and computers. These hardware components are combined with specialized software into an integrated traveler information system. Most rural systems are designed to provide information to a motorist on weather, road, or traffic conditions downstream from his or her location, using visibility sensors, pavement sensors, and variable message signs (*2*).

## PROBLEM STATEMENT

This paper focuses on evaluating proposed technologies and application of a rural ATIS. The prototype system differs from other rural applications of ATIS in the following ways:

K. Ullah and W. A. O'Neill, Department of Civil and Environmental Engineering, Utah State University, Logan, Utah 84322-4110. A. B. Bishop, College of Engineering, Utah State University, Logan, Utah 84322-4110.

- The system is designed for a regional application, incorporating a network of rural roads.
- Pretrip information is important.
- Improved safety is the primary concern; however, an additional benefit associated with improved statewide maintenance management is realized.
- Roadway environment, as well as weather conditions, influences design parameters for the system.

This system differs from other rural weather information systems in that real-time data are collected for the entire region and along each road traveled by maintenance crews. Data from point source systems are less reliable in mountainous areas because conditions change as frequently as the roadside environment. Research conducted in Wyoming for the I-80 corridor indicates that weather and road information from point source systems rarely coincides with motorists' perceptions of the conditions (*3*).

Rural canyon roads in Utah have high traffic volumes in the winter because they provide access to several ski resorts and recreational areas used for Nordic skiing, snowmobiling, sledding, hunting, and ice fishing. Average annual daily traffic (AADT) for two of these canyons is shown in Figures 1 and 2. Traffic accidents during the winter months are a major problem in rural Utah. The magnitude of winter weather accidents is described in detail later in this paper. Not only is there a heavy cost associated with loss of life and property damage, but also many hours are wasted by stranded motorists waiting for tow trucks to help them back onto the road.

An ATIS is proposed that monitors roadway conditions and uses dynamic mapping techniques to communicate the information to the public. The potential market for this system is as follows:

- Tourists who stay in the urban areas and drive to different resorts during their vacation,
- Resort workers who commute from the city to the resorts because they cannot afford the high cost of living in the resort communities,
- Private shuttle services from the airport to resorts,
- Rural school bus operators, and
- Anyone using the rural road system for work, recreational, or sustenance-related reasons.

The proposed system basically operates as follows:

- Maintenance vehicles involved with plowing and salting activities are equipped with vehicle-tracking devices.
- Location information is sent to a central traffic control center where it is processed and integrated with other information (data on fog, wind, avalanches, accidents, etc.).

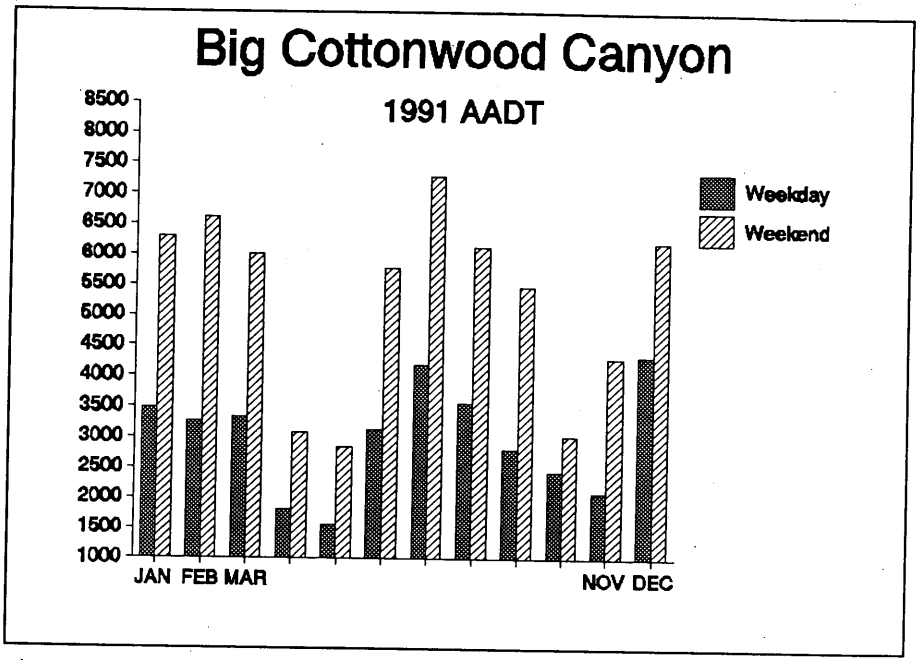


**FIGURE 1** Traffic volume on a rural canyon road: Big Cottonwood Canyon, 1991 AADT.

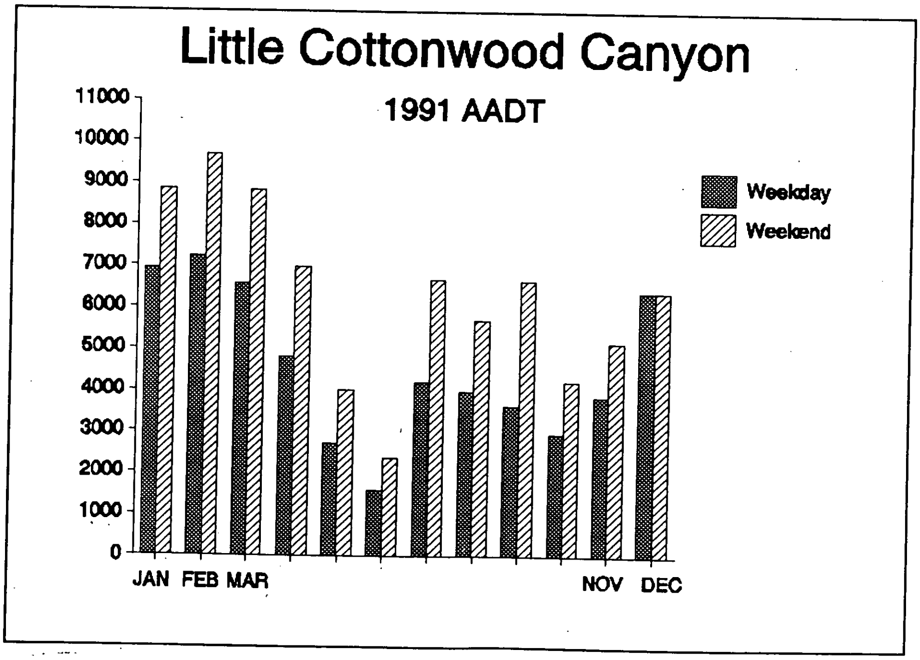


**FIGURE 2** Traffic volume on a rural canyon road: Little Cottonwood Canyon, 1991 ADDT.

• Roadway condition information is communicated to the public via television, telephone, radio, and interactive display terminals placed at strategic locations (resort lobbies, hotel lobbies, car rental agencies, and employment and shopping centers).

A substantial financial investment is required to implement this system. In addition, a long-term financial commitment is required to maintain and operate the system. A decision must be made on whether the potential benefits of this system are worth the cost. One way to answer this question is described below.

## COST MODEL

The exact cost of the proposed system is difficult to determine. However, a cost estimate can be derived on the basis of a few simple assumptions. The cost of high-technology equipment and software changes from year to year. As the number of high-technology applications and users grows, instrument costs should continue to decrease in the future. The dollar value of future equipment and services is not the same as it is in the present. To account for this behavior in our cost estimation model, future year costs are discounted to present value equivalents, called present worth of cost (PWOC). A discount rate of 7 percent is used in calculating PWOC. Instrument life is assigned a value of 10 years. Finally, the proposed ATIS is expected to operate during the winter months, from November to March.

PWOC is calculated from the following equation (*4–6*):

$$\text{PWOC} = I + \sum_{j=1}^{n} A\, PW_j - T\, PW_n \quad (1)$$

where

$I$ = initial cost = $(\Sigma_{k=1}^{8} IC_k)$, and $IC_k$ is the initial cost of item $k$;
$A$ = annual cost = $(\Sigma_{k=1}^{5} a_k)$, and $a_k$ is the annual cost of item $k$;
$T$ = salvage value; and
$PW_j$ = present worth factor for year $j = 1/[(1 + r)^j]$, and $r$ is the discount rate (7 percent) and $j$ varies from 1 to 10 years.

Cost analysis of the proposed ATIS considers both global positioning system (GPS) and radio technology for tracking locations of maintenance vehicles.

### Nonrecurring Costs

The first step in estimating the cost of the proposed system is to determine the initial investment or nonrecurring (one-time) costs. All costs associated with installation of equipment and preparation for its operation are included as a part of this investment. One-time costs include such items as system design, programming, system testing, equipment acquisition, and training. The costs may occur at any time during the life cycle of the system. For the sake of simplicity, an assumption is made that nonrecurring costs occur only during the first year of the cycle. Table 1 gives initial cost estimates for this model. The following assumptions are made in deriving these figures.

**TABLE 1 Nonrecurring Costs**

| COST ITEM | NOTATION | AMOUNT |
|---|---|---|
| Construction/Renovation of Roadway Management Center (RMC) | $IC_1$ | $ 12,000 |
| Hardware/software for location finding | $IC_2$ | |
| GPS | | $100,800 |
| Radio | | $ 84,000 |
| RMC Hardware | $IC_3$ | $ 8,000 |
| Remote site hardware (60 sites) | $IC_4$ | $192,000 |
| RMC data transmission modem | $IC_5$ | $ 200 |
| Remote site modems | $IC_6$ | $ 12,000 |
| Display software at remote sites | $IC_7$ | $ 60,000 |
| Interactive hardware at remote sites | $IC_8$ | $ 20,100 |

*Cost of Roadway Management Center*

A centralized roadway management center (RMC) will be used to receive, collect, and monitor information sent from maintenance vehicles. This information will be integrated with accident and weather information, then dispatched to remote sites for use by the public. This center will also produce maintenance data for monitoring and tracking maintenance activities. Initial cost for this center includes construction or renovation fees. In this study, construction of a one-room addition to the existing regional maintenance headquarters is assumed. Cost depends on the size of the extra room as well as internal plant requirements (temperature control, additional floor support for mainframes/equipment, etc.). Construction cost is estimated to be approximately $12,000 for this purpose.

*Cost of Location Finding (GPS/Radio) Instrumentation*

This is one of the largest costs for the proposed system. Two technologies have been investigated, namely GPS and radio communication networks. GPS equipment, with mobile satellite communication for tracking, costs about $1,200.00 for each maintenance vehicle. It is assumed that these systems provide one-way communication only, since the vehicles are already equipped with two-way radio communication.

A radio-based tracking system requires small, in-vehicle mobile data terminals or PCs interfaced with a vehicle's radio modem. The cost of this equipment is $1,000 for each maintenance vehicle. This cost is based on the assumption that a sufficient radio network has been established by private industry in the region. Companies currently marketing this technology are focusing on large urban market areas. Even though this technology seems less expensive to implement, a delay of several years can be expected before it is available in rural areas.

Eighty-four state maintenance vehicles provide service to the study area. Total cost of in-vehicle location-finding equipment is calculated by multiplying the number of vehicles by the cost per vehicle.

*Hardware and Software Costs*

To send data files from the RMC to remote sites for use by the public, the following equipment is needed:

- IBM, Intergraph 6000, or equivalent work station with a c400 processor in the RMC (the initial cost is estimated as $8,000);
- One IBM 486 PC having a memory of at least 30 megabytes at each remote site for graphic display of road conditions;
- One 9,600- or 14,400-band modem at the RMC and one at each other location, each costing $200; and
- Micro-station 32 software and some custom C programs to show the paths of maintenance vehicles using locational data received in the RMC. Location data are placed in a graphic control file. Once sent to remote computers, it is ready to be displayed. Software costs should not exceed $1,000 per site.

There are more than 60 hotels and motels in and around Salt Lake City where visitors may stay during winter months. If PCs are used and 50 of them and 10 information centers (resorts, malls, employment centers, etc.) are considered for display of roadway conditions during snowy weather, at least 60 PCs would be required for this study. (It is not possible to sell this system as a service to these remote sites because information is being gathered by the state and is therefore public.) Cost is calculated per unit site. Each 486 PC costs about $3,200, including a monitor.

### *Other Equipment Costs*

Video converters may be used to display roadway conditions on a large screen instead of a small computer screen in each location. Different types of equipment can be used for this purpose. One approach is to use a projection monitor connected to the computer and a projection screen. For a color display, the cost of this equipment is $2,800. Another approach uses a videoconverter hooked to the computer and a color television to show the map display on a large TV screen. The cost of this equipment is $399, excluding the TV. So the total cost will be $2,100 including a large television, which is less expensive than the previous approach mentioned. Another method that provides an interactive system uses touch-screen equipment instead of a keyboard. A touch screen is affixed to the computer monitor and then plugged into the computer. The equipment is considered in the present study. Touch-screen interactive capabilities add approximately $335 to the cost of each remote-site monitor.

## Recurring Costs

The second step in the cost-estimation process is to determine recurring costs (annual costs), those associated with maintenance and operation of the system. Data communication costs, personnel services, space occupancy, supplies, and utilities are examples of recurring costs. Table 2 contains information on recurring costs used in this model. The following assumptions are made in deriving these figures.

### *Operating and Maintenance Cost of RMC*

An assumption is that the RMC will operate with two staff persons. Both people are paid a gross salary of $3,000 per month in the first year. A 5 percent increase in the salary is assumed for subsequent years.

**TABLE 2 Recurring Costs**

| COST ITEM | NOTATION | AMOUNT |
|---|---|---|
| Roadway Management Center Staffing (first year, 5% annual increase) | $a_1$ | $ 72,000 |
| Spatial database maintenance | $a_2$ | $ 2,000 |
| Satellite use fee<br>Radio access fee | $a_3$ | $ 50,400<br>$ 10,080 |
| Telephone fee for remote sites | $a_4$ | $2,304 |
| Maintenance cost at remote sites | $a_5$ | $ 60,000 |

### *Purchase Cost of Road Network Data Base*

A graphic-based system is proposed that uses maps to convey road-condition information as well as accident and weather information. This spatial data base must contain roads in the region to accommodate interactive queries by users on optimal routes. An updated road network data base may be purchased from a private organization each year due to construction of new roads or closing of existing roads. The Utah Department of Transportation (UDOT) itself may be able to supply these data, so base map update costs could be insignificant. However, it is assumed that $2,000 is required each year to purchase these data.

### *Access Fees for Vehicle-Tracking Equipment*

In the current market, an access fee of $10 per vehicle per month is estimated for a radio-based system. If more than 200 position fixes per vehicle per month are required, a higher cost will be incurred. An extra cost of $50 per vehicle per month may be necessary when using satellites for data communication. This cost is based on estimates from freight companies using this technology as well as vendor price quotes.

### *Telephone Fee*

Data files are sent through existing telephone lines. The service fee is comparable to a monthly telephone bill. Fees depend on time of day (highest during peak hour, lowest during off-peak hour) and length of time needed to send data files. In the proposed study, maintenance vehicles are assumed to work early in the morning in most cases. But this varies depending on the weather. A plowing period may not be more than 2 hr, because it is Utah's policy to clear snow from roads within 2 hr. However, in case of continuous snow, this period may be much longer.

In the present study, a snow removal period is taken as 8 hr a day. There are 152 days from November through March. A 10-year weather history from the Utah Climate Center indicates that it snows more than $^1/_2$ in. in the study area for an average of 24 days during this period. Maps at remote sites are updated every 15 min. In an 8-hr period, data transmission occurs 32 * 60 times. Assuming 15 sec per site to send information, it will take 480 min per day. Using a cost of $0.20 per minute, the total cost per day is $96; that is, 2,304 per year.

*Maintenance Cost at Remote Sites*

Each facility where current roadway conditions are shown has potential maintenance needs, related to hardware failure or vandalism, for example. The maintenance cost is estimated to be $1,000 per year.

### Additional Model Assumptions

Salvage or terminal value is defined as the expected value of hardware and software at the end of its useful life, which is 10 years in this study. This value is denoted as $T$ in Equation 1. To determine the salvage or terminal value, the most important criterion is whether the item will be sold, reused, or continue in operation for another cycle. If the asset is sold or reused, the value is the actual market value less the cost of sale or redistribution. If an asset is to be scrapped, the only value is the scrap value less costs of dismantling and selling. For the sake of simplicity, in this study all hardware and software is considered to be dismantled after 10 years. Hence, salvage value of the proposed ATIS is considered zero after 10 years, as a conservative approach.

During the 10-year life, new technology is expected to become available that can be incorporated into the system. The ATIS described here may become obsolete by that time; however, with the addition of some new features the basic principal will remain the same.

In doing a cost analysis of both GPS and radio technology for the next 10 years (from 1993 to 2002), all cost estimates for each year were expressed in current dollar value. A discount factor of 7 percent is applied to convert future dollar value into present value. The value of this factor varies from project to project and is based on good judgment. Studies have shown that a 6 to 10 percent rate is practical in most cases (*6,7*).

### Results of the Cost Analysis

PWOC for ATIS using GPS and radio-based technology is given in Table 3. The number of remote sites receiving this service is assumed to be 60 in this analysis. Radio technology will cost slightly less than GPS technology over a 10-year period. However, the cost figures do not take into account the cost associated with delayed implementation of the system using radio technology. GPS design may be implemented almost immediately, whereas a sufficient radio network must be installed before implementing a radio-based tracking system.

**TABLE 3 Cost Analysis of ATIS over 10 Years**

| | Cost of GPS-based System | Cost of Radio-based System |
|---|---|---|
| Year 1 | 579,590 | 525,108 |
| Year 2 | 166,219 | 131,002 |
| Year 3 | 158,430 | 125,517 |
| Year 4 | 151,094 | 120,334 |
| Year 5 | 144,180 | 115,433 |
| Year 6 | 137,664 | 110,798 |
| Year 7 | 131,519 | 106,410 |
| Year 8 | 125,723 | 102,256 |
| Year 9 | 120,253 | 98,321 |
| Year 10 | 115,090 | 94,593 |
| TOTAL | $1,829,761 | $1,529,770 |

## BENEFITS ANALYSIS

IVHS is supposed to provide various benefits, such as reductions in congestion, pollution, energy consumption, and accidents, as well as improved mobility. An additional benefit of ATIS is improved data for winter maintenance management; however, to follow a conservative approach, only benefits due to reductions in accidents are considered.

Accident data for different roads leading to ski resorts are used in the analysis. Only accidents that occurred during winter months or snow and icy, wet conditions are selected from the data base. A shortcoming of the data is that they did not provide information on delays of stranded motorists (waiting for tow trucks) stuck in heavy snow during bad weather. In such incidents, there is typically no damage to vehicles or drivers, although lost time and towing expenses can result. Historic trend information is used to estimate the number of future accidents that would occur in the study area if the proposed technology is not implemented.

Accurately estimating the benefits of this technology is difficult because of drivers' potential responses.

1. Some drivers will not use information supplied by the system. Many drivers currently do not call designated telephone numbers for up-to-date road and travel information. Some people will choose not to activate in-vehicle devices or observe information kiosks in hotels or employment centers. Accident potential for drivers ignoring travel information is the same after implementation of the system as it is before.

2. Some drivers will ignore system information received, because of the importance of their trip or their lack of confidence in the system or technology. Technology breakdowns may lead people to disregard available information in the future. Secondly, if inaccurate or outdated information is presented, drivers may come to distrust all such information in the future. Such drivers will then be classified in Category 1. Accident potential for drivers in Category 2 will not change.

3. Finally, some drivers use the information provided by the system. Studies indicate that informed drivers travel more cautiously and are more likely to cancel trips (*3,8*). In this case, the following three conditions may result (*a*) Drivers will proceed cautiously or avoid hazardous routes, reducing accident potential. (*b*) Drivers will delay trips; these drivers' chance of becoming involved in an accident is reduced, but it is difficult to estimate the potential accident reduction. (*c*) Drivers will cancel their trips. In such cases, there will be no accidents. However, cancellation of trips may result in a loss of revenue at the intended destination.

To better understand driver acceptance of ATIS, surveys on driver response to ATIS should be conducted in hotels and at other appropriate locations. Such surveys were not conducted in the present study because of resource limitations.

The prototype system is evaluated by assuming different percentages of accident reduction and calculating corrresponding benefits. These benefits include reductions in the number of fatal accidents, personal injuries, and property damage only (PDO) accidents on roads within the study area. Percentage of accident reduction in relation to the cost-effectiveness of the system is evaluated later in this paper.

### Analysis of Data

Accident data for the 5 months, November through March, during a 5-year period from 1987 to 1991, were analyzed. During this period, only accidents occurring in snow were considered in the analysis in order to relate the number of accidents with the effectiveness of snow-removal activities.

Despite the availability of data from UDOT, there was a problem with data quality and completeness. Accident data files must be integrated with traffic and road inventory data for the analysis. No data were available for three roads in the study area for 1987. Unfortunately, AADT data on some roads were not consistent at all.

Other research using accident data bases indicated that other problems with the data could occur. For instance, not all accidents are reported, particularly in urban areas where PDO accidents often are not reported. In general, the more severe an accident, the more likely it is that the accident will be reported. Also a multivehicle accident is more likely to be reported than a single-vehicle accident of equal severity. Accidents are probably less likely to be reported during bad weather than during good weather (*9*).

The interrelationship of various accident causal factors makes data analysis and interpretation difficult. Usually, the number of road accidents should have some relation to traffic volume. Several studies show that this relation is more complex than a simple proportion (*10*). In this study area, AADT is analyzed separately both for rural and urban roads for the last 5 years, from 1987 to 1991. Each road studied is found to have several sections with different AADT. The percentage change in AADT for each section is calculated. Weighted change in AADT is then calculated by considering the change in different sections and corresponding lengths. The percentage change in AADT for the last 4 years is determined separately both for rural and urban roads. No general pattern is identified from these calculations. This may be because of bad data or the uncertain behavior of travelers along those road segments. Because of the lack of trend in AADT change, only the number of accidents is analyzed for the purpose of prediction of accidents.

Accidents on rural and urban roads are analyzed separately because the manner of occurrence of traffic accidents varies greatly in these areas. Accidents can be classified into various categories depending on severity, cause of accident, type of collision, for example. Accidents have been classified into five types based on severity for an FHWA study (*11*):

1. PDO: those accidents in which only damage to the vehicle or roadside property results;
2. Minor injury: those injuries that require minor treatment, such as treatment for abrasion, pain, nausea, or hysteria;
3. Medium injury: those which may include a lump on head, minor lacerations, bruises, or crushed finger, for example;
4. Serious injury: any injury other than fatal injury that prevents a person from walking, driving, or performing normal activities; and
5. Fatal injury: any injury that results in death within 30 days.

A variety of methods exist to quantify accidents, such as accident rate per mile, accident based on population, accident rate based on vehicle-miles of travel, number of accidents based on severity. In the present case, analysis is done according to number of various types of accidents based on severity. Table 4 summarizes the number of PDO, minor injury, medium, serious, and fatal injury accidents on rural urban roads during snow or snowstorms during winter months, for the past 5 years. Whereas there is no uniform pattern for the number of accidents on separate road segments, an increased pattern is observed for total accidents within the last 5 years.

On average, a 10 percent increase in accidents occurred in the past 5 years on rural roads. The percentage is used to estimate any increase in future accidents on rural roads. On average, a 31 percent increase in accidents on urban roads occurred over the past 5 years. In this study, an average, conservative increase of 10 percent is applied to predict future urban accidents.

Table 5 gives percentages of different types of accidents with respect to total accidents for rural and urban roads. A one-way analysis of variance test was conducted to determine whether the percentages of various accident types among different years were similar or not. A conclusion from this test is that the percentage of accidents by type does not vary significantly from year to year. On average, 72.84 percent of accidents are PDO, 12.64 percent are minor, 7.5 percent are medium, 6.75 percent are serious, and 0.28 percent are fatal injury accidents for rural areas. For urban roads in the study area, it is assumed that 71.64 percent of accidents are PDO, 15.33 percent minor, 7.55 percent medium, 5.24 percent serious and 0.24 percent are fatal injury accidents.

Assuming a 10 percent annual increase in the number of accidents in the study area, total accidents for the next 10-year period may be calculated (Table 6).

### Analysis of Safety Benefits

Safety benefits vary from year to year throughout the service life because of variation in the dollar value assigned to different types of accidents. Benefits are converted to present value using a discount rate for comparison purposes. Present Worth of Benefit (PWOB) is calculated as follows (*4–6*):

$$\text{PWOB} = \sum_{n=1}^{10} B_n PW_n \qquad (2)$$

where

$B_n$ = benefit varying from year to year,
$PW_n$ = present worth factor = $1/(1 + r)^n$, and
$r$ = 7 percent.

Safety benefit $B_n$ is estimated from the following formula (*4*):

$$B_n = N_f \sum_{i=1}^{5} P_i S_i C_i \qquad (3)$$

where

$N_f$ = total number of expected future accidents,
$P_i$ = percentage of accidents of type $i$,

**TABLE 4 Total Accidents During Winter Months and Under Snowy Conditions Within Study Area**

| | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|
| Rural Roads in Study Area | | | | | |
| Property Damage Only | 307 | 452 | 328 | 356 | 401 |
| Minor Accidents | 47 | 83 | 46 | 60 | 84 |
| Medium Accidents | 54 | 40 | 23 | 32 | 42 |
| Serious Accidents | 25 | 31 | 33 | 39 | 42 |
| Fatal Accidents | 0 | 2 | 2 | 3 | 0 |
| TOTAL | 433 | 608 | 432 | 490 | 569 |
| Urban Roads in Study Area | | | | | |
| Property Damage Only | 336 | 860 | 551 | 571 | 622 |
| Minor Accidents | 86 | 118 | 130 | 137 | 158 |
| Medium Accidents | 31 | 55 | 60 | 76 | 88 |
| Serious Accidents | 13 | 64 | 46 | 38 | 54 |
| Fatal Accidents | 0 | 3 | 1 | 0 | 6 |
| TOTAL | 466 | 1100 | 788 | 822 | 928 |

$S_i$ = expected reduction in type $i$ accidents, and
$C_i$ = average cost of type $i$ accidents.

Now the problem boils down to estimating the expected reduction in PDO, minor, medium, serious and fatal injury accidents. Until the system is installed and used for an extended period of time, a reasonable estimate of accident reduction is difficult to make. The expected reduction may depend on the various drivers' reactions as mentioned before. It may vary for different types of accidents and result in greater reduction in fatal accidents than PDO accidents. To simplify the estimate, therefore, accident reduction is considered to be uniform for all types of accidents.

**TABLE 5 Percentages of Accidents by Type and Year on Rural and Urban Roads in the Study Area**

| | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|
| Rural Roads | | | | | |
| Percent Property Damage Only | 70.9 | 74.3 | 75.9 | 72.6 | 70.5 |
| Percent Minor | 10.9 | 13.7 | 10.7 | 12.2 | 14.8 |
| Percent Medium | 12.5 | 6.6 | 5.3 | 6.3 | 7.4 |
| Percent Serious | 5.8 | 5.1 | 7.6 | 8.2 | 7.4 |
| Percent Fatal | 0 | 0.3 | 0.5 | 0.6 | 0 |
| Urban Roads | | | | | |
| Percent Property Damage Only | 72.1 | 78.2 | 69.9 | 69.5 | 67.0 |
| Percent Minor | 18.5 | 10.7 | 16.5 | 16.7 | 17.0 |
| Percent Medium | 6.7 | 5.0 | 7.6 | 9.3 | 9.5 |
| Percent Serious | 2.8 | 5.8 | 5.8 | 4.6 | 5.8 |
| Percent Fatal | 0 | 0.3 | 0.1 | 0 | 0.7 |

NOTE: Numbers are rounded to the nearest tenth.

**TABLE 6 Estimated Number of Accidents During Winter Months and Under Snowy Conditions on Rural and Urban Roads**

| | '92 | '93 | '94 | '95 | '96 | '97 | '98 | '99 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rural | 626 | 683 | 740 | 797 | 854 | 910 | 967 | 1024 | 1081 | 1138 | 1195 |
| Urban | 1021 | 1114 | 1206 | 1299 | 1392 | 1485 | 1578 | 1670 | 1763 | 1856 | 1949 |

To further complicate the analysis, methods used to determine costs for different accident types are not yet standardized. The average cost of the various types of accidents varies according to different organizations. Cost estimates are composed of various components, such as wage loss, medical expenses, insurance administration costs, and motor-vehicle repair or replacement costs. According to the National Safety Council (*12*), estimated costs for different types of accidents in 1992 are as follows:

- Fatal injury, $450,000;
- Serious injury, $42,400;
- Medium injury, $10,700;
- Minor injury, $3,300; and
- PDO accident, $1,100.

These costs are used in the benefit analysis. Given the assumptions and data described above, the safety benefit is calculated such that $S_i = S_j$ for $i$ and $j$. Safety benefits and corresponding PWOB for both rural and urban roads are calculated using several values for percent of accident reduction, namely 1 percent, 2 percent, and 3 percent, as indicated in Table 7.

Another type of benefit achieved by this system is improved data for budgeting and planning maintenance operations. The system will help the maintenance division keep track of road mileage plowed or salted and other pertinent information. Improved decision making may result in more efficient planning routes for snowplow crews as well as in better inventory practices. The system should help achieve lower costs for maintenance work and provide improved service to the public. The system may also be used, during other seasons, to track the maintenance crews during their routine work. It is very difficult to quantify this type of benefit, and it is not considered in the study.

## SENSITIVITY ANALYSIS

Net present value (NPV) and benefit/cost ratio are used to evaluate the proposed systems. NPV and B/C ratio are calculated as follows:

$$\text{NPV} = \text{PWOB} - \text{PWOC}$$

$$\text{B/C ratio} = \text{PWOB}/\text{PWOC}$$

**TABLE 7 Safety Benefits for Various Accident Reduction Values**

| PWOB | $S_i$ = 1% | $S_i$ = 2% | $S_i$ = 3% | $S_i$ = 4% |
|---|---|---|---|---|
| Rural | $391,453 | $ 782,907 | $1,174,360 | $1,565,813 |
| Urban | $561,615 | $1,123,231 | $1,684,646 | $2,246,461 |
| Total | $953,068 | $1,906,138 | $2,859,206 | $3,812,275 |

Table 8 gives the value of these statistics for the proposed system at different accident reduction rates. NPV is positive and the B/C ratio is greater than one when the accident reduction rate is 2 percent or more. The break-even period for different accident reduction rates is indicated. With a 2 percent reduction in accidents, the GPS-based ATIS would pay itself off in 9 years. The amount decreases significantly with a 3 percent accident reduction rate.

Costs are based on estimates of different equipment costs, fees, and so forth and often represent best judgment. To compensate for uncertainty, sensitivity analysis was done to evaluate the impact of changes in data.

The variables considered in the sensitivity analysis are (*a*) staff salary, (*b*) GPS instrument cost, (*c*) telephone fee for data transmission, and (*d*) the discount factor. The relative sensitivity of these variables for ±20 percent variation is in Figures 3 and 4 for 2 percent and 3 percent accident reduction, respectively. Both figures indicate that staff salary is the most sensitive factor. Other factors are relatively insensitive.

## CONCLUSIONS

A prototype ATIS for a rural regional application is proposed to improve winter weather safety. The system provides pretrip information to travelers during snowy weather in the winter. Information on current road conditions allows drivers to make their own decision about their trip or alternate routes. Other information, such as wind speed or pavement temperature, can be sent to the RMC depending on the technology used in the future. However, this is not considered in this study.

In the study, both GPS and radio systems are found to be cost-effective when the accident reduction is as low as 2 percent for

**TABLE 8 Cost/benefit Statistics for Proposed ATIS**

| System | NPV | B/C Ratio | Break even point |
|---|---|---|---|
| 1% Accident Reduction | | | |
| GPS | -876,693 | 0.52 | N.A. |
| Radio | -576,701 | 0.62 | N.A. |
| 2% Accident Reduction | | | |
| GPS | 76,376 | 1.04 | 8.85 yr |
| Radio | 376,368 | 1.24 | 5.61 yr |
| 3% Accident Reduction | | | |
| GPS | 1,029,444 | 1.56 | 3.26 yr |
| Radio | 1,329,436 | 1.86 | 2.48 yr |

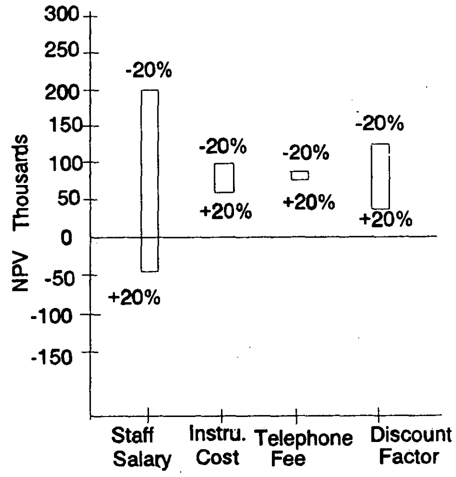


**FIGURE 3 Sensitivity analysis at a 2 percent accident reduction rate.**

all types of accidents. Sensitivity analysis of the cost variables indicates that the NPV is still positive with more expensive hardware than what was used in the study.

Only benefits related to accident reduction are considered here. However, there are other nonmonetary benefits of this system that are difficult to quantify. The proposed ATIS has a great impact on planning and budgeting maintenance operations, as mentioned before. It will save time for estimating maintenance cost each year

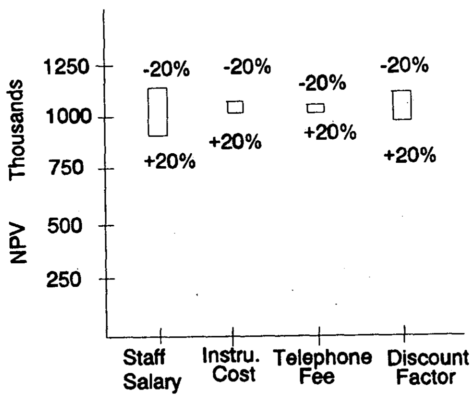


**FIGURE 4 Sensitivity analysis at a 3 percent accident reduction rate.**

and provide improved data for effective forecasting and decision making. The system would be more cost-effective than what was shown here.

A survey on travelers' behavior should be conducted to understand their perspective if this type of system is implemented. This survey would help to estimate the percentage of travelers using system information to change their route or delay trips. Such behaviors may offer better data with which to estimate the percentage reduction in accidents.

A better method for predicting future accidents is needed. Other factors such as population change, vehicle registration, employment activity, road surface condition, and law enforcement in the surrounding area of each road also need to be considered to better estimate the number of accidents in the future.

## ACKNOWLEDGMENT

Funding for this research was received from the Mountain Plains Consortium of University Transportation Centers.

## REFERENCES

1. Euler, G. W. Intelligent Vehicle/Highway Systems: Definitions and Applications. *ITE Journal*, Nov. 1990, pp. 17–22.
2. Yamin, M. H. Analysis of the Integrated Weather Monitoring System in Indianapolis, Indiana. Presented at 1991 North American Snow Conference, Montreal, Canada, April 1991.
3. French, K. A., and E. M. Wilson. Evaluating the Potential of Remote Sensing Rural Roads and Travel Conditions. Presented at the 72nd Annual Meeting of the Transportation Research Board, Washington, D.C., 1993.
4. *NCHRP report 162*, 1975.
5. *Cost-Benefit Analysis Handbook*, Department of Veterans Affairs, Aug. 1989.
6. Abelson, P. *Cost Benefit Analysis and Environmental Problems*, Saxon House, Fairborough, England, 1979.
7. Sassone, P. G., and W. A. Schaffer. *Cost-Benefit Analysis: A Handbook*. Academic Press, New York, 1978.
8. Russam, K., and D. J. Jeffery. Route Guidance and Driver Information Systems; An Overview. *Electronics and Power*, April 1986, pp. 295–299.
9. Brinkman, C. P. Toward Improved Highway Safety Analysis. *Public Roads*, Vol. 50, No. 2, Sept. 1986, pp. 49–53.
10. Frantzeskakis, J. M. Accident Analysis on Two Non-Controlled Access National Highways in Greece. *ITE Journal*, Feb. 1983, pp. 26–32.
11. *The Costs of Highway Crashes*. Report DOT-RD-91-055, FHWA, U.S. Department of Transportation, 1991.
12. National Safety Council, 1992.

*Publication of this paper sponsored by Committee on Transportation Economics.*